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Sampling Commercial Catches of Marine Fish and Invertebrates

L'échantillonnage des prises commerciales de poissons et d'invertébrés marins

W.G. Doubleday and D. Rivard

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Proceedings of a Workshop held at Ottawa, February 23–25, 1982

Compte rendu d'un atelier tenu à Ottawa, du 23 au 25 février 1982

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W. G. Doubleday and D. Rivard

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Abstract

DOUBLEDAY, W. G., AND D. RIVARD [ED.] 1983. Sampling commercial catches of marine fish and invertebrates. Can. Spec. Publ. Fish. Aquat. Sci. 66: 290 p.

This publication contains the proceedings and contributed papers of a workshop on the sampling of commercial catches for marine fish and invertebrates. The Workshop reviewed the history of catch sampling, current practice and standards, as well as the performance of various sampling programs. The importance of commercial catch sampling for the determination of biological parameters of exploited populations is discussed. Sampling programs are analyzed in the context of their contribution to resource assessment and their impact on management advice. Finally, the proceedings suggest new directions and contain specific recommendations on various aspects of sampling to form a basis for the design of future sampling programs.

Résumé

DOUBLEDAY, W. G. ET D. RIVARD [ÉD.] 1983. L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Publ. spéc. can. sci. halieut. aquat. 66 : 290 p.

On rapporte ici les conclusions d'un atelier sur l'échantillonnage des prises commerciales de poissons et d'invertébrés marins, ainsi qu'une série d'articles présentés au cours de l'atelier. Le rapport couvre l'historique de l'échantillonnage des prises, les pratiques et les normes courantes, ainsi que le rendement de divers programmes d'échantillonnage. On souligne l'importance des programmes d'échantillonnage sur les prises pour l'estimation des paramètres biologiques des populations exploitées. Les programmes d'échantillonnage sont analysés quant à leur contribution à l'évaluation des ressources et à leur influence sur les avis de gestion. Finalement, puisqu'il identifie des voies nouvelles et apporte des recommandations précises quant à certains aspects de l'échantillonnage, ce rapport constitue un point de référence pour le développement des futurs programmes d'échantillonnage.

Preface

In recognition of the importance of commercial catch sampling for fisheries management and in order to maintain satisfactory practices in the implementation of sampling programs, the Department of Fisheries and Oceans held a workshop on the sampling of commercial catches at Ottawa, February 23–25, 1982. This workshop was the third of a series aiming at the review of scientific and technical aspects of specific research programs of the Department. The workshop was attended by more than 30 experts of various disciplines representing the Department of Fisheries and Oceans, as well as by a number of invited specialists.

The topic for this workshop was initially proposed by the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC). The workshop objectives and content were elaborated thereafter, by a special committee composed of S. Stevenson, K. C. T. Zwanenburg, R. F. J. Bailey, and W. G. Doubleday. The success of the workshop is due, in part, to the participation of a number of authors who, in response to an invitation from the special committee, devoted time and effort in the preparation of manuscripts on specific issues. We also wish to acknowledge the contribution of session chairmen who led discussions and provided a synopsis of the scientific contributions and recommendations for their respective sessions. All manuscripts received outside review by one or more referees after the workshop, prior to their inclusion in this report. Special thanks are due to the referees whose suggestions clarified and improved original manuscripts, as well as the workshop report. We also thank the Scientific Information and Publications Branch for providing technical assistance and financial support.

The publication of this report has been made possible only by the active participation of those aforementioned. This workshop contributed to a better understanding of a number of technical aspects of commercial catch sampling, served to reiterate the importance of sampling programs for fishery management and the development of scientific advice, and provided a number of useful recommendations for the implementation of future sampling programs.

Préface

Face à l'importance de l'échantillonnage des prises commerciales pour la gestion des pêches et afin d'assurer le maintien de pratiques adéquates dans l'application des techniques d'échantillonnage, le Ministère des Pêches et des Océans a tenu à Ottawa, du 23 au 25 février 1982, un atelier sur le sujet. Cet atelier est le troisième d'une série visant à réviser les aspects scientifiques et techniques de programmes de recherche spécifiques du Ministère. Ont assisté à l'atelier, une trentaine de personnes de disciplines diverses représentant le Ministère des Pêches et des Océans, ainsi qu'un certain nombre de spécialistes invités.

Le sujet de l'atelier a été proposé par le Comité scientifique consultatif des pêches canadiennes dans l'Atlantique (CSCPCA). Ses objectifs et son contenu ont été élaborés par la suite par un comité spécial composé de S. Stevenson, K. C. T. Zwanenburg, R. F. J. Bailey et W. G. Doubleday. Le succès de l'atelier est en partie dû au concours des nombreux auteurs qui, en réponse à l'invitation du comité spécial, ont consacré temps et efforts à la préparation de manuscrits faisant le point sur un sujet particulier. Nous désirons également souligner le concours des présidents des séances qui ont mené les débats et ont fourni une synopsis des contributions scientifiques et des recommandations pour leurs séances respectives. Suite à l'atelier, les manuscrits ont fait l'objet d'une révision indépendante par un ou plusieurs scientifiques en vue de leur publication dans le présent rapport. Nous remercions l'équipe de réviseurs dont les suggestions ont permis de clarifier et d'améliorer les manuscrits originaux et le rapport même de l'atelier. Nous remercions également la Direction de l'information et des publications scientifiques pour son aide technique et son support financier.

La publication du présent document est donc le résultat de la participation active de tous ceux mentionnés ci-haut. Ce colloque a permis de mieux comprendre un certain nombre des aspects techniques de l'échantillonnage des prises commerciales, a réaffirmé l'importance des programmes d'échantillonnage pour la gestion des pêches et la formulation des avis scientifiques, et a permis d'élaborer de nombreuses recommandations quant à la mise sur pied des programmes d'échantillonnage futurs.

Workshop Report

Rapport de l'atelier

Introductory Address

B. S. MUIR

Director General, Department of Fisheries and Oceans, Fisheries Research Directorate, Ottawa, Ont. K1A 0E6

During the 1970s, increasing regulation of commercial groundfish fisheries led to a demand for increased precision in scientific advice for resource management. While the sampling of commercial catch is a cornerstone in the provision of scientific advice to management, we are still operating with standards derived in the early seventies under the International Commission for the Northwest Atlantic Fisheries (ICNAF). These standards were aimed primarily at improving inadequate sampling and were not based on an optimal design. Nevertheless, the organization and planning of sampling and the processing of sampling data play an important role in the provision of annual management advice. The expenditures of the Department of Fisheries and Oceans (DFO) on commercial catch sampling are substantial and an assessment of sampling practices and performance is needed to ensure an efficient process. This assessment is doubly important in view of the reorganization of the Atlantic Fisheries zone into three regions: the Newfoundland, the Scotia–Fundy, and the Gulf Region.

Under the ICNAF regime, each foreign country was responsible for the sampling of its commercial fleet. Sampling techniques and the priority level placed on sampling varied from country to country. At sea sampling of the biological characteristics for foreign commercial catches was initiated by Canada in 1977. Canadian observers are now both monitoring the operations of the foreign fleet and obtaining biological samples. Observers also gather information on catch rates, bycatch, and discards of both commercial and semicommercial species. Information on species mix and catch rates for foreign fishing vessels is extremely valuable in evaluating foreign fishing plans.

Demands for scientific advice for fisheries management have increased since the Canadian extension of fisheries jurisdiction in 1977. In addition, heightened awareness of the provinces and segments of the fishing industry to the value of scientific advice has increased the minimum acceptable precision of biomass estimates and catch projections. In response to these demands for advice on the status of the stocks, the major part of the financial resources received on the extension of fisheries jurisdiction was directed towards improving the information inputs for the application of current theory to the provision of advice.

Allocution d'ouverture

B. S. MUIR

Directeur général, Ministère des Pêches et des Océans, Direction générale de la recherche sur les pêches, Ottawa, Ont. K1A 0E6

Au cours des années 1970, par suite de l'accroissement de la réglementation régissant la pêche commerciale des poissons de fond, on a commencé à exiger une plus grande précision des avis scientifiques touchant la gestion des ressources. L'échantillonnage des captures commerciales est la pierre angulaire de la préparation de ces avis scientifiques; or, nous fonctionnons toujours avec des normes issues de la CIPANO (Commission internationale pour les pêches de l'Atlantique Nord-Ouest). Ces normes ont d'abord été établies pour améliorer un échantillonnage insuffisant et non pour assurer un plan d'échantillonnage optimal. Il n'en reste pas moins que l'organisation et la planification de l'échantillonnage, de même que le traitement des données d'échantillonnage, jouent un rôle important dans la production annuelle des avis scientifiques pour la gestion des stocks. Les dépenses engagées par le Ministère des Pêches et des Océans (MPO) pour l'échantillonnage des prises commerciales sont assez importantes et justifient une évaluation du processus d'échantillonnage et de son rendement en vue d'en assurer son efficacité. Cette évaluation est d'autant plus importante vu la réorganisation des activités du MPO dans la zone de pêche de l'Atlantique en trois régions, c'est-à-dire les régions de Terre-Neuve, de Scotia-Fundy et du Golfe.

Sous le régime de la CIPANO, les pays étrangers effectuaient chacun l'échantillonnage de leur propre flotte commerciale. Les techniques d'échantillonnage et le niveau de priorité accordé à l'échantillonnage variaient d'un pays à l'autre. L'échantillonnage en mer des caractéristiques biologiques des prises commerciales étrangères a été instauré par le Canada en 1977. À présent, des observateurs canadiens sont chargés à la fois de surveiller les opérations des flottes étrangères et d'en obtenir des échantillons biologiques. Ils recueillent également des renseignements sur les prises par unité d'effort, sur les prises accidentelles et sur les rejets d'espèces tant commerciales que semi-commerciales. Les renseignements sur les espèces composant la prise et sur les taux de capture des navires de pêche étrangers ont une très grande valeur, notamment lorsqu'il s'agit d'évaluer les plans de pêche de ces pays.

Les besoins d'avis scientifiques destinés à la gestion des pêches ont considérablement augmenté depuis que le Canada a étendu sa juridiction sur les pêches en 1977. Le minimum de précision acceptable pour les estimations de biomasse et les projections des captures a dû être haussé, puisque les provinces et certains secteurs de l'industrie de la pêche sont devenus de plus en plus conscients de la valeur de ces avis scientifiques. Pour pouvoir répondre à toutes les demandes d'avis sur l'état des stocks, on a dû affecter la majeure partie des ressources financières obtenues par suite de l'extension de la juridiction sur les pêches à l'amélioration des données afin de pouvoir appliquer la théorie courante à la production d'avis scientifiques.

Domestic sampling activities have also increased steadily since 1977. For example, the total number of fish measurements processed in the Newfoundland region increased from a level of 194 000 in 1976 to 1 072 000 in 1980. Similar trends were observed in the other Atlantic regions and in the Pacific region.

The objectives of this workshop are threefold:

1) To review historical and current biological sampling practice, performance, and standards from commercial marine fish and invertebrate catches.

2) To present the results of recent research on commercial catch sampling and on the determination of biological parameters for exploited populations.

3) To advise DFO on needs for further research and changes in commercial catch sampling and related programs.

The recommendations developed during this workshop will constitute a benchmark through which future sampling programs can be constructed in the most fruitful manner.

Par conséquent, l'intensité de l'échantillonnage par le Canada a augmenté sans arrêt depuis 1977. Ainsi, le nombre total des mesures effectuées dans la région de Terre-Neuve est passé de 194 000 en 1976 à 1 072 000 en 1980. Des tendances similaires ont été observées dans les autres régions de l'Atlantique et dans la région du Pacifique.

On a défini trois objectifs pour l'atelier:

1) Faire l'historique de l'échantillonnage biologique (techniques, rendement et normes) des prises commerciales de poissons et d'invertébrés marins.

2) Présenter les résultats de recherches récentes sur l'échantillonnage des prises commerciales et sur l'évaluation des paramètres biologiques pour les populations exploitées.

3) Conseiller le MPO sur les recherches à entreprendre et sur les changements qu'il faudrait apporter à l'échantillonnage des prises commerciales et aux programmes connexes.

Les recommandations élaborées dans le cadre du présent atelier constitueront un point de référence pour la mise sur pied ou l'amélioration des futurs programmes d'échantillonnage.

Review of History of Commercial Catch Sampling, Standards, and Current Practice with Emphasis on the CAFSAC[1] Area

CHAIRPERSON: R. WELLS

The harvest of marine fish, invertebrates and plants in the NAFO[2] area is large and complex. In 1975–79, for example, the average total harvest was about 1.6×10^6 t of which 72% was of fish, 27% of invertebrates, and 1% of plants. The value of the invertebrate harvest is enhanced by the presence of such highly desirable species as scallops and lobsters. The area considered is several thousand miles long from north to south and extends from the intertidal areas to several hundred miles offshore. A wide variety of vessels and gears are in use. Generally, the number of species in sufficient abundance for commercial exploitation increases from north to south. In addition, there are recreational fisheries in the southern part of the area.

Landing statistics are available for a few species and areas for hundreds of years and detailed biological sampling has been carried out for about the last 50 yr. Sampling has been increased substantially over the period, especially since 1976. Sampling is carried out at landing ports and at sea. Because of the diversity of fisheries, many of the smaller fisheries are not sampled or are undersampled. As well, some of the more extensive fisheries may be infrequently sampled at the beginning and end of the season when landings are small. The adequacy of the current level of sampling is quite

[1]Canadian Atlantic Fisheries Scientific Advisory Committee.
[2]Northwest Atlantic Fisheries Organization.

Historique de l'échantillonnage des prises commerciales, des normes et des pratiques courantes s'y rattachant, l'accent étant mis sur la zone du CSCPCA[1]

PRÉSIDENT : R. WELLS

La récolte de poissons, d'invertébrés et de plantes marines dans la zone de l'OPANO[2] est importante et complexe. Entre 1975 et 1979, par exemple, la récolte totale moyenne s'est élevée à environ, $1{,}6 \times 10^6$ t; elle se composait de poissons (72 %), d'invertébrés (27 %) et de plantes marines (1 %). La valeur de la récolte d'invertébrés est élevée à cause de la présence d'espèces de haute valeur, comme le pétoncle et le homard. La zone étudiée a plusieurs milliers de milles de long du nord au sud et s'étend des régions intertidales jusqu'à plusieurs centaines de milles au large des côtes. On y utilise un nombre varié de navires et d'engins. En général, le nombre d'espèces dont l'abondance est suffisante pour permettre l'exploitation commerciale augmente en descendant vers le sud. Notons également la présence d'une pêche récréative dans la partie méridionale de la région.

On dispose de statistiques de débarquement couvrant plusieurs centaines d'années sur un petit nombre d'espèces et de régions. Des échantillonnages biologiques détaillés ont en outre été effectués au cours des cinquante dernières années; l'intensité de l'échantillonnage a augmenté considérablement durant cette période, particulièrement depuis 1976. L'échantillonnage est effectué dans les ports de débarquement et en mer. À cause de la diversité des pêches, les pêcheries les moins importantes échappent souvent à l'échantillonnage ou sont insuffisamment échantillonnées. De même, certaines

[1]Comité scientifique consultatif des pêches canadiennes dans l'Atlantique.
[2]Organisation des pêches de l'Atlantique Nord-Ouest.

variable as compared with some arbitrary standard such as the NAFO standard and, in general, is not necessarily related to appropriate statistical measures of precision and bias.

pêcheries importantes peuvent être insuffisamment échantillonnées au début et à la fin de la saison de pêche, lorsque les débarquements sont faibles. L'intensité d'échantillonnage actuelle est très variable si on la compare à certaines normes arbitraires comme celles de l'O.P.A.N.O.; de façon générale, le niveau d'échantillonnage n'est pas nécessairement établi en fonction de mesures statistiques appropriées de précision et de biais.

The review of sampling of commercial groundfish by Stevenson provides details of procedures used in areas 2 and 3 of NAFO. Opportunity to sample for length and age is unrestricted and sampling is considered good in relation to arbitrary standards such as the NAFO minima. The history, performance, and application of commercial sampling for lobster, crab, shrimp, scallops, and squid catches in Newfoundland were reviewed by Parsons et al. Sampling has been more systematically carried out in recent years than formally. Although sampling intensity is very low, relative to the total catch for each species, the data obtained have proved valuable in the estimation of various population parameters.

Dans sa revue de l'échantillonnage des prises commerciales de poisson de fond, Stevenson étudie en détail les procédures utilisées dans les zones 2 et 3 de l'OPANO. L'échantillonnage est satisfaisant par rapport à la norme arbitraire minimale de l'OPANO et les échantillons semblent bien répartis quant à la longueur et à l'âge. Parsons et al. passent en revue l'historique, la performance et les pratiques d'échantillonnage pour les prises de homard, de crabe, de crevette, de pétoncle et d'encornet à Terre-Neuve. L'échantillonnage s'est effectué de façon plus systématique au cours des dernières années qu'auparavant. Même si l'intensité d'échantillonnage est très faible par rapport au total des prises pour chaque espèce, les données obtenues se sont révélées très utiles pour l'estimation de divers paramètres biologiques.

Rowell provides a description of Canadian sampling of commercial catches of invertebrates and marine plants in NAFO areas 4 and 5 and points out that the management of invertebrate stocks tends to require greater dependence on statistical and logbook data than on catch sampling. Coverage increased sharply in the late 1970s but still tends to focus on key ports.

Rowell décrit l'échantillonnage, par le Canada, des prises commerciales d'invertébrés et de la récolte de plantes marines dans les zones 4 et 5 de l'OPANO; il mentionne que la gestion des stocks d'invertébrés dépend beaucoup plus des statistiques des débarquements et des renseignements fournis dans les livres de bord que de l'échantillonnage des prises. Bien que la couverture de l'échantillonnage ait augmenté de façon marquée à la fin des années 1970, l'échantillonnage tend encore à se concentrer sur quelques ports importants.

Lussiaà-Berdou et al. present a review of sampling by the province of Quebec in the Gulf of St. Lawrence. The aims, procedures, and intensity of sampling have been documented for various vertebrate and invertebrate species. Problems associated with adequate sampling at point of landing and also at sea are outlined. A detailed review of sampling of snow crab catches in the southwestern Gulf of St. Lawrence, from 1977 on, leads Bailey to conclude that the level of accuracy in size-frequency distribution was probably suitable for perceived needs.

Lussiaà-Berdou et al. passent en revue l'échantillonnage fait par la province de Québec dans le golfe du Saint-Laurent : ils discutent des objectifs, des procédures et de l'intensité de l'échantillonnage pour diverses espèces de vertébrés et d'invertébrés. Les problèmes associés au besoin d'atteindre un niveau d'échantillonnage adéquat au débarquement et en mer sont présentés brièvement. À partir d'une revue détaillée de l'échantillonnage du crabe des neiges dans le sud-ouest du golfe du Saint-Laurent depuis 1977, Bailey conclut que le niveau de précision obtenu pour les distributions des fréquences de taille relatives est probablement suffisant pour les besoins perçus.

Sampling of the complex fishery in the southern NAFO area is reviewed by Burns et al. Access to sampling of individual catches was not always unrestricted. The challenging problem of the rational distribution of limited sampling effort to a complex of many potential sampling units with varied problems is outlined.

Significant increases in funding since 1976 have led to increased sampling rates which, in many cases, now meet or exceed the arbitrary ICNAF minimum standard. These programs should now be reviewed in detail to determine their adequacy in producing information for stock assessments and other purposes. The dispersion of samples during the fishing season and geo-

L'échantillonnage de la pêche commerciale dans la zone la plus méridionale de l'OPANO est passé en revue par Burns et al. Certaines contraintes empêchent parfois l'échantillonnage des prises. Les auteurs soulignent que la répartition rationnelle de l'effort d'échantillonnage, qui est limité, sur un ensemble aussi complexe que variable constitue un véritable défi.

Une augmentation significative des ressources financières depuis 1976 a mené à une augmentation des taux d'échantillonnage qui, dans plusieurs cas, atteignent maintenant ou même dépassent la norme arbitraire minimale de l'OPANO. Ces programmes devraient maintenant être révisés en détail afin de déterminer leur abilité à fournir l'information nécessaire à l'évaluation des stocks et à d'autres fins. La graphically should be studied in relation to possible biases.

répartition géographique et temporelle des échantillons doit faire l'objet d'études afin de déterminer les biais possibles.

Implications of Accuracy of Sampling Information on Management Advice

CHAIRPERSON: H. POWLES

As Pope (this session) has put it, stock assessment is a "somewhat recursive, not to say subjective, science which does not lend itself to examination of variances." In addition, assessment methodology is new and has been to some extent developed in response to time-specific demands, so that evaluation of the science has lagged behind development. As a result, the subject of this session has not been treated in detail in past work (with at least one notable exception), although impact of errors in inputs to assessments on their results has been treated in various ways. Consequently, the papers presented at this session represent a particularly valuable contribution to the examination of assessment methods.

Published sampling manuals for fishery sciences (e.g. Gulland 1966; Bazigos 1974), although treating basic techniques for estimating and controlling variance through sampling design, did not relate sampling error to errors in management advice (in fact could not, since formulation of management advice was not a defined discipline at the time they were written as it is now). Thus Gulland (1966) noted, for example, that determination of sample size required a balance between the need to reduce variance to a minimum and practical considerations of obtaining samples, but did not suggest desirable levels of variance to aim for.

Sampling efficiency was treated annually by the ICNAF Standing Committee on Research and Statistics relative to the ICNAF sampling guideline of 1 length sample/1000 t/quarter, but apart from some analyses of impact of sampling errors on age composition estimates (Doubleday 1976), analysis of impact of such errors on management advice was not made. A 10% coefficient of variation in age composition estimates was used by ICNAF as a guideline, apparently on grounds similar to those justifying the sampling intensity guideline (i.e. a guideline was needed). Doubleday (1976) identified the most important potential sources of error in sampling stocks of cod, mackerel, and silver hake for population age composition estimates. These were aging errors and nonrandom distribution of sampling throughout the total catch. In addition, he established that finer temporal stratification of sampling could increase accuracy and precision of age composition estimates (in particular

Incidences de la précision des données d'échantillonnage sur les avis de gestion

PRÉSIDENT: H. POWLES

Comme l'a souligné Pope au cours de la présente séance, l'évaluation des populations constitue « une science un peu récursive, pour ne pas dire subjective, qui ne se prête pas à l'examen des variances ». En outre, il s'agit d'une science nouvelle créée dans une certaine mesure pour répondre à des exigences particulières; son évaluation s'est donc trouvée décalée par rapport à son développement. Par voie de conséquence, le thème de la présente séance n'a jamais été traité en détail auparavant (à part une exception notable), bien que l'effet des erreurs dans les données sur les résultats de l'évaluation ait déjà fait l'objet de diverses études. Les documents présentés au cours de la présente séance apportent donc une contribution très valable à l'étude des méthodes d'évaluation.

Même s'ils traitent des techniques de base pour évaluer et contrôler la variance à l'intérieur du plan d'échantillonnage, les manuels parus sur l'échantillonnage dans le domaine des sciences halieutiques (par ex. Gulland 1966; Bazigos 1974) ne font pas le lien entre les erreurs d'échantillonnage et les erreurs dans les avis de gestion des stocks (de toute façon, ils ne le pouvaient pas, puisqu'au moment de leur rédaction, la formulation d'avis pour la gestion des stocks n'était pas une discipline aussi bien définie qu'aujourd'hui). Gulland (1966) note par exemple que, pour établir la taille d'un échantillon, il faut créer un équilibre entre la nécessité de réduire la variance au minimum et certaines considérations pratiques quant à l'obtention des échantillons; il ne fait cependant aucune suggestion quant aux niveaux de variance qu'il faut viser.

Le Comité permanent de recherche et de statistique de la CIPANO s'est penché chaque année sur l'efficacité de l'échantillonnage (son examen portait sur la ligne directrice de la CIPANO concernant l'échantillonnage, soit un échantillon de longueur/1 000 t/trimestre); cependant, bien que l'on ait effectué certaines analyses sur l'effet des erreurs d'échantillonnage sur les estimations de la composition en âge (Doubleday 1976), aucune analyse n'a été faite sur l'impact de telles erreurs sur les avis concernant la gestion des stocks. La CIPANO a utilisé comme ligne directrice un coefficient de variation de 10 % dans les estimations de la composition en âge, apparemment pour les mêmes motifs qui ont justifié la promulgation d'une ligne directrice portant sur l'intensité de l'échantillonnage (i.e. une ligne directrice était nécessaire). Doubleday (1976) a identifié les plus importantes sources éventuelles d'erreurs dans l'échantillonnage de stocks de morue, de maquereau et de merluche pour les estimations de la composition en âge de la population. Il s'agissait là d'erreurs de lecture d'âge et d'erreurs reliées à la distribution non-aléatoire de l'échantillon-because of rapid transition in age compositions due to entry of new recruits), but that spatial stratification at finer than the Division scale would not substantially improve such estimates.

nage sur la prise totale. Doubleday démontra en outre qu'une stratification temporelle plus fine de l'échantillonnage pourrait accroître l'exactitude et la précision des estimations de la composition en âge (à cause notamment de l'évolution rapide de la composition en âge due à l'arrivée de nouvelles recrues), mais qu'une stratification spatiale plus précise que les Divisions utilisées n'améliorerait pas de façon substantielle ces estimations.

Sensitivity analyses of assessment models (e.g. Doubleday 1979; Rivard and Doubleday 1979; other references in papers from this session) have contributed to an understanding of the behavior of these models in response to errors in inputs and thus have led to general insights into the effect of sampling errors on advice. In a similar vein, Pope and Garrod (1975) examined the impact of errors in estimates of fishing mortality and catchability coefficient on management advice.

At least one published paper has been directed toward investigation of impact of sampling errors on biomass and mortality estimates from sequential population analysis (SPA). Pope (1972) developed cohort analysis as a form of sequential population analysis more amenable to estimation of variances, and used the technique to calculate variance ratios in N_i and F_i as a function of variance ratios in the catch matrix, annual fishing mortality, and the number of "years back" in the cohort analysis. Pope's analysis went as far as to provide a simple graphical technique for estimating effects of errors in the catch matrix on SPA results. Although the graphical technique is usable under fairly unrealistic constraints, relaxation of these does not appear to lead to large errors in variance ratio estimates. In any case, formulae can be used in cases where departure from constrained conditions is large. The importance of this paper to investigation of errors in SPA may have been somewhat overlooked in concentrating on cohort analysis as an assessment tool. This paper is similar in approach to that of Pope (this session) in that it provides a "model" of sequential population analysis which permits examination of variances.

The analyses presented during this session represent techniques for modeling components of the stock assessment process so that critical input parameters — those whose variability has a significant effect on management advice — can be identified.

Pope investigated total allowable catches (TAC); Rivard, the tuning of SPA and catch projections; Mohn, the tuning of SPA and the Schaefer production model; White, the general concepts of influential variables (influence) and impact of errors (regret) as they affect the design of sampling programs for stock assessments; and finally, Pope and Gray, the relationship between the precision of assessment data and the precision of total allowable catches.

Les analyses de sensibilité des modèles d'évaluation (par ex. Doubleday 1979; Rivard et Doubleday 1979; on trouvera d'autres références dans les documents de la présente séance) ont permis de mieux comprendre le comportement de ces modèles en réponse aux erreurs dans les données, tout en donnant lieu à des découvertes d'ordre général quant aux effets des erreurs d'échantillonnage sur les avis. Dans la même veine, Pope et Garrod (1975) ont étudié l'impact des erreurs dans les estimations de la mortalité par pêche et du coefficient de capturabilité sur les avis de gestion.

On trouve dans la littérature au moins une étude portant directement sur l'analyse des effets des erreurs d'échantillonnage sur les estimations de la biomasse et de la mortalité, à partir d'une analyse séquentielle des populations. Pope (1972) a mis au point l'analyse par cohortes (laquelle constitue une forme d'analyse séquentielle qui se prête mieux à l'évaluation des variances); il a utilisé cette technique pour calculer les rapports de variance de N_i et F_i comme fonction des rapports de variance dans la matrice des captures ainsi que de la mortalité annuelle par pêche et du nombre d'années de rétro-calcul dans l'analyse par cohortes. Pope poussa l'analyse jusqu'à mettre au point une technique graphique simple permettant d'évaluer les effets des erreurs dans la matrice des captures sur les résultats de l'ASP (analyse séquentielle des populations). Même si cette technique graphique est utilisable en présence de contraintes plutôt irréalistes, la relaxation des contraintes ne semble pas conduire à des erreurs importantes dans les estimations du rapport de variance. On peut toujours se servir d'équations pour les cas où l'écart par rapport aux contraintes est important. En se concentrant sur l'analyse par cohortes en tant qu'outil d'évaluation, on a peut-être un peu oublié l'importance de cette méthode pour l'étude des erreurs dans l'ASP. Par son approche, ce document est semblable à celui de Pope (présente séance), en ce sens qu'il présente un « modèle » d'analyse séquentielle permettant l'examen des variances.

Les analyses présentées au cours de la présente séance constituent des techniques de mise au point de modèles pour les composantes du processus d'évaluation des stocks, ce qui permet d'identifier les paramètres d'entrée critiques (c.-à-d. ceux dont la variabilité a un effet important sur les avis de gestion).

Pope a étudié le total des prises admissibles (TPA); Rivard, l'ajustement de l'ASP et les projections des prises; Mohn, l'ajustement de l'ASP et le modèle de production de Schaefer; White, les concepts généraux de variables d'importance (« influence ») et l'effet des erreurs (« regret »), dans la mesure où ils affectent la conception des programmes d'échantillonnage destinés à l'évaluation des stocks; et finalement, Pope et Gray ont étudié la relation entre la précision des données d'évaluation et la précision du total des prises admissibles.

Determination of the relative impact on advice of variability in respective input parameters should permit design of sampling programs which allocate sampling effort efficiently, that is in such a way that appropriate levels of precision are attained at each step of the assessment process. Critical parameters will differ from fishery to fishery and from time to time within a fishery depending on stock status and history, fishery characteristics, etc.

The analyses presented fall into two classes: analytical and simulation. Each approach has perceived advantages and disadvantages for modeling the stock assessment process: (+ = perceived advantage; - = disadvantage)

Analytical	*Monte-Carlo Simulation*
+ Simple	- Complex
+ Elucidates processes	- Processes not evident
+ Can be generalized	- Situation — specific
- Comparison with "truth" impossible	+ Model results can be compared with "truth" (input data for the simulation)
- Supply easily-grasped "gut-feeling" impression of situation	+ Permit subtler understanding of situation
- Require simplification, approximation, do not explain data as satisfactorily.	+ Explain more complex data sets.

Both approaches can shed light on the problem at hand and both should be used for verification of assessments. Availability of computer programs to perform simulations would assist scientists in critically examining their techniques.

A requirement for objective criteria for fitting models (in particular for tuning sequential population analyses) was expressed and one paper directly addressed this need. Some flexibility may continue to be required in fitting data to models, given the often contradictory character of assessment data. In any case, other measures of "goodness of results" will be required in addition to objective goodness of fit criteria.

The impact of errors in assessments must be considered in designing sampling programs. If the impact of errors (or "regret") is high, even when errors occur infrequently (as is the case for many stock assessments), care must be taken in dealing with the "tails" of sampling distributions and ensuring that risks of serious errors are sufficiently low. Defining the regret function for a given situation may not be possible in quantitative terms; in any case it requires incor-

Après avoir déterminé l'effet relatif de la variabilité des divers paramètres de départ sur les avis, on devrait pouvoir concevoir des programmes d'échantillonnage qui répartiront de façon efficace l'effort d'échantillonnage (c.-à-d. d'une façon telle que des niveaux de précision appropriés pourront être atteints à chaque étape du processus). Les paramètres critiques varieront d'une pêcherie à l'autre et parfois dans une même pêcherie en fonction de l'état et de l'historique du stock, des caractéristiques de la pêche, etc.

Les analyses présentées se répartissent en deux catégories : approche analytique et approche de simulation. Les avantages et les désavantages que comporte chaque approche en rapport avec la mise au point d'un modèle pour le processus d'évaluation des stocks se résument comme suit (+ = avantage perçu; - = désavantage perçu):

Approche analytique	*Approche de simulation*
+ simple	– complexe
+ explique les processus	– processus non évidents
+ peut être généralisée	– se rapporte à une situation particulière
– impossible de comparer avec la « réalité »	+ les résultats du modèle peuvent être comparés avec la « réalité » (données d'entrée pour la simulation)
– donne une impression « viscérale » et facile à saisir de la situation	+ assure une compréhension plus approfondie de la situation
– exige une simplification, une approximation; explique moins bien les données.	+ explique les ensembles de données plus complexes

Les deux approches peuvent contribuer à l'identification des problèmes et servir à vérifier les évaluations. En ayant à leur disposition des programmes informatiques permettant de réaliser des simulations, les scientifiques seraient en mesure d'examiner leurs techniques d'un oeil critique.

On a mentionné la nécessité de disposer de critères objectifs pour ajuster les modèles (en particulier, pour mettre au point les analyses séquentielles des populations); cette exigence a d'ailleurs fait l'objet d'un document. Vu le caractère fréquemment contradictoire des données d'évaluation, il faudra peut-être continuer à faire preuve de souplesse dans l'adaptation des données aux modèles. Dans tous les cas, on aura besoin d'autres mesures de la « qualité des résultats », en plus de critères objectifs pour évaluer la qualité de l'ajustement.

Il faut tenir compte de l'effet des erreurs dans les évaluations au moment de la conception des programmes d'échantillonnage. Si l'effet des erreurs (ou « regret ») est important, même quand les erreurs ne se produisent pas fréquemment (comme c'est le cas pour la plupart des évaluations de stocks), on devra traiter avec soin les échantillons qui s'écartent de la tendance centrale et s'assurer que les risques d'erreurs sérieuses sont suffisamment bas. La fonction de regret pour une situation donnée pourra être impossible à poration of socioeconomic as well as biological factors.

The following recommendations are proposed from the results of this session:

1) Stock assessments should be modeled, using the techniques presented here and elsewhere, in order to:
   a) identify critical input parameters, variability of which has a significant impact on TACs; and
   b) estimate confidence limits on TACs.

2) Sampling should be planned to minimize variance on estimates of critical parameters, i.e. to direct effort at areas where reduction of variance will improve accuracy and precision of advice.

3) Such analyses should be incorporated into the ongoing stock assessment process to permit rapid response of sampling programs to changes in stocks and fisheries.

4) Impact of errors should be considered in designing sampling programs.

Subsampling Catches to Estimate Age, Sex, Maturity, and Other Biological Parameters

CHAIRPERSON: A. T. PINHORN

Variances associated with scientific advice provided to fisheries managers are a function of the variances associated with the individual input parameters to assessment models. In the case of Total Allowable Catches (TACs) such input parameters are selectivity factors, recruitment estimates, average weight-at-age values, terminal fishing mortality, and catch-at-age estimates. Variances associated with these input parameters can be further subdivided into variances associated with the different components of the parameters. For example, in the case of catch-at-age numbers, there are variances associated with subsampling the catch for estimation of numbers of fish at each length, variances associated with subsampling this sample for aging structures, and variances associated with actually estimating ages from skeletal structures.

The paper by Smith and Maguire addressed the problem of estimating the variance associated with estimates of numbers of fish at each length. Significant differences were found in length-frequency distributions from different areas and months of capture. A simple multinomial model could not adequately accommodate the large amount of variation present but a compound multinomial distribution may prove to be more flexible in this regard once the estimation theory has been fully established.

The paper by Baird outlined a method to select optimum numbers of skeletal structures for aging in a

définir sur le plan quantitatif; dans tous les cas, il faudra incorporer des facteurs socio-économiques et biologiques.

La liste des recommandations suivante a été mise au point à partir des discussions qui ont eu lieu au cours de la séance :

1) On devrait utiliser des modèles d'évaluation basés sur les techniques, présentées ici et dans d'autres documents,
   a) afin de définir les paramètres de départ critiques, dont la variabilité a un effet important sur le TPA (total des prises admissibles);
   b) afin d'évaluer les limites de confiance des TPA.

2) Les échantillonnages devraient être planifiés de façon à réduire au minimum la variance dans les estimations des paramètres critiques (c.-à-d. que les efforts devraient être concentrés sur les zones où la réduction de la variance permettra d'accroître la précision des avis).

3) De telles analyses devraient être intégrées au processus actuel d'évaluation des stocks de façon que les programmes d'échantillonnage puissent réagir rapidement aux changements qui surviennent dans les stocks et les pêches.

4) Il faudrait tenir compte de l'effet des erreurs au moment de la conception des programmes d'échantillonnage.

Sous-échantillonnage des prises afin d'évaluer l'âge, le sexe, la maturité et autres paramètres biologiques

PRÉSIDENT : A. T. PINHORN

Les variances associées aux avis scientifiques qui sont fournis aux gestionnaires des pêches sont fonction des variances reliées aux divers paramètres d'entrée des modèles d'évaluation. Dans le cas du calcul du TPA (total des prises admissibles), ces paramètres sont les facteurs de sélectivité, les estimations du recrutement, le poids moyen à l'âge, la mortalité par pêche pour la dernière année et les prises estimées pour chacun des groupes d'âge. Les variances reliées à ces paramètres peuvent être subdivisées en variances reliées aux différentes composantes de chaque paramètre. Ainsi, dans le cas des captures par groupe d'âge, il existe des variances reliées au sous-échantillonnage de la prise en vue de l'estimation du nombre de poissons pour chaque longueur, des variances reliées au sous-échantillonnage de cet échantillon pour le prélèvement de structures permettant la détermination de l'âge, et des variances reliées aux évaluations de l'âge à partir de telles structures.

Le document de Smith et Maguire, qui a été présenté au cours de la présente séance, porte sur le problème de l'évaluation de la variance reliée aux estimations du nombre de poissons pour chaque classe de longueur. Des différences importantes ont été notées dans la distribution des fréquences de longueur pour des régions et des mois de capture différents. Un modèle multinomial simple ne pourrait pas accommoder la grande variation présente; par contre, une distribution multinomiale composée pourrait se révéler plus souple à cet égard, une fois établie solidement la théorie de l'estimation.

Le document de Baird met en relief une méthode permettant de déterminer des nombres optimaux de structures stratified sampling scheme. The equation proposed for estimating the variance of the numbers of fish caught of a particular length and age assumed that the variance associated with the total numbers at that length in the catch was zero. The variance of the total number caught at each age is then the sum of these variances at each length for that age. With this technique, if the level of precision for a given age is not at the desired level, then the length group contributing most to the total variance can be identified and the stratified selection for that length group adjusted. In a case study of cod from NAFO Division 3L using a catch length frequency and age-length key derived by combining data collected from 1976 to 1980, coefficients of variation for the major age groups were in the vicinity of 10%, and except for the youngest age, coefficients of variation for ages up to 16 were less than 20%. In discussion, it was pointed out that it may not be necessary for all ages and lengths to be sampled equally and that the various usages of age and length data should be considered in deciding on precise sampling schemes. In particular, average weight at age should be investigated in this manner because of its importance in provision of advice.

Gavaris and Gavaris addressed the problem of estimating the variance of catch-at-age numbers for one cod stock in the Newfoundland area. In the example used, the variance component due to the estimate of the proportion at age comprised almost all of the variation for a given age, and within this variance component the within-length variance was the dominant factor. This implies that to manipulate the variance, a good strategy would be to vary age sampling. It was demonstrated that the precision of average weight at age was critical to TAC calculations, especially for certain age groups. For the example presented in the paper, the imprecision of the catch-at-age estimates for ages 4 and 5 in this stock accounted for over 85% of the total variance. It was pointed out in discussion that a number of assumptions had to be made in the analyses and that the results should be interpreted with caution. A number of useful suggestions for further work in this regard were contained in the paper.

The paper by Labonté addressed the problem of estimating ages from skeletal structures, in this case otoliths from capelin in the Gulf of St. Lawrence. It was shown that problems arising when reading growth annuli on otoliths are responsible for the important overlap of age groups in the age-length keys. When these keys are applied to length-frequency distributions, an important distortion of age frequencies will sometimes be introduced. Enhancing age-length keys by fitting normal curves over age-frequency distributions greatly reduced this overlap. Subsequent discussion pointed out that length distributions of age

osseuses (servant à la lecture de l'âge) à prélever dans un schéma d'échantillonnage stratifié. L'équation proposée pour évaluer la variance du nombre de poissons capturés d'une longueur et d'un âge particuliers suppose que la variance reliée au nombre total pour cette longueur dans la prise est égale à zéro. La variance du nombre total capturé pour chaque âge est donc égale à la somme de ces variances pour chaque longueur à cet âge. Si la précision pour un âge donné ne se situe pas au degré désiré, on peut, grâce à cette technique, déterminer la classe de longueur qui contribue le plus à la variance totale et ajuster la sélection stratifiée pour cette classe. Dans une étude de cas sur la morue effectuée dans la division 3L de l'OPANO, pour laquelle on a utilisé une fréquence de longueur provenant de la prise et une clé âge-longueur obtenue par la combinaison de données recueillies entre 1976 et 1980, on a constaté que les coefficients de variation pour les principaux groupes d'âge se situaient aux alentours de 10 % et qu'à l'exception des plus jeunes groupes d'âge, les coefficients de variation pour les sujets de moins de 16 ans étaient inférieurs à 20 %. On a signalé au cours d'une discussion qu'il n'était pas nécessaire d'échantillonner tous les âges et toutes les longueurs de manière égale et qu'il faudrait tenir compte des divers usages qu'on va faire des données sur l'âge et la longueur lorsqu'on met au point des schémas précis d'échantillonnage. Il faudrait notamment étudier de cette manière le poids moyen par âge, vu son importance dans la formulation des avis.

Le document de Gavaris et Gavaris s'attaque à la question de l'évaluation de la variance des nombres estimés par groupes d'âge dans la prise pour un stock de morue de la région de Terre-Neuve. Dans l'exemple utilisé, la composante de la variance résultant de l'estimation de la proportion par âge englobe presque la totalité de la variation pour un âge donné; à l'intérieur de cette composante, la variance relative aux classes de longueur constitue le facteur dominant. Par conséquent, le fait de varier l'échantillonnage en fonction de l'âge pourrait constituer une bonne stratégie pour manipuler la variance. Les auteurs démontrent que la précision du poids moyen par âge est vitale pour les calculs du TPA, en particulier pour certains groupes d'âge. Pour le cas présenté dans ce document, l'imprécision des estimés de la capture à l'âge, pour les sujets de 4 et 5 ans, représente plus de 85 % de la variance totale. On a souligné au cours d'une discussion que ces analyses reposent sur un certain nombre d'hypothèses et que les résultats doivent par conséquent être interprétés avec prudence. À cet égard, le document contient plusieurs excellentes suggestions de travaux futurs.

Le document de Labonté porte sur le problème de l'évaluation de l'âge à partir de structures osseuses (dans ce cas, des otolithes de capelan du golfe du Saint-Laurent). L'auteur démontre que des problèmes d'interprétation des anneaux de croissance des otolithes entraînent un chevauchement important des âges dans les clés âge-longueur. L'application de ces clés aux distributions de fréquences de longueur introduit une déformation parfois importante des distributions de fréquences d'âge. L'amélioration des clés âge-longueur par l'ajustement de courbes normales à la distribution des fréquences d'âge permet de réduire grandement ce chevauchement. Suivit une discussion au cours de laquelle on souligna groups in particular samples may overlap for biological reasons.

The papers presented at this session dealt only with the errors associated with catch-at-age numbers and its various components, and then in a preliminary manner only in most cases. There are, however, other input parameters to provision of management advice that can be derived from subsampling commercial catches. Information on sex ratios and proportion of mature fish at age or length are important parameters when advice on current or target spawning biomass is being presented. Data on growth changes, both seasonally and annually, and especially on average weights at age are critical in the calculation of TACs. Within the catch-at-age matrix itself, such parameters as fishing mortalities and selectivity factors are estimated from numbers caught at each age and these too are important parameters to TAC estimation. While some limited work on the variances associated with catch-at-age numbers and their related selectivity factors and fishing mortalities has been done in the past, more investigation along these lines is necessary. Virtually no estimation of variances associated with other biological parameters derived from catch sampling has been done and more emphasis needs to be placed on this aspect of the work if confidence limits are to be placed on the final management advice.

Considering all these aspects, the following recommendations emerged from the presentation of papers and discussion within the session:

1) The variances associated with all input parameters to TACs should be investigated to determine the importance of these various components to the total variance. This would indicate which input parameters need to be precisely determined, which of course will impact on sampling schemes.

2) The bias, as well as the variance, in estimation of input parameters need to be defined.

3) Coefficients of variation need not be equal for all age- or size-classes of individuals and the exact sampling configuration may be dictated in the end by the use to which particular subsets of sampling data may be put.

4) Sampling schemes may need to be adjusted periodically to account for dominant year-classes passing through a fishery or contributing to the rebuilding of stocks. In some cases, it may be necessary to examine catch projections for several years in advance and adjust sampling schemes accordingly.

5) In interpreting results of age reading of samples, care should be taken to ensure that unusual results are

le fait que les distributions de longueur des groupes d'âge dans des échantillons particuliers peuvent aussi se chevaucher pour des motifs biologiques.

Les documents présentés au cours de la présente séance ne traitaient que des erreurs reliées aux captures à l'âge et à leurs diverses composantes et, dans la plupart des cas, de façon préliminaire seulement. Il existe cependant d'autres paramètres qui servent à la formulation d'avis pour la gestion des stocks et qui peuvent être obtenus à partir d'un sous-échantillonnage des prises commerciales. Les informations sur la proportion relative des sexes et la proportion de poissons matures, selon l'âge ou la longueur, sont des paramètres importants pour la présentation d'avis sur la biomasse reproductrice, existante ou souhaitée. Les données sur les changements de croissance, tant saisonniers qu'annuels, et en particulier sur le poids moyen à l'âge constituent des données vitales pour le calcul du TPA. À l'intérieur même de la matrice des captures à l'âge, des paramètres comme la mortalité par pêche et les facteurs de sélectivité sont évalués à partir du nombre de sujets capturés pour chaque âge; ce sont aussi des paramètres importants pour le calcul du TPA. Il serait nécessaire de procéder à des études plus approfondies dans ce domaine, vu le nombre relativement restreint de travaux qui ont été effectués dans le passé sur les variances associées à la capture à l'âge, et sur la variance des estimations des facteurs de sélectivité et de la mortalité par pêche pour chaque groupe d'âge. On n'a effectué pratiquement aucune évaluation des variances reliées à d'autres paramètres biologiques obtenus à partir de l'échantillonnage des prises; il faut donc mettre davantage l'accent sur cet aspect du travail si l'on veut pouvoir inscrire les limites de confiance dans la version définitive des avis pour la gestion des stocks.

Les recommandations suivantes ont été élaborées en tenant compte de tous les points soulevés lors de la présentation des documents et des discussions qui ont eu lieu au cours de la séance :

1) Il faudrait étudier de façon approfondie les variances reliées à tous les paramètres servant au calcul du TPA afin de mesurer l'importance de ces diverses composantes par rapport à la variance totale. Cette étude permettrait de déterminer quels paramètres doivent être définis avec précision, ce qui aura naturellement un effet sur les schémas d'échantillonnage.

2) Il faut définir le biais et la variance qui existent dans l'évaluation des paramètres de départ.

3) Les coefficients de variation peuvent ne pas être égaux pour tous les âges et toutes les tailles; la configuration exacte de l'échantillonnage sera peut-être finalement déterminée par l'usage qu'on fera des sous-ensembles particuliers des données d'échantillonnage.

4) Il faudra peut-être ajuster périodiquement les schémas d'échantillonnage pour tenir compte des classes d'âge dominantes qui transitent dans une pêche ou qui contribuent à la reconstitution des stocks. Dans certains cas, il sera peut-être nécessaire d'examiner les projections de prises pour plusieurs années à l'avance et d'ajuster en conséquence les schémas d'échantillonnage.

5) Lorsqu'on interprète les résultats de la lecture d'âge des échantillons, il faudrait prendre le temps d'examiner les

given special attention. In certain cases, there may be valid biological explanations for the results observed; in other cases, unusual results can simply be the manifestation of age reading errors which should be eliminated.

résultats inhabituels. Dans certains cas, les résultats obtenus peuvent s'expliquer par des motifs biologiques valables; dans d'autres, ces résultats peuvent être engendrés par des erreurs de lecture d'âge qu'on devrait tenter d'éliminer.

Sampling Techniques and Related Analyses

CHAIRPERSON: J. G. POPE

This session considered a group of eight papers concerned with various facets of sampling.

The first two papers had a common theme: *Levels of Precision — Sea Versus Shore Sampling* by Baird and Stevenson and *Comparison of Finfish Length-Frequency Distributions Estimated from Samples Taken at Sea and in Port* by Zwanenburg and Smith. In his presentation, Baird emphasized that the variability of length sampling mostly results from between ship variances which make shore sampling generally more cost effective provided no biases are involved (e.g. rejection at sea). This was illustrated from an example based on Div. 3L American plaice. Zwanenburg and Smith found that significant differences existed between samples taken on land and at sea. The discussion that followed concerned the importance of the differences and how such differences could arise. Some suggestions were that at sea sampling may be biased if sets are not sampled at random. There is a need for some other criterion for sampling a set than "This looks like a good set to sample for cod." Examples were discussed which indicated that haphazard criteria such as this can lead to samples being taken from more abundant smaller fish. Similarly, onshore sampling is seldom based on a truely random sample of the entire landing. For example, there is often a tendency for a measuring team to arrive some time after the unloading process has begun and hence it is possible to only sample fish from some of the locations that the vessel has worked. For example, samples might tend to come too often from the last few sets that may be made close to shore on the steam home.

An important point was made that independent checks on the validity of sampling were valuable from time to time to avoid biases resulting from sampling which, due to the problems of the fisheries industry, must often be haphazard rather than truly random. Such checks serve to prevent samplers from becoming

Techniques d'échantillonnage et analyses connexes

PRÉSIDENT : J. G. POPE

Au cours de la présente séance, nous avons étudié un groupe de huit documents traitant des divers aspects de l'échantillonnage.

Les deux premiers documents avaient le même thème : *Levels of Precision — Sea Versus Shore Sampling* [Niveaux de précision — échantillonnage en mer versus au port] de Baird et Stevenson, et *Comparison of Finfish Length-Frequency Distributions Estimated from Samples Taken at Sea and in Port* [Comparaison de la distribution des fréquences de longueur estimées à partir des échantillons pris en mer et au port] par Zwanenburg et Smith. Dans sa présentation, Baird a mis l'accent sur le fait que la variabilité de l'échantillonnage de longueur provient la plupart du temps des variances entre les navires; l'échantillonnage à terre est donc en général plus rentable, à condition toutefois qu'il ne comporte aucun biais (par ex. le rejet à la mer). Les auteurs ont illustré leur propos par un exemple fondé sur la plie canadienne de la Division 3L. Zwanenburg et Smith ont découvert des différences importantes entre les échantillons pris à terre et en mer. Une discussion a suivi sur l'importance des différences et sur leur origine. Certains participants ont suggéré que l'échantillonnage en mer peut être biaisé si les traits de chalut ne sont pas échantillonnés au hasard. L'échantillonnage d'un trait de chalut doit se fonder sur d'autres critères qu'une simple opinion du genre « ce trait semble excellent pour échantillonner la morue ». Une discussion sur un certain nombre d'exemples a permis d'établir que des critères aussi arbitraires que celui qu'on vient de mentionner peuvent aboutir à un choix d'échantillons favorisant les plus petits poissons (lesquels sont plus abondants). De même, l'échantillonnage à terre se fonde rarement sur un échantillon véritablement aléatoire de la totalité du débarquement. Ainsi, l'équipe d'échantillonneurs a souvent tendance à n'arriver sur les lieux qu'après le début du processus de déchargement; elle aura alors la possibilité d'échantillonner seulement le poisson capturé dans certains des lieux de pêche où le bateau s'est rendu. Par exemple, les échantillons pourraient provenir trop souvent des derniers traits de chalut faits sur le chemin du retour, c'est-à-dire près des côtes.

Un participant a signalé fort judicieusement qu'il était utile de procéder de temps à autre à des vérifications indépendantes de la validité de l'échantillonnage pour éviter les biais résultant de l'échantillonnage; à cause des problèmes auxquels fait face l'industrie de la pêche, cet échantillonnage doit souvent être effectué fortuitement plutôt que de façon complacent about their procedures and help to prevent them from choosing samples in ways that are based on convenience rather than the need for representative samples. Next, *Port Sampling for Age Composition of Pacific Halibut Landings* by Quinn, Best, Bijsterveld, and McGregor explained the sampling that the IPHC (International Pacific Halibut Commission) carry out for west coast halibut and presented a general methodology for estimation of catch in numbers and average weight at age. Because it is based on otolith sampling, this process is rather different in type to the sampling of east coast demersal fisheries. The numbers of otoliths required to achieve a satisfactory coefficient of variation within strata were considered. In discussion, it was pointed out that often users wanted to make use of individual strata results as well as the combined total international catch-at-age data and this might lay some stress on sampling individual strata more precisely than the need for an overall coefficient of variation would require. Next, *The Sampling Program for Herring and Capelin in Newfoundland* by Carscadden, Miller, Moores, and Nakashima was considered. There were two themes to this paper. It first described the fisheries and their sampling considering the adequacy of the sampling of herring and capelin in terms of numbers of samples/1000 t. The second part of the paper considered the Monte Carlo simulations of random and stratified otolith samples from known populations of herring and capelin. Results from this were somewhat inconclusive due to doubts about the sensitivity of the available test statistic.

The Use of Length and Age Data for Estimating the Age Structure of a Collection of Fish by Fournier was considered next. This paper considered various approaches to the use of small amounts of age data to elucidate the decomposition of length distributions into age distributions. In discussion it was noted that log maximum likelihood methods might be a particularly flexible means of considering the sampling schemes under various assumptions of prior distribution functions.

Determination of the Size Composition of the Landed Catch of Haddock from NAFO Division 4X During 1968-81 by O'Boyle, Cleary, and McMillan was presented by K. Zwanenburg. This considered, in detail, problems in sampling this stock. In the discussion, the problem of whether to continue the same pattern of sampling or adopt a new stratification was considered. It was suggested that if, in fact, the old pattern resulted in biases, it would be most important to set the last year right — thus someone would not be

véritablement aléatoire. De telles vérifications empêchent les échantillonneurs de devenir trop peu rigoureux dans leur travail et de fonder leur échantillonnage plus sur la commodité que sur la nécessité d'obtenir des échantillons représentatifs. Le document suivant, intitulé *Port Sampling for Age Composition of Pacific Halibut Landings* [Échantillonnage au port pour la composition par âge des débarquements de flétan du Pacifique] et rédigé par Quinn, Best, Bijsterveld et McGregor, explique la façon dont la CIFP (Commission Internationale du flétan du Pacifique) échantillonne le flétan de la côte Ouest et présente une méthode générale pour estimer les nombres capturés et le poids moyen à l'âge. Ce type d'échantillonnage est très différent de celui des pêches d'espèces démersales de la côte Est, puisqu'il se fonde sur des échantillons d'otolithes. On a étudié le nombre d'otolithes requis pour satisfaire à divers critères en vue de l'obtention d'un coefficient de variation satisfaisant à l'intérieur des strates. Au cours de la discussion qui a suivi, on a souligné le fait que les usagers veulent fréquemment se servir des résultats par strates individuelles de même que des données par classe d'âge du total combiné des prises internationales; ceci suggère que l'échantillonnage des strates individuelles doit être plus intense que ne l'exigerait le seul besoin d'obtenir un coefficient de variation global. On s'est ensuite penché sur le document de Carscadden, Miller, Moores et Nakashima, intitulé *The Sampling Program for Herring and Capelin in Newfoundland* [Le programme d'échantillonnage du hareng et du capelan à Terre-Neuve]. Le document aborde deux thèmes principaux. Ses auteurs décrivent en premier lieu les pêches et leur échantillonnage, et se demandent quel nombre d'échantillons par 1000 t convient pour l'échantillonnage du hareng et du capelan. Dans la deuxième partie du document, ils étudient les simulations de Monte-Carlo faites sur des échantillons aléatoires et stratifiés d'otolithes, pris dans des populations connues de hareng et de capelan. Les résultats ne sont toutefois pas révélés concluants à cause des doutes soulevés sur la sensibilité des tests statistiques disponibles.

Le document de Fournier intitulé *The Use of Length and Age Data for Estimating the Age Structure of a Collection of Fish* [L'utilisation des données de longueur et d'âge pour évaluer la structure d'âge d'un ensemble de poissons] a ensuite été présenté. Le document analyse diverses approches axées sur l'utilisation de petites quantités de données sur l'âge afin d'expliquer la décomposition des distributions de fréquences de longueur en distributions d'âge. Au cours de la discussion qui a suivi, on a signalé que les méthodes de probabilité maximale pouvaient constituer un moyen particulièrement souple d'examiner les schémas d'échantillonnage selon les diverses hypothèses inspirées par les fonctions de distribution antérieures.

K. Zwanenburg a ensuite présenté le document rédigé par O'Boyle, Cleary et McMillan, intitulé *Determination of the Size Composition of the Landed Catch of Haddock from NAFO Division 4X During 1968-81* [Définition de la composition en taille de prises d'aiglefin débarquées dans la Division 4X de l'OPANO de 1968 à 1981]. Ce document examine en détail les problèmes reliés à l'échantillonnage de ce stock. Au cours de la discussion qui a suivi, on s'est demandé s'il fallait poursuivre le même schéma d'échantillonnage ou adopter une nouvelle stratification. On a émis l'idée que, si constrained by what had gone on historically. Mr Wells was of the opinion that it was best to get it right but perhaps one ought to see as well what the differences were using simulations.

In a revised paper, *Principal Component Methods for Exploratory Data Analysis of Commercial Length-Frequency Data*, McGlade and Smith show that principal component analysis is a powerful method for the exploratory analysis of length-frequency data. The technique is helpful in recognizing the existence of spatial and temporal patterns in length frequency and might thus be valuable in indicating suitable stratification.

The last paper presented was *Commercial Catch Sampling: a Review of its Usage in the Management of Contagiously Distributed Subtidal Mollusc Species* by Jamieson. The problems of sampling mollusc species were carefully considered in the paper. In particular, the difficulties generated by the mixing of catches between areas were stressed. At present, commercial catch statistics are used little but could have a future potential for stock assessment. It was suggested that research vessel surveys might be a better way of understanding these stocks.

In conclusion, this session raised a number of important questions and provided some useful suggestions for their solution. An underlying theme, however, was the need for sampling schemes to have a low bias as well as a low variance. This is a requirement that is rather less easy to quantify at present than the requirement for a low variance; it is nevertheless perceived to be of great importance and it may well be the basis for more elaborate sampling designs (more strata and more independent checks) than would be justified strictly from the need for a low variance alone. This session on sampling techniques thus drew our attention to what may in fact be a fundamental constraint which may condition the optimization of sampling schemes. It also underlined the need for regular critical examination of sampling schemes to avoid complacency about their results and pointed out an area where more understanding of the consequences of errors would be valuable. Thus the important general questions that this session raised are "How do we detect bias? How do we reduce bias? What is the impact of biased esti-

l'ancien schéma aboutit effectivement à des biais, il serait particulièrement important de corriger la dernière année et ainsi, on ne devrait pas être trop influencé par ce qui s'est produit antérieurement. M. Wells s'est dit d'avis qu'il valait mieux corriger le schéma, mais aussi peut-être examiner les différences en utilisant des simulations.

Le document de McGlade et Smith intitulé *Principal Component Methods for Exploratory Data Analysis of Commercial Length-Frequency Data* [Utilisation de l'analyse en composantes principales pour l'analyse préliminaire des données sur les fréquences de longueur des prises commerciales], qui apparaît ici sous une forme révisée, suggère que l'analyse en composantes principales est une méthode puissante pour « explorer » les données sur les fréquences de longueur. Cette technique est utile pour identifier des tendances temporelles ou spatiales qui peuvent être présentes dans les fréquences de longueur, et peut donc servir à l'évaluation d'une stratification particulière.

Le dernier document présenté était celui de Jamieson : *Commercial Catch Sampling: a Review of its Usage in the Management of Contagiously Distributed Subtidal Mollusc Species* [Échantillonnage des prises commerciales : revue de son utilisation pour la gestion des espèces de mollusques infra-littorales, distribuées d'une manière contagieuse]. Le document examine avec soin les problèmes reliés à l'échantillonnage des espèces de mollusques. L'auteur insiste également sur les difficultés soulevées par le mélange des prises provenant de diverses zones. À l'heure actuelle, les statistiques sur les prises commerciales sont peu utilisées, mais elles pourraient servir plus tard à évaluer les stocks. On a déclaré que la meilleure façon d'étudier ces stocks serait peut-être d'effectuer des relevés à l'aide de navires de recherche.

On peut dire, en conclusion, que la présente séance a permis de soulever un certain nombre de problèmes importants, tout en suscitant des suggestions utiles quant à leur résolution. La nécessité d'établir des schémas d'échantillonnage comportant un biais faible en plus d'une variance faible a constitué l'un des thèmes sous-jacents de la séance. Il s'agit là d'une exigence plus difficile à quantifier à l'heure actuelle que le besoin d'une faible variance; cette exigence est cependant jugée très importante et pourrait même constituer le fondement de plans d'échantillonnage plus élaborés (c.-à-d. comportant plus de strates et plus de vérifications indépendantes) que ne le justifierait le seul besoin de produire une faible variance. Ainsi, la présente séance sur les techniques d'échantillonnage a attiré notre attention sur ce qui pourrait constituer une contrainte fondamentale, à laquelle serait conditionnée l'optimisation des schémas d'échantillonnage. Elle nous a également fait prendre conscience de la nécessité de procéder régulièrement à un examen critique des schémas d'échantillonnage afin d'éviter toute complaisance face aux résultats obtenus; elle nous a permis enfin de découvrir un domaine où il serait utile de mieux mates on the fishing industry and what is the cost of reducing bias by an improved sampling program?"

comprendre les conséquences des erreurs. Les importantes questions d'ordre général que la présente séance a soulevées sont les suivantes : « Comment peut-on déceler les biais? Comment peut-on réduire les biais? Quelle est l'influence d'une estimation biaisée pour l'industrie de la pêche et quel est le coût d'une réduction du biais par une amélioration des programmes d'échantillonnage? »

Planning and Organization

CHAIRPERSON: V. C. ANTHONY

The papers presented at this workshop indicate that sampling programs in Canada and the United States vary considerably from species to species and fishery to fishery. Sampling programs differ in their design due to different objectives which may be related to management approaches or to the biology of the animal. A sampling program for finfish often differs from that for crustaceans, for example, due to the biology of the animals. The planning and organizational session, therefore, was able to derive information from a variety of sampling programs. One paper reviewed the use of the sampling standards recommended 8 yr ago in ICNAF while another presented information on the planning and development of a new sampling program. A method of designing and evaluating a sampling program was discussed and the value of a new sampling vehicle — the observer program — was explored. The paper by Beckett recalled the ICNAF sampling standard developed in 1974 of collecting one sample per thousand tonnes of fish landed for each division, quarter of year, and gear. This was a minimum standard that required 200 fish to be measured for length and one fish per centimetre length-group to be taken for age. The standard is still being followed today although in many cases it is not being used as a minimum but as an acceptable level of sampling. The standard has the obvious disadvantages of being a general guideline and not applying to any one fishery in particular. It provides more samples in larger fisheries irrespective of need and does not address any of the problems in sampling such as variance, bias, and cost. There is also the question of where and when to take the samples in addition to the standard question of how many samples to take for a given level of landings. It was pointed out, for example, that at certain times of the year under conditions of fast growth, the number of samples taken should be increased substantially over those times of the year when growth is either not taking place (such as with crustaceans) or when growth is slow. The participants also recognized that the variance between landings and the costs of estimation were greater than the variance within landings and its associated costs. The number of samples to be taken, then, is a function of which

Planification et organisation

PRÉSIDENT : V. C. ANTHONY

Les documents présentés lors de l'atelier ont démontré que les programmes d'échantillonnage mis en application au Canada et aux États-Unis varient considérablement selon les espèces et selon les pêches. La conception de ces programmes diffère à cause des objectifs particuliers qu'ils comportent et qui peuvent être reliés à la gestion ou à la biologie du stock en question. Un programme d'échantillonnage pour le poisson se distingue ainsi d'un programme pour les crustacés à cause des caractères biologiques particuliers à ces deux types d'animaux. La séance sur la planification et l'organisation a permis d'obtenir des renseignements à partir de programmes d'échantillonnage variés. Un document a examiné, entre autres, l'utilisation des normes d'échantillonnage recommandées il y a huit ans par la CIPANO; un autre a examiné la planification et la mise au point d'un nouveau programme d'échantillonnage. On a discuté d'une méthode de conception et d'évaluation des programmes d'échantillonnage et étudié la valeur d'un nouveau moyen d'échantillonnage : le programme des observateurs. Le document rédigé par Beckett rappelle la norme d'échantillonnage mise au point par la CIPANO en 1974 et consistant à recueillir un échantillon par mille tonnes de poissons débarqués, et ce, pour chaque division, chaque trimestre et chaque engin de pêche. Il s'agit là d'une norme minimale selon laquelle il faut choisir 200 poissons pour en mesurer la longueur et un poisson par groupe de longueur (un groupe par centimètre) pour en déterminer l'âge. Cette norme est encore respectée aujourd'hui, même si, dans de nombreux cas, elle ne constitue pas un minimum, mais bien un niveau acceptable d'échantillonnage. Les désavantages de la norme sont évidents : il ne s'agit que d'une ligne directrice générale qui ne s'applique à aucune pêche en particulier; elle donne lieu à un prélèvement d'échantillons plus important dans les pêches les plus vastes, sans tenir compte des besoins, et ne s'attaque à aucun des problèmes de l'échantillonnage (par ex. la variance, le biais et le coût). On se demande toujours combien d'échantillons doivent être prélevés pour un nombre donné de débarquements, mais une autre question se pose aussi : où et quand doit-on prélever les échantillons? On a par exemple souligné le fait qu'à certaines époques de l'année, lorsque la croissance est plus rapide, il faudrait que le nombre d'échantillons prélevés soit beaucoup plus élevé qu'aux époques où la croissance est nulle (par exemple, chez les crustacés) ou lente. Les participants ont admis que la variance entre les débarvariance is being estimated, the cost of reducing the variance, and the precision needed for analysis.

quements et les coûts de son estimation étaient plus considérables que la variance à l'intérieur des débarquements et les coûts qui s'y rattachent. Le nombre d'échantillons prélevés dépend donc de la variance à estimer, des coûts relatifs à une diminution de la variance, et de la précision nécessaire à l'analyse.

The paper by Beckett also indicated the size groupings for taking length frequencies by species that was also agreed to under ICNAF in 1974. The workshop participants noted that these guidelines were insufficient and unrealistic in many cases, and they have been considerably altered over time. In some cases, the size groupings for sampling should vary within the age-length key for a particular species, gear, area, and time. One suggestion was to have a coefficient of variation of 10% for those age-classes that were contributing to the bulk of the catches and let this percentage increase for older ages. This level of 10% was suggested in ICNAF in 1974 as the desirable level for numbers caught at each age.

Le document de Beckett fait également état des groupements de taille servant à établir les fréquences de longueur par espèce et que la CIPANO a convenu d'adopter en 1974. Les participants ont fait observer que ces lignes directrices sont insuffisantes et même irréalistes dans nombre de cas et qu'elles ont été considérablement modifiées au cours des années. Dans certains cas, les groupements de taille pour l'échantillonnage devraient varier à l'intérieur de la clé âge-longueur pour certaines composantes particulières comme l'espèce, l'engin, la zone et l'époque de l'année. On a entre autres suggéré d'introduire un coefficient de variation de 10 % pour les classes d'âge qui constituent la plus grande partie des prises et de permettre une augmentation de ce pourcentage pour les sujets plus âgés. Ce chiffre de 10 % a déjà été suggéré en 1974 par la CIPANO, qui le considérait comme le niveau souhaitable pour les nombres capturés par groupe d'âge.

The paper by Kulka and Waldron reviewed the history, the analysis of sampling effort, and the program benefits of the observer program in the Canadian Atlantic region. This program was originally formulated to evaluate the small mesh foreign fisheries on the Scotian Shelf but has expanded greatly to provide resource assessment data, surveillance information, and support to the developing Canadian industry. In terms of the percent of landings sampled in the observer program, the coverage from the observer program appears to be adequate. The group could not agree, however, that the percentage of catch sampled was a proper index to the adequacy of sampling. There was also a question of whether a vessel behaved differently in respect to its discarding procedure when an observer was on board. It is also possible that observers do not sample randomly at sea but look at particular sets or at particular portions of the catches. Another problem with the Canadian observer program with respect to sampling is that the assessment scientists have little to say over the deployment of observers among the fleets. The observers are deployed according to regulatory requirements which leads to some inefficiencies in sampling. The overall level of required observer coverage is so great, however, that the samples obtained are still cost effective and very useful. Being the sole source of foreign data, the sampling program has replaced the sampling schemes of individual flag states. It thus complements the domestic shore sample data base. As well, an observer program provides additional information that cannot be

Le document de Kulka et Waldron fait l'historique et l'analyse de l'effort d'échantillonnage et des avantages reliés au programme des observateurs dans la région de l'Atlantique canadien. Ce programme avait pour but, à son origine, l'évaluation de la pêche effectuée avec des filets à petites mailles par les flottes étrangères sur le plateau continental de la Nouvelle-Écosse; le programme s'est étendu par la suite et fournit maintenant des données pour l'évaluation des ressources, pour la surveillance des pêches, et sert ainsi de soutien à l'industrie canadienne en pleine croissance. Si l'on en juge par le pourcentage des débarquements échantillonnés, le programme des observateurs semble bien couvrir les pêches. Selon les participants toutefois, on ne peut pas affirmer que le pourcentage de la capture échantillonné représente un indice approprié de la suffisance de l'échantillonnage. On peut se demander aussi si les pêcheurs ne suivent pas un patron de rejet différent lorsqu'un observateur est à bord du bateau. Il est également possible que les observateurs ne prélèvent pas les échantillons au hasard lorsqu'ils se trouvent en mer, mais qu'ils examinent plutôt les prises provenant de traits de chalut particuliers ou certaines portions particulières des prises. Le programme des observateurs canadiens soulève un autre problème en rapport avec l'échantillonnage : les chercheurs responsables de l'évaluation des ressources participent peu aux décisions concernant la répartition des observateurs dans les flottes de pêche; les observateurs sont affectés à des navires selon les exigences de la réglementation, ce qui aboutit à une certaine inefficacité de l'échantillonnage. Néanmoins, la couverture requise des observateurs se situe dans l'ensemble à un niveau si élevé que les échantillons prélevés demeurent rentables et très utiles.

obtained by shore side sampling and in this regard can be very valuable.

Puisqu'il constitue la seule source d'information sur la prise des pays étrangers, le programme d'échantillonnage canadien a effectivement remplacé les programmes d'échantillonnage de ces pays. Le programme des observateurs sert donc de complément au programme canadien d'échantillonnage au port. Ce programme fournit également des renseignements supplémentaires qui ne peuvent être obtenus par un échantillonnage à terre; à ce titre, le programme peut se révéler d'une grande valeur.

The paper by H. Powles was unique in that it discussed the sampling requirements for a research region that is just being formed. The objectives of the paper were to outline those elements that are necessary for developing a sampling plan. The paper reviewed both the effectiveness and efficiency of sampling programs and used the 1974 ICNAF guideline as a target level of sampling. This paper examined the efficiency of using centralized locations as opposed to setting up "forward bases" located in the heart of fishing areas as alternatives for collecting data. This paper led to a discussion of the marginal costs of taking unscheduled additional samples which can be an important consideration in planning a sampling program. An additional suggestion for a sampling guideline was proposed as some function associated with the economic value of the fisheries.

Le document de H. Powles est unique en ce sens qu'il traite des exigences d'échantillonnage pour une région de recherche qui vient tout juste d'être créée. Il a pour objet de souligner les éléments nécessaires à la mise au point d'un plan d'échantillonnage; l'auteur y étudie l'efficacité des programmes d'échantillonnage, en utilisant comme niveau d'échantillonnage visé la ligne directrice émise par la CIPANO en 1974. L'auteur se demande s'il est plus efficace d'utiliser, comme solutions de rechange pour la cueillette des données, des emplacements centralisés au lieu d'installer des postes avancés en plein coeur des zones de pêche. Ce document a suscité une discussion sur les frais supplémentaires reliés au prélèvement d'échantillons additionnels non prévus, ce qui peut être un élément important pour la planification d'un programme d'échantillonnage. Un autre participant a suggéré de mettre au point une ligne directrice d'échantillonnage où l'effort d'échantillonnage serait une fonction de la valeur économique des diverses pêches.

In a paper by Silvert and Powles, the design of a sampling program was examined through the application of operations research methods. Optimal allocation of a sampling strategy was achieved with a given objective function with certain constraints and a feedback loop. A sampling design was evaluated in its ability to minimize regret at the management objective level and then provide feedback to the design to improve the sampling procedures. Such a technique allows one to look at the propagations of errors as the data are processed and to test for applicability in achieving desired objectives. It provides an easy procedure for updating the sampling program when it becomes obvious that conditions for sampling change. A case study applied to cod was evaluated with this technique which indicated very clearly the value of having detailed and precise information on those things that actually drive the system such as costs. For this particular case study, the desirability of sampling newly recruited fish in a trawl fishery happened to be of major concern; this indicated the potential uniqueness of sampling requirements for fisheries and the need for flexibility in creating our sampling designs as well as adjusting them from year to year.

Dans leur document, Silvert et Powles étudient la conception d'un programme d'échantillonnage fondé sur l'application de méthodes de recherche opérationnelle. La mise au point d'une stratégie d'échantillonnage optimale a été réalisée avec une fonction objective donnée, qui tenait compte de certaines contraintes et permettait un ajustement de l'échantillonnage en fonction des résultats obtenus. Le plan d'échantillonnage a été conçu afin de réduire le regret au minimum en ce qui concerne les objectifs de gestion et de fournir un moyen aux responsables du plan d'améliorer la méthode d'échantillonnage. Une telle technique permet de déceler l'introduction d'erreurs au cours du traitement des données et de vérifier si le plan, tel qu'appliqué, rencontre les objectifs visés. Elle comporte une méthode simple de mise à jour du programme d'échantillonnage, lorsqu'il devient évident que les conditions d'échantillonnage ont changé. On a évalué, à l'aide de cette technique, une étude de cas portant sur la morue; cette évaluation a démontré très clairement combien il est important de disposer de renseignements détaillés et précis sur les éléments qui constituent véritablement le moteur du système (par exemple, les coûts). Dans cette étude de cas, en particulier, la désirabilité d'un échantillonnage des nouvelles recrues à une pêche au chalut apparut comme une préoccupation majeure, ce qui démontrait à quel point les exigences d'échantillonnage peuvent être uniques pour chaque pêche et à quel point l'instauration et l'ajustement, année après année, des plans d'échantillonnage doivent être souples.

The discussion indicated problems of post optimizing when conditions change and that while it is extremely beneficial to look back at sampling deficiencies, changing a sampling plan for the future

Au cours de la discussion qui a suivi, on a fait état des problèmes reliés à l'optimisation ultérieure, lorsque les conditions changent; s'il est extrêmement avantageux de pouvoir revenir sur les imperfections de l'échantillonnage, il faut requires that similar circumstances apply. If circumstances change over time, then the results of even an improved sampling plan can also be undesirable.

s'assurer de la permanence de ces changements si l'on veut modifier le plan d'échantillonnage pour l'avenir. Si les conditions changent au fil du temps, même les résultats obtenus avec un plan d'échantillonnage amélioré pourront ne pas être souhaitables.

The last paper by Lamoureux et al. reviewed the sampling programs for snow crabs, and lobsters in Quebec. The paper outlined the justification for geographic and seasonal sampling according to changes in growth, abundance, and effort from one area and time to another. The advantages and disadvantages of sampling at sea and on land were reviewed. The authors indicated that the assessment of snow crab and lobster dictated sampling priorities that were different from finfish when it is possible to age the animals involved. The authors concluded that at sea sampling was far more important than shore sampling because the estimation of recruitment is only possible at sea. A brief discussion on the selectivity of nets and traps and the changes in catch per effort of both small and large individuals due to increases in mesh size and lath spacing demonstrated the need for flexibility in sampling over time.

Le dernier document, de Lamoureux et al., étudie les programmes d'échantillonnage du crabe des neiges et du homard au Québec. Les auteurs discutent le choix des endroits et des saisons à échantillonner en fonction des variations de la croissance, de l'abondance et de l'effort de pêche déployé d'une zone à l'autre et d'une époque à l'autre. Ils analysent les avantages et les désavantages d'un échantillonnage effectué à la fois en mer et à terre. Les auteurs signalent que l'évaluation du crabe des neiges et du homard est assujettie à des priorités d'échantillonnage différentes de celles du poisson, dont il est possible de déterminer l'âge. Ils en arrivent à la conclusion que l'échantillonnage en mer est beaucoup plus important que l'échantillonnage au port, puisque l'évaluation du recrutement n'est possible qu'en mer. Au cours d'une brève discussion traitant de la sélection des filets et des cages, et de l'influence de l'augmentation de la grosseur des mailles et de l'espacement des lattes sur le taux de capture de sujets petits et grands, les participants en ont conclu qu'il faut faire preuve de souplesse lorsque l'échantillonnage est étalé dans le temps.

While it was not possible to explore in detail all of the various requirements of ideal sampling programs in a few hours, a few general requirements that apply to all sampling programs were obvious, and some specific recommendations were made by the group. Because sampling programs vary considerably in their requirements among species, fisheries, and time, a clear idea of the beginning objectives is required. Planners should not ignore the fact that these objectives are liable to change, and thus a sampling program must be flexible. Each scientist should have a detailed knowledge of the evolution of variances at all stages of sampling for his fishery, both at shore and at sea. The cost and efficiency of sampling should be known at those places and times, and by those sampling methods that are potentially available in designing a sampling program. A monitoring program should be established based on several standards of review which will allow the adequacy of the sampling program to be evaluated on a timely basis and also provide the substance for changing the program. Finally, sources of supplementing the sampling program should be identified such as research vessel surveys, observer programs, or additional sampling under various situations.

Il a été impossible d'explorer en détail en quelques heures toutes les exigences que devrait comporter un programme d'échantillonnage idéal; les participants ont cependant réussi à dégager quelques exigences générales évidentes, pouvant s'appliquer à tous les programmes d'échantillonnage, et à faire un certain nombre de recommandations précises. Il est essentiel d'avoir une idée nette des objectifs de départ, car les exigences des programmes d'échantillonnage varient considérablement selon l'espèce, le type de pêche et l'époque de l'année. Les planificateurs ne devraient pas oublier que ces objectifs sont sujets à changement et que les programmes d'échantillonnage doivent donc être souples. Tous les chercheurs devraient posséder une connaissance approfondie de la pêche dont ils sont responsables; ils devraient par exemple être familiers avec l'évolution de la variance à toutes les étapes de l'échantillonnage, que ce soit à terre ou en mer. Ils devraient connaître le coût et l'efficacité de l'échantillonnage par les méthodes dont on dispose au moment de la conception des programmes d'échantillonnage, et ce, pour tous les endroits et toutes les périodes de l'année visés. Il faudrait mettre sur pied un programme de révision fondé sur un certain nombre de règles d'examen qui permettraient de vérifier de façon régulière si le programme d'échantillonnage est approprié et qui permettraient d'identifier la nature des changements à apporter au programme. Enfin, il faudrait identifier les apports supplémentaires possibles au programme d'échantillonnage (par exemple : les relevés des navires de recherche, les programmes d'observateurs et les échantillonnages additionnels qui s'imposent dans diverses situations).

Specific recommendations made by the participants were:

1) new general standards for sampling marine fisheries at both minimum and desirable levels should be formulated;

Voici la liste des recommandations précises faites par les participants :

1) il faudrait formuler de nouvelles normes générales pour le niveau minimal et le niveau souhaitable d'échantillonnage des pêches en mer;

2) a protocol of how the sample is taken should be devised;

3) scientists should routinely estimate their coefficients of variation for their sampling programs and monitor how the coefficients vary over time;

4) the criteria for sampling should be reviewed regularly due to changes in the population and the needs of assessments;

5) biologists should become fully involved in the sampling activities and the review procedure;

6) scientists should utilize analytical techniques and models such as operations research methods containing feedback loops to evaluate the sensitivities of their sampling plans and the efficiencies of change dictated by the evolving sampling requirements.

2) il faudrait mettre au point une procédure pour le prélèvement des échantillons;

3) les chercheurs devraient évaluer régulièrement les coefficients de variation de leurs programmes d'échantillonnage et surveiller la fluctuation de ces coefficients au cours du temps;

4) il faudrait réviser régulièrement les critères d'échantillonnage, en fonction des changements qui surviennent dans les populations et des besoins d'évaluation;

5) les biologistes devraient participer pleinement aux activités d'échantillonnage et au processus de révision des programmes;

6) les chercheurs devraient utiliser des techniques et des modèles analytiques (par exemple, des méthodes de recherche opérationnelle permettant l'autocorrection des programmes) afin d'évaluer la sensibilité de leur plan d'échantillonnage et l'efficacité des modifications imposées par l'évolution des exigences de l'échantillonnage.

Summary and Conclusion

CHAIRPERSON: W. G. DOUBLEDAY

HISTORICAL SAMPLING STANDARDS AND PRACTICES

Ten years ago, marine fisheries in the northwest Atlantic and, to some extent, the Northeast Pacific were dominated by distant water fleets of many nations. Both sampling techniques and levels of sampling varied unevenly between fleets and fisheries sometimes necessitating the application of samples for one country to catches of another. Increasing demands for scientific advice on fisheries management were responded to by a steady increase in the number of stocks considered in quantitative resource assessments and in the sophistication of these assessments. In this context, the Standing Committee on Research and Statistics (STACRES) of ICNAF, promoted study of sampling methods and desirable levels of sampling activity for commercial catches.

Attention was focused on techniques of sampling and aging as well as on the required size and number of samples. In 1974, ICNAF adopted a minimum standard on sampling rates for commercial catches. The reasoning behind the standard was to provide a rough but useful guideline that could be widely applied to improve the quality of data available for stock assessment without unduly increasing the cost of sampling programs.

The appropriateness of tailoring the sampling program to the use of the resulting data was recognized, but practical considerations limited advice to a target 10% coefficient of variation of the age composition. The need for more sophisticated analysis required to

Résumé et conclusion

PRÉSIDENT : W. G. DOUBLEDAY

HISTORIQUE DES NORMES ET DES PRATIQUES D'ÉCHANTILLONNAGE

Il y a 10 ans, dans les zones de pêche du nord-ouest de l'Atlantique et, dans une certaine mesure, dans celles du nord-est du Pacifique dominaient les flottes de pêche internationales à grand rayon d'action. Les techniques et les niveaux d'échantillonnage variaient beaucoup selon les flottes et les types de pêches; on devait même parfois appliquer les résultats des échantillonnages des prises d'un pays donné aux prises d'un autre pays. L'augmentation du nombre de demandes d'avis scientifiques pour la gestion des pêches a mené à une augmentation soutenue du nombre de stocks devant faire l'objet d'évaluations quantitatives et à un raffinement des évaluations. C'est dans cette optique que le Comité permanent de recherche et de statistique (CPRS) de la CIPANO a encouragé l'étude des méthodes d'échantillonnage et des niveaux souhaitables d'échantillonnage pour les prises commerciales.

On a accordé une attention particulière aux techniques d'échantillonnage et de détermination des âges de même qu'aux exigences touchant la taille et le nombre des échantillons. En 1974, la CIPANO a adopté une norme minimale quant aux taux d'échantillonnage des prises commerciales. En mettant au point cette norme, la CIPANO se proposait de fournir une ligne directrice, très générale mais tout de même utile, qui pourrait être largement appliquée afin d'améliorer la qualité des données disponibles pour l'évaluation des stocks, et ce, sans accroître indûment le coût des programmes d'échantillonnage.

On a reconnu qu'il est approprié d'adapter les programmes d'échantillonnage à l'usage qu'on compte faire des données; des considérations d'ordre pratique limitent cependant les avis à un coefficient de variation visé de 10 % pour la composition en âge. On a souligné qu'il est nécessaire de study the relationship between sampling accuracy and quality of assessment advice was noted. Emphasis was placed on the number and distribution of samples as opposed to the number of fish in a sample. The stratification by gear/division/quarter gave some control over potential bias from a nonrandom choice of samples.

The extension of fisheries jurisdiction in 1977 led to dramatic changes in commercial catch sampling. The catches of distant water fleets which had often been poorly sampled were greatly reduced and observers were deployed on board to sample at sea together with other duties. At the same time, increased funding was directed at the marine resource assessment program in Canada, which permitted a great increase in the number of samples taken. In recent years, the minimum ICNAF sampling standard has been exceeded in most cases and national control over sampling programs has permitted consideration of more sophisticated sampling targets.

Estimates of commercial catch at age have been little used in the assessment of marine invertebrate resources. Special features of invertebrate fisheries frequently include processing at sea which transforms animals caught by removing shells and altering water content. The need for knowledge of the composition of commercial catches to evaluate the impact of proposed regulations affecting the age composition of catches has been recognized. Sampling programs for commercial catches are now being analyzed in the context of overall improvements to resource assessment methodology for marine invertebrates.

procéder à des analyses plus approfondies afin d'étudier le rapport entre la précision de l'échantillonnage et la qualité des avis sur l'évaluation. On a mis l'accent sur le nombre et la distribution des échantillons par opposition au nombre de poissons dans un échantillon. La stratification selon l'engin, la division et le trimestre a permis d'exercer un certain contrôle sur les biais éventuels résultant d'un choix non-aléatoire d'échantillons.

L'extension de la juridiction canadienne sur les pêches en 1977 a provoqué des changements considérables dans l'échantillonnage des prises commerciales. Les prises des flottes de pêche à grande distance, qui avaient été souvent échantillonnées de façon médiocre, ont été considérablement réduites; on a confié à des observateurs, entre autres tâches, le soin de faire l'échantillonnage en mer des prises commerciales. Simultanément, on a dirigé de nouveaux fonds vers le programme canadien d'évaluation des ressources marines, ce qui a permis d'accroître considérablement le nombre d'échantillons prélevés. Au cours des dernières années, la norme d'échantillonnage minimal de la CIPANO a été dépassée dans la plupart des cas; un contrôle national sur les programmes d'échantillonnage a permis d'envisager des cibles d'échantillonnage plus élaborées.

Les estimations des prises commerciales par âge ont été peu utilisées dans l'évaluation des populations d'invertébrés marins. Les pêches d'invertébrés comportent certaines caractéristiques particulières; mentionnons entre autres la transformation en mer des captures, en retirant les coquilles et en modifiant le contenu en eau. On a reconnu qu'il est nécessaire d'acquérir des connaissances sur la composition des prises commerciales afin d'évalüer l'impact des règlements proposés sur la composition en âge des prises. On analyse à présent les programmes d'échantillonnage des prises commerciales dans la perspective des améliorations globales qui pourraient être apportées aux méthodes d'évaluation appliquées aux stocks d'invertébrés marins.

Results of Research Presented at the Workshop

Studies presented at the workshop and published in this volume contribute to understanding a number of technical aspects of commercial catch sampling.

One group of studies focused on the impact of sampling on projection of total allowable catches. The importance of accurate estimation of partially recruited year-classes and accurate forecasting of mean weight at age in the achievement of target exploitation rates was emphasized. Insights were presented on the still subjective, but rapidly evolving subject of tuning virtual population analyses. The concepts of influential points and variables and regret associated with errors of estimation were raised in the context of yield per recruit calculations but can be applied much more widely.

Résultats de recherche présentés dans le cadre de l'atelier

Les études présentées dans le cadre de l'atelier et publiées dans le présent document permettent de mieux comprendre un certain nombre des aspects techniques de l'échantillonnage des prises commerciales.

Un certain nombre de ces études soulignaient l'impact de l'échantillonnage sur la projection du total des prises admissibles. On a insisté sur l'importance d'une évaluation précise des classes d'âge partiellement recrutées et d'une prévision juste du poids moyen par âge pour atteindre les taux d'exploitation visés. Des points de vue nouveaux ont été présentés sur la question toujours controversée, mais soumise à une évolution rapide, de l'ajustement des analyses de populations virtuelles. Les concepts de points et de variables d'influence, et de regret relié aux erreurs d'évaluation ont été évoqués dans le cadre des calculs du rendement par recrue; ces concepts peuvent cependant être appliqués d'une manière beaucoup plus large.

Another group of papers aimed at quantifying the precision of sample-based estimates and comparing sampling schemes. When discards at sea are not significant, equal sampling precision can be achieved at lower cost at the point of landings as can be achieved at sea.

Three papers addressed the problem of design and optimization of sampling programs. Significant cost savings are possible in the achievement of quantified sampling objectives if optimization techniques are applied.

Une autre série de documents visait à quantifier la précision des estimations fondées sur les échantillons et à comparer les schémas d'échantillonnage. Lorsque les rejets à la mer ne sont pas importants, il est possible d'obtenir aux points de débarquement la même précision d'échantillonnage qu'en mer, mais à un coût moindre.

Trois documents s'intéressaient aux problèmes de conception et d'optimisation des programmes d'échantillonnage. Il est possible de faire de grandes économies dans la réalisation des objectifs d'échantillonnage quantifiés en appliquant des techniques d'optimisation.

New Directions

This workshop suggests that recent trends away from subjective approaches to formulating fishery management advice will continue. Increasing computing capabilities and standardization of estimation procedures has permitted some quantitative analyses linking quality of sampling data to resulting catch projections and other advice. Some approaches previously used in "tuning" of virtual population analyses are called into question by these analyses and new emphasis is being directed at key input parameters. Explicit incorporation of the sampling design as a likelihood function in estimation procedures is a significant new development. Such an approach, further elaborated, promises to provide clear and explicit linkage between sampling programs and results produced.

As insights into influential and critical sample parameters accumulate, it will become possible to optimize sampling programs from a cost effectiveness point of view. Arbitrary sampling standards can then give way to analytically determined targets.

The workshop considered that more attention should be devoted to defining the role of commercial fisheries information, including sampling of catch compositions for invertebrate fisheries. Analysis of sampling data and planning of sampling programs should be carried out as an important phase in the analysis of the implications of alternative management measures and the provision of scientific advice.

Besides identifying these long-term trends, the workshop drew attention to the following six problems which require further examination:

1) the revision of sampling level standards;

2) analysis of parameters obtained from sampling for individual commercially important fish stocks from the point of view of variance and influence on management advice;

3) evaluation of the adequacy of existing sampling programs for estimation of mean weights at age;

Nouvelles orientations

Les participants au présent atelier croient que se poursuivra la tendance récente qui consiste à s'éloigner des approches subjectives lors de la formulation des avis pour la gestion des pêches. L'accroissement des capacités de calculs informatisés et la normalisation des méthodes d'estimation ont permis de réaliser certaines analyses quantitatives reliant la qualité des données d'échantillonnage aux projections sur les prises et aux autres avis qui en résultent. Ces analyses remettent en question certaines approches appliquées précédemment à l'ajustement d'analyses de populations virtuelles; on met à présent l'accent sur les paramètres d'entrée critiques. L'incorporation explicite du plan d'échantillonnage en tant que fonction de probabilité dans la méthode d'évaluation constitue une nouveauté importante. Une telle approche, lorsqu'elle sera plus élaborée, permettra d'établir un lien net et explicite entre les programmes d'échantillonnage et les résultats obtenus.

Plus les points de vue nouveaux sur les paramètres d'échantillons importants s'accumuleront, plus il sera possible d'optimiser les programmes d'échantillonnage du point de vue de la rentabilité. Les normes arbitraires d'échantillonnage pourront alors céder la place à des objectifs établis par analyse.

Les participants à l'atelier croient qu'il faudrait se consacrer davantage à la définition du rôle des données sur les pêches commerciales, y compris l'échantillonnage de la composition des prises dans la pêche d'invertébrés. Il faudrait que l'analyse des données d'échantillonnage et la planification de programmes d'échantillonnage deviennent une étape importante de l'analyse des répercussions des mesures alternatives de gestion des pêches et de la formulation des avis scientifiques.

En plus d'identifier ces tendances à long terme, les participants ont souligné l'importance des six problèmes suivants, qu'il faudrait examiner de façon plus approfondie :

1) la révision des normes fixant le niveau d'échantillonnage;

2) l'analyse des paramètres obtenus à partir de l'échantillonnage pour chaque stock de poissons commercialement important, du point de vue de la variance et de l'influence exercée sur les avis pour la gestion des stocks;

3) l'évaluation des programmes d'échantillonnage existants pour vérifier s'ils sont appropriés à l'estimation du poids moyen par âge;

4) documentation of procedures to estimate the mean weight at age and catch at age from samples and catch statistics;

5) analysis of sampling data to determine the appropriate variables for stratification of the sampling design and the appropriate number of strata to efficiently control potential sampling biases;

6) documentation of procedures employed to choose a sample from a vessel's catch.

4) la documentation des procédures d'estimation du poids et des captures à l'âge à partir des données d'échantillonnage et des statistiques sur la capture;

5) l'analyse des données d'échantillonnage afin de déterminer les variables appropriées pour la stratification du plan d'échantillonnage, ainsi que le nombre de strates nécessaire pour contrôler efficacement les biais éventuels dans l'échantillonnage;

6) la documentation des procédures utilisées pour choisir un échantillon à partir des prises d'un bateau.

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Review of History of Commercial Catch Sampling, Standards, and Current Practice with Emphasis on the CAFSAC Area

Historique de l'échantillonnage des prises commerciales, des normes et des pratiques courantes s'y rattachant, l'accent étant mis sur la zone du CSCPCA

A Review of the Sampling of Commercial Groundfish Catches in Newfoundland

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A review of the commercial groundfish catch sampling program in the Newfoundland region is presented. A description of this program in terms of the fisheries sampled, the organization and manpower involved, and the systems and techniques used is given. A 5-yr historical review (1976–80) of the program's sampling performance, using a measure of relative efficiency based on the number of length samples collected per each 1000 t of fish caught for each species, NAFO division, quarter of the year, and gear type is also presented. Results of this review indicate that, in terms of minimum standards recommended by NAFO, sampling is generally very good, and where deficiencies do occur they are for relatively small landings. A need for more emphasis on the sampling of the inshore fishery is also apparent.

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Le rapport présente un aperçu du programme d'échantillonnage des prises commerciales de poissons de fond dans la région de Terre-Neuve. On décrit le programme en fonction de la pêche échantillonnée, de l'organisation et de la main-d'oeuvre nécessaire, et des systèmes et techniques utilisés. On donne aussi un compte rendu historique quinquennal (1976–80) du succès de l'échantillonnage, quantifié en terme d'efficacité relative selon le nombre d'échantillons prélévés par 1000 t de prises de chaque espèce, dans chaque division de l'OPANO, au cours de chaque trimeste et pour chaque type d'engin. Les résultats de cette récapitulation révèlent que, par rapport aux normes minimales recommandées par l'OPANO, l'échantillonnage est généralement très bon. Là où il est insuffisant, il s'agit d'assez petits débarquements. Il est aussi évident qu'on doit accroître l'échantillonnage de la pêche côtière.

Introduction

With the declaration of Canada's 200-mi limit in 1977 and the associated increase in emphasis on the effective management of the various stocks in the Canadian zone, the collection of biological catch sampling data for use in the assessments of the stocks has increased in importance in recent years. Considerable manpower and monies have been allocated to catch sampling programs, making it more important than ever that these resources be used as efficiently as possible in terms of optimizing quality and quantity of data returns.

This paper reviews the current program for sampling the commercial groundfish catches of the Newfoundland domestic fishery. Emphasis is placed on the functioning of the Commercial Groundfish Sampling Section of Research and Resource Services, St. John's, with some mention of the role played by the Newfoundland Observer Program in sampling offshore catches. This latter program is reviewed more thoroughly in another paper at this workshop.

The paper is presented in two parts. The first is a description of the domestic catch sampling program in the Newfoundland region and the second is a 5-yr historical review of its performance.

Description of the Program

This section is intended for use at this workshop as a source of background information on the current program for sampling domestic groundfish catches in the Newfoundland region. The inshore and offshore fisheries are discussed separately because they are considered sufficiently discrete and their sampling programs sufficiently different to merit it.

THE FISHERIES

Offshore — The Newfoundland offshore mobile fleet consists of 83 trawlers (NAFO tonnage classes 4 and 5)[1]

[1]NAFO (Northwest Atlantic Fisheries Organization) tonnage classes 4 and 5 are 150–499.9 and 500–999.9 GRT, respectively.

making trips of between 8 and 12 d duration primarily to NAFO subareas 2, 3, and 4. Of these vessels, 65 are stern trawlers and 18 are relatively outdated side trawlers. They fish mainly for cod, American plaice, redfish, yellowtail, witch, turbot, and haddock, with minor catches of various other species. These vessels land at 12 major ports on the east and south coasts of Newfoundland. Otter trawls are generally used by these vessels, but in recent years mid-water trawls have been used occasionally.

Inshore — It is difficult to obtain the actual number of inshore vessels fishing groundfish in Newfoundland; however, the enormous size of the fleet is reflected in the number of vessels registered by the Department of Fisheries and Oceans in 1980:

Size class		Number registered
0–34′	(0–10.5 m)	18 176
35–64′	(10.6–19.5 m)	1 392
65–99′	(19.6–30.2 m)	26
Total		19 594

Most of the smaller vessels (0-19.5 m) fish with codtraps, handlines, gill nets, and longlines, while most of the larger vessels use shrimp trawls, groundfish trawls, and Danish seines. Trips are normally of 1 d duration, except for some of the larger vessels which may make trips of several days. Catches in recent years have consisted primarily of cod, plaice, and turbot, with smaller amounts of various other groundfish species. Fish from the inshore sector are landed at virtually every coastal community in Newfoundland.

Organization and Manpower

Within the Groundfish Management Program of Research and Resource Services in Newfoundland, the Commercial Groundfish Sampling Section has the primary responsibility for commercial catch sampling of both the inshore and offshore domestic fishery. In recent years the Foreign Cooperative Research Section, through the Newfoundland Observer Program, has also begun biological sampling onboard Newfoundland offshore vessels (see Kulka et al. 1983). The sampling of groundfish catches in Newfoundland is organized as follows:

Commercial Groundfish Sampling Section	Foreign Cooperative Research Section (Observer Program)
Port sampling — domestic inshore and offshore groundfish.	Sea sampling — foreign and domestic offshore all species (including groundfish).
Sea sampling — discard surveys on domestic offshore vessels.	

The Commercial Groundfish Sampling Section collects and processes age and length sampling data for use by the various species sections; however, otolith reading is left to the expertise within the various user groups. The Sampling Section has a contingent of six permanent technicians and up to 2 yr of term manpower per year. The primary responsibility of these technicians is port sampling; however, they are also involved in two to three discard survey trips each per year onboard commercial trawlers, special projects on inshore vessels, as well as research vessel trips when work schedules permit. Two permanent technicians are stationed at a port sampling office on the Burin Peninsula, which is a high volume offshore landing area. All other staff are stationed in St. John's from where they proceed on field trips, ranging from 1 d to several weeks in duration, to sample offshore landings at major plants as well as at various inshore landing areas in Newfoundland. Another port sampling office is not practical because of the seasonality and wide geographic distribution of inshore landings, and the considerable distances between each of the major offshore plants.

The section also carries out a discard survey program which is designed to monitor discard rates and collect age and length data on the discard portions of catches in known or suspected problem areas. This program is limited by manpower resources and normally entails sending pairs of observers on an average of eight offshore fishing trips in a particular year.

Sampling Procedures and Techniques

Newfoundland groundfish landings may originate, at one end of the scale, from large offshore trawlers landing at modern processing plants or, at the other end, from small inshore vessels fishing on a daily basis and landing at fishermen's stages in remote areas. Therefore, actual sampling procedures must be varied to fit the prevailing conditions.

Offshore — These landings occur at major processing plants in the larger ports and normally provide the best sampling conditions due to the consistently high volume of landings and the relatively modern facilities. Sampling of landings at these plants is generally a fairly standard procedure. Newfoundland offshore vessels return to port with their catches stored in ice and separated by species and date into pens. Depending on the company, cod and haddock are normally landed gutted, flatfish species are landed either gutted or bobtailed[2] and redfish are landed round. The fish are generally pumped ashore by means of suction pumpers where ice and shack[3] are removed and the landings weighed. These fish are then iced and stored in boxes, pens, or tanks in holding rooms awaiting processing. The size of discharge weighings[4] are fairly standard at a particular plant, but many vary from between 115 and 230 kg among plants. The technicians, having verified the dates and areas of the landings being discharged by comparing vessel hold reports with vessel logs, obtain

[2]Bobtailed refers to severing the fish's tail at the line of the caudal peduncle.

[3]Fish rejected as being in too poor condition to process for human food.

[4]Units by which vessel catches are weighed when discharging (normally in pounds)

a sample of 300–400 fish. The sample size normally depends on the size of discharge weighings being used at a particular plant and many vary accordingly. When species such as cod are culled into size categories, a sample from each category is obtained. All fish in a particular weighing or box are usually measured. This procedure allows actual sample weights to be obtained for the calculation of average weights and also prevents sampling bias due to the separation of fish by size within a particular box or weighing. Otoliths are collected as a stratified subsample from those measured. A predetermined number of otoliths at each length group are aimed for in a particular quarter for each species, NAFO division (stock area for redfish), and sex where applicable. From one to five otoliths are normally collected per length group from a particular sample, depending on the prospects for completing a certain stratified scheme within a given quarter. An analysis is currently being carried out in the Newfoundland region with a view to the optimization of current otolith stratification schemes (see Baird 1983).

Inshore — These landings are rather seasonal and scattered, making the logistics involved in sampling them with available manpower resources very complex. Fish are normally landed round and are gutted on shore by small boat fisherman; however, the catches from the larger longliners are usually gutted on board before docking. Fish are transferred onshore in a number of ways including buckets, baskets, nets, and suction unloaders. Samples are normally obtained after the fish have been sold to a processing plant; however, sampling on board vessels or on wharves is carried out when fish are not sold directly to a plant. Usually a sample of from 300 to 400 fish is measured, but this can vary between 100 and 1000 fish in some instances. Normally, if time permits and the landing is of a relatively manageable size, the total catch is measured. Similar to the offshore sampling, otoliths are collected as a stratified subsample from those measured and based on predetermined quarterly stratification schemes for each species, NAFO division, and sex where applicable.

Review of Sampling Performance (1976–80)

A 5-yr historical review (1976–80) of the commercial groundfish catch sampling performance in the Newfoundland region is presented. Several papers have reviewed sampling efficiencies and performance during this period (e.g. Rivard et al. 1980; NAFO 1980); however, these papers dealt with a single year's sampling and were generally in terms of total Canadian sampling performance. Notwithstanding the need for regional interaction in the sampling of commercial groundfish catches on the East Coast, this review will focus on the domestic catch sampling program in the Newfoundland region. It is hoped that such a review will constitute an important step in bringing major areas of undersampling and oversampling to the forefront so that a more optimal distribution of sampling effort may be planned in future.

Methods

Sampling performance is examined in terms of the minimum recommended level of sampling of one length sample per each 1000 t of fish caught for each species, division, quarter of the year, and gear (ICNAF[5] Redbook 1974). This measure of sampling performance should be viewed as one of relative rather than of absolute efficiency. Indeed, sampling at these levels is probably inadequate, as several case studies in 1975 indicated that the sample size required to obtain the target of estimating numbers at age with a coefficient of variation of not more than 10% considerably exceeded the minimum requirement (ICNAF Redbook 1975). However, as a means of comparing relative sampling performance over a series of years and between various species/division/gear/quarter strata, it is perhaps as useful as any other measure.

The sampling of the inshore and offshore fisheries is analyzed separately. Sampling of the offshore fishery is further broken down into port and observer sampling for 1979 and 1980, when the deployment of observers on domestic vessels began. For the purpose of this review, the inshore and offshore fisheries are separated on the basis of gear types. Inshore gears include codtraps, gill nets, longlines, and handlines. Offshore gears are primarily otter trawls but midwater trawls, pair trawls, shrimp trawls, and Danish seines are also included in this category.

Strata with landings of less than 100 t are disregarded in this review. It was felt that with limited manpower and the lack of real time-detailed landing statistics, the logistics involved in sampling such incidental landings were far too impractical to allow them much consideration. Table 1 indicates that for the entire 1976–80 period, strata less than 100 t amounted to only 2.3% of the overall groundfish landings. For cod, which was by far the major species landed during this period, less than 1% was from strata less than 100 t. On the other hand, about 34% of haddock,

TABLE 1. Summary of Newfoundland landings for (species/division/gear/quarter) strata < 100 t and not included in the analyses as compared to total Newfoundland landings for the years 1976–80.

Species	Total landings (t) for strata < 100 t 1976–80	Total landings (t) 1976–80	% of total Landings < 100 (t)
Cod	7 570	880 330	0.9
Haddock	2 040	6 020	33.9
Redfish	7 640	158 930	4.8
Am. plaice	6 920	279 270	2.5
Yellowtail	1 120	67 450	1.7
Witch	5 770	43 360	13.3
Turbot	4 570	114 290	4.0
Total	35 630	1 549 650	2.3

[5]International Commission for the Northwest Atlantic Fisheries.

TABLE 2. Summary of the number of (species/division/gear/quarter) strata sampled at a rate of 1 sample per 1000 t or greater (i.e. numerator) compared to the actual number of these strata occurring for a particular stock area and year (i.e. denominator). A — offshore fishery, B — inshore fishery.

Species	Stock area	1976	1977	1978	1979	1980	% Strata sampled efficiently 1976–80	% Strata sampled efficiently 1980
				A. Offshore Fishery				
Cod	2J3KL	3/5	6/7	7/7	9/10	8/10	85	80
	3M		1/1	0/1			50	
	3NO	2/5	3/5	8/8	7/7	3/6	74	50
	3Ps	3/4	2/3	2/3	1/2	2/3	67	67
	3Pn4RS	5/13	4/7	3/9	2/11	3/10	34	30
	4T	0/2			0/1		0	
	4VsW	0/4	0/3	0/4	3/4	2/5	25	40
	4X					1/2	50	50
	5Z			0/1			0	
	Total	13/33	16/26	20/33	22/35	19/36	55	53
	%	39	62	61	63	53		
Redfish	2+3K	2/3	4/4	6/10	6/10	2/4	65	50
	3LN	4/8	4/6	2/5	6/8	2/5	56	40
	3M	3/4	2/3	2/3	2/2		75	
	30	2/2	1/3	2/2	1/4	1/1	58	100
	3P	7/10	4/9	3/8	4/10	4/9	48	44
	4RST	2/5	1/2	1/2	1/2	2/2	54	100
	4VWX	1/4	0/6		3/7	1/4	24	25
	Total	21/36	16/33	16/30	23/43	12/25	53	48
	%	58	48	53	53	48		
Am. plaice	2+3K	1/2	2/2	1/2	2/3	2/2	73	100
	3LNO	9/12	10/12	12/12	12/13	12/12	90	100
	3M	0/1					0	
	3P	4/4	3/6	3/3	2/4	3/4	71	75
	4RST	0/6	0/2	1/6	1/4	1/4	14	25
	4VWX	1/2		2/2		2/2	83	100
	Total	15/27	15/22	19/25	17/24	20/24	70	83
	%	56	68	76	71	83		
Yellowtail	3LNO	7/10	8/8	9/9	10/10	7/8	91	88
	3Ps	2/3	1/1	1/1	2/3	0/1	67	0
	4VWX					0/1		0
	Total	9/13	9/9	10/10	12/13	7/10	85	70
	%	69	100	100	92	70		
Witch	2J3KL	1/1	3/3	2/2	2/3	2/2	91	100
	3NO	5/5	1/3	5/5	1/3	1/2	72	50
	3P	1/4	2/7	1/4	2/4	2/4	35	50
	4RST	1/4	2/6	1/5	2/6	2/5	31	40
	4VWX	0/2		0/1	1/1		25	
	Total	8/16	8/19	9/17	8/17	7/13	49	54
	%	50	42	53	47	54		
Turbot	2+3KL	0/1	2/3	2/3	4/6	3/4	69	75
	4R	0/1	1/1	1/2	3/3	1/1	75	100
	4VN			0/1	1/1		50	
	Total	0/2	3/4	3/6	8/10	4/5	67	80
	%	0	75	50	80	80		

TABLE 2. (*Concluded*)

Species	Stock area	1976	1977	1978	1979	1980	% Strata sampled efficiently 1976–80	1980
Haddock	3O			1/1	1/1		100	
	3Ps		1/1			1/1	100	100
	4VW			1/1		1/3	50	33
	4X			0/1	0/1		0	
	5			0/1	0/1		0	
	Total		1/1	2/4	1/3	2/4	50	50
	%		100	50	33	50		
	Grand Total (Offshore)	66/127	68/114	79/125	91/145	71/117	60	61
	%	52	60	63	63	61		
				B. Inshore Fishery				
Cod	2J3KL	6/21	13/24	12/22	12/26	14/25	48	56
	3Ps	3/10	2/12	6/12	7/13	8/13	43	62
	3Pn4Rs	1/13	4/13	3/15	3/15	4/15	21	27
	Total	10/44	19/49	21/49	22/54	26/53	39	49
	%	23	39	43	41	49		
Redfish	2+3K	0/1	0/1	0/1	0/2	0/1	0	0
	3LN	0/1	0/2				0	
	3P	0/1	0/1	0/1	0/1		0	
	Total	0/3	0/4	0/2	0/3	0/1	0	0
	%	0	0	0	0	0		
Am. plaice	2+3K	1/3	1/2	1/1	1/2	0/2	40	0
	3LNO	0/3	0/3	1/3	2/3	3/3	40	100
	3P	0/1	0/1	0/3	0/2	0/3	0	0
	4RST	0/1	0/1	1/3	0/3	0/3	9	0
	Total	1/8	1/7	3/10	3/10	3/11	24	27
	%	13	14	30	30	27		
Witch	2J3KL	2/3	1/2	1/2	1/2		56	
	%	67	50	50	50			
Turbot	2+3KL	3/8	5/7	2/7	5/8	5/8	56	63
	4R		0/1	0/2	0/2	0/2	0	0
	Total	3/8	5/8	2/9	5/10	5/10	44	50
	%	50	63	22	50	50		
	Grand Total (Inshore)	16/66	26/70	27/72	31/79	34/75	37	45
	%	24	37	38	39	45		

for which landings were relatively very low, was from strata less than 100 t. Although in the course of a regular sampling program some of these strata should be and inevitably are sampled, they are not considered a major area of contention.

Results and Discussion

Proportion of Strata Sampled Efficiently

A summary by stock area and year of the numbers of species/division/gear/quarter strata that were sampled at a rate of one sample per 1000 t or greater is presented in Table 2. Overall, 61% of the offshore strata were sampled at or above the recommended minimum rate in 1980, which was about the same as for the 5-yr review period (60%). About 45% of the inshore strata were sampled efficiently in 1980, compared to the average of 37% for 1976–80. For the offshore and inshore strata, there was an 8 and 13% increase, respectively, between 1976 and 1977, which was probably due to an increase in manpower around that time. However, from 1977 onward, no significant increase occurred in the percentage of either offshore or inshore strata sampled efficiently. Although the deployment of observers on offshore vessels during 1979 and 1980 did add to the overall offshore sampling performance in terms of numbers of samples collected, these samples were normally from strata that had been sampled at or above the minimum level by the port sampling program. The data presented, thus, mask any performance increase associated with the expansion of the observer program to the domestic offshore fleet.

Although the data give an indication of the relative efficiency of sampling coverage over the various strata, they do not take into consideration the relative importance of one strata to another in terms of amounts landed, since all strata are given equal weight.

Distribution of Sampling Effort by Strata Size

Comparing the 1980 distribution of sampling effort by strata size with that for 1976–80, it appears that not much change has taken place (Table 3). During 1980 both off-

TABLE 3. Summary of sampling effort expended for the years 1976–80 by (species/division/gear/quarter) strata sizes 100–499, 500–999 and >1000 t. Number of strata sampled/number of strata occurring.

	1976–80			1980		
Species	100–499 t	500–999 t	>1000 t	100–499 t	500–999 t	>1000 t
			A. Offshore fishery			
Cod	18/76 (24%)	19/23 (83%)	51/64 (80%)	2/15 (13%)	1/2 (50%)	16/19 (84%)
Haddock	4/9 (44%)	1/3 (33%)	—	1/2 (50%)	1/2 (50%)	—
Redfish	27/76 (36%)	25/39 (64%)	42/52 (81%)	3/15 (20%)	4/5 (80%)	4/5 (80%)
Am. plaice	14/49 (29%)	16/19 (84%)	54/54 (100%)	4/11 (36%)	5/5 (100%)	8/8 (100%)
Yellowtail	19/26 (73%)	8/8 (100%)	21/21 (100%)	3/6 (50%)	—	4/4 (100%)
Witch	23/66 (35%)	8/9 (89%)	7/7 (100%)	4/11 (36%)	1/1 (100%)	1/1 (100%)
Turbot	5/15 (33%)	7/7 (100%)	5/5 (100%)	1/2 (50%)	2/2 (100%)	1/1 (100%)
Total Offshore	110/317 (35%)	84/108 (78%)	180/203 (89%)	18/62 (29%)	14/17 (82%)	34/38 (90%)
			B. Inshore fishery			
Cod	7/67 (10%)	10/37 (27%)	96/140 (69%)	2/12 (17%)	2/6 (33%)	27/35 (77%)
Redfish	0/13 (0%)	—	—	0/1 (0%)	—	—
Am. plaice	3/31 (10%)	0/3 (0%)	8/12 (67%)	1/8 (13%)	0/1 (0%)	2/2 (100%)
Witch	5/8 (63%)	1/1 (100%)	—	—	—	—
Turbot	4/21 (19%)	0/5 (0%)	18/19 (95%)	1/5 (20%)	0/1 (0%)	4/4 (100%)
Total Inshore	19/140 (14%)	11/46 (24%)	122/171 (71%)	4/26 (15%)	2/8 (25%)	33/41 (81%)

TABLE 4. Summary of Newfoundland landings (t) sampled at a rate of 1 sample per 1000 t or greater as compared to total Newfoundland landings. Only (species/division/gear/quarter) strata >100 t considered.

		Offshore				Inshore			
		Landings sampled efficiently	Total landings	% Landings sampled efficiently		Landings sampled efficiently	Total landings	% Landings sampled efficiently	
Species	Stock area	1980	1980	1980	1976–80	1980	1980	1980	1976–80
Cod	2J3KL	42 135	42 507	99	99	70 320	96 246	73	70
	3NO	3 250	4 435	73	89				
	3Ps	2 498	2 673	93	90	26 051	28 935	90	71
	3Pn4RS	15 352	24 869	62	69	7 748	36 522	21	30
	4Vn	0	1 444	0	14	—	—	—	—
	4VsW	4 103	5 572	74	60	—	—	—	—
	4X	319	419	76	76	—	—	—	—
	Total	67 657	81 919	83	81	104 119	161 703	64	62
Redfish	2+3K	3 020	3 362	90	65	0	145	0	0
	3LN	949	2 596	37	65	—	—	—	0
	3O	880	880	100	68	—	—	—	—
	3P	4 188	6 021	70	62	—	—	—	0
	4RST	594	594	100	76	—	—	—	—
	4VWX	1 812	2 781	65	36	—	—	—	—
	Total	11 443	16 234	70	65	0	145	0	0
Am. plaice	2+3K	3 568	3 568	100	93	0	983	0	76
	3LNO	41 181	41 181	100	96	3 339	3 339	100	45
	3P	1 613	1 740	93	93	0	541	0	0
	4RST	121	530	23	7	0	744	0	13
	4VWX	254	254	100	87	—	—	—	—
	Total	46 737	47 273	99	94	3 339	5 607	60	50
Yellowtail	3LNO	11 207	11 515	97	96	—	—	—	—
	3Ps	0	189	0	86	—	—	—	—
	4VWX	0	129	0	0	—	—	—	—
	Total	11 207	11 833	95	95	—	—	—	—
Witch	2J3KL	977	977	100	97	—	—	—	65
	3NO	184	345	53	81	—	—	—	—
	3P	309	518	60	63	—	—	—	—
	4RST	1 210	2 006	60	66	—	—	—	—
	Total	2 680	3 846	70	74	—	—	—	65
Turbot	2+3KL	2 964	3 118	95	87	26 565	27 556	96	78
	4R	625	625	100	91	0	740	0	0
	Total	3 589	3 743	96	88	26 565	28 296	94	77
Haddock	3Ps	107	107	100	100	—	—	—	—
	4VW	931	1 544	60	76	—	—	—	—
	Total	1 038	1 651	63	79	—	—	—	—
	Grand Total	144 351	166 499	87	79	134 023	195 751	68	64

shore and inshore strata with landings greater than 1000 t had a fairly good coverage of 90 and 81%, respectively. Offshore strata with landings of between 500 and 999 t also received quite a good coverage (82%), as compared to only 25% for inshore strata belonging to this size class. Both offshore and inshore strata with landings of between 100 and 499 t were sampled at very low rates (only 29 and 15%, respectively). Although it appears from the data that most emphasis is being placed on the more important strata in terms of amounts landed, there does appear to be a need for more emphasis on the strata with smaller landings. For these strata, the catches are usually so small and irregular that, with limited resources, the logistics involved in obtaining samples from all or most of them render the operation impractical.

Proportion of Landings Sampled Efficiently

A summary by stock area of the proportion of landings that were sampled efficiently in 1980, as compared to the 1976–80 period, is presented in Table 4. Overall, 87% of all offshore groundfish landings considered were sampled efficiently in 1980, compared to 79% for the 5-yr review period. Inshore landings were not sampled as well, with 68% sampled efficiently, compared to 64% for the review period. Taking into consideration that in 1980 over 195 000 t of a total of some 362 000 t considered were inshore landings, more emphasis should be placed on this sector of the fishery.

Relative Sampling Efficiencies

A summary of average sampling efficiencies for 1976–80 is presented in Table 5. All species and sectors were sampled above the 1.0 level during this period. Average offshore sampling efficiencies ranged from 2.7 to 6.1 for the various species, with average inshore rates ranging from 1.3 to 10.4. For a particular species, offshore sampling efficiencies were generally higher than inshore ones during the review period. Efficiency levels for 1980 were also generally higher than the average for the 5-yr review period.

Table 6 presents a detailed summary by stock area of the 1980 average sampling efficiencies broken down into offshore, inshore, port sampling, and observer sampling components. A summary by species is also presented graphically in Fig. 1. Average inshore sampling efficiencies by species ranged from 1.9 to 2.7, which was consistently lower than for the offshore (port + observer) which ranged from 3.0 to 8.4. A listing of those stock areas and associated landings for which sampling efficiencies during 1980 were either low (i.e. <1.0) or relatively high (i.e. >10.0) is given in Table 7.

It is apparent that cases of either low (i.e. <1.0) or relatively high (i.e. >10.0) sampling efficiencies are normally associated with small landings. A more uniform distribution of sampling effort relative to landings is desirable; however, from a practical point of view, the logistics involved in carrying out such an optimal distribution of sampling effort are too complex. The limited manpower resources that hamper sampling flexibility and the unavailability of real time-detailed landing statistics (especially inshore landings) prohibit the optimal distribution of sampling effort. Historical landing data are currently used in the port sampling program to set sampling priorities; however, these data are often of limited value because of sudden changes in fishing patterns which may occur from one year to the next.

TABLE 5. Summary of average sampling efficiencies by species and year. Sampling efficiency is the ratio of the number of length samples to each 1000 t landed by (species/division/gear/quarter) strata.

Species	Sector	1976	1977	1978	1979	1980	Average 1976–80
Cod	Offshore	2.1	3.7	2.8	2.0	3.0	2.7
	Inshore	0.9	2.4	2.3	1.7	2.0	1.9
Haddock	Offshore	—	10.9	5.8	2.6	5.0	6.1
	Inshore	—	—	—	—	—	—
Redfish	Offshore	2.3	3.6	2.6	3.7	3.8	3.2
	Inshore	—	—	—	—	—	—
Am. plaice	Offshore	1.3	1.4	3.0	3.1	6.4	3.0
	Inshore	0.2	0.8	1.0	1.9	2.7	1.3
Yellowtail	Offshore	4.4	4.6	4.3	5.0	4.9	4.6
	Inshore	—	—	—	—	—	—
Witch	Offshore	4.2	2.1	2.6	4.5	8.4	4.4
	Inshore	9.3	13.9	15.2	3.2	—	10.4
Turbot	Offshore	0.0	2.7	2.3	5.0	4.5	3.6
	Inshore	2.7	3.6	0.7	1.0	2.3	2.1

TABLE 6. Detailed summary of 1980 average sampling efficiencies by stock area. Sampling efficiency is the ratio of the number of length samples to each 1000 t landed by species/division/gear/quarter) strata.

Species	Stock area	Offshore			Inshore
		Port	Observer	Total	Port
Cod	2J3KL	1.9	2.8	4.7	2.4
	3NO	1.6	0.4	2.0	0.0
	3Ps	2.2	1.3	3.5	2.1
	3Pn4RS	0.3	0.4	0.7	1.3
	4Vn	0.0	0.7	0.7	—
	4VsW	1.1	1.1	2.2	—
	4X	1.6	0.0	1.6	—
	Total	1.3	1.7	3.0	1.9
Haddock	3Ps	9.3	0.0	9.3	—
	4VW	0.7	2.9	3.6	—
	Total	2.9	2.1	5.0	1.9
Redfish	2+3K	2.5	0.3	2.8	—
	3LN	3.2	2.1	5.3	—
	3O	4.5	0.0	4.5	—
	3P	2.8	0.8	3.6	—
	4RST	3.6	2.9	6.5	—
	4VWX	0.0	2.2	2.2	—
	Total	2.5	1.3	3.8	—
Am. plaice	2+3K	4.4	1.0	5.4	0.0
	3LNO	3.2	3.4	6.6	9.8
	3Ps	2.6	2.6	5.2	0.0
	4RST	0.0	2.1	2.1	0.0
	4VWX	11.5	6.7	18.2	0.0
	Total	3.3	3.1	6.4	2.7
Yellowtail	3LNO	4.5	0.4	4.9	—
	3Ps	0.0	0.0	0.0	—
	4VWX	0.0	0.0	0.0	—
	Total	4.5	0.4	4.9	—
Witch	2J3KL	6.7	6.0	12.7	—
	3NO	10.9	0.0	10.9	—
	3P	7.0	0.0	7.0	—
	4RST	0.8	5.9	6.7	—
	Total	5.2	3.2	8.4	—
Turbot	2+3KL	3.8	0.2	4.0	2.9
	4R	4.8	1.6	6.4	0.0
	Total	4.0	0.5	4.5	2.3

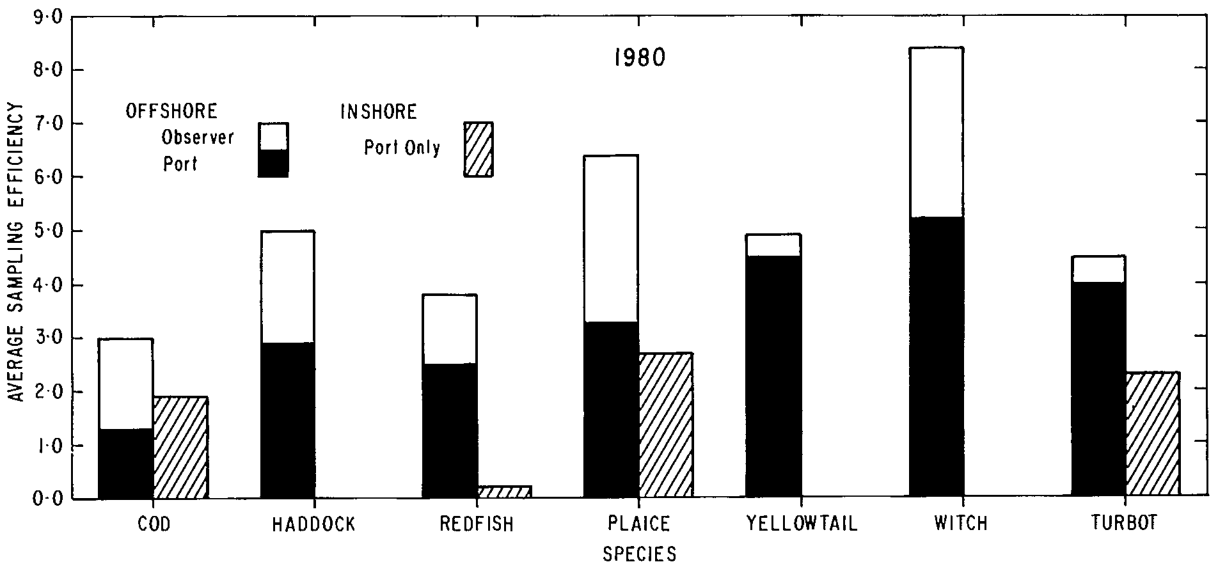

FIG. 1. Relative sampling efficiencies by species for various components of the 1980 Newfoundland groundfish sampling program.

TABLE 7. Sampling efficiencies during 1980.

Sector	Species	Stock	Efficiency	Landings (t)[a]
		Efficiency levels <1.0		
Offshore	Cod	3Pn4RS	0.7	24 869
		4Vn	0.7	1 444
	Yellowtail	3Ps	0.0	189
		4VWX	0.0	129
Inshore	Am. plaice	2+3K	0.0	983
		3Ps	0.0	541
		4RST	0.0	744
	Turbot	4R	0.0	740
		Efficiency levels >10.0		
Offshore	Am. plaice	4VWX	18.2	254
	Witch	2J3KL	12.7	977
		3NO	10.9	345
Inshore	Am. plaice	3LNO	9.8	3339

[a]Only landings for strata >100 t considered.

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Sampling of Commercial Catches for Invertebrates in Newfoundland

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The history, performance and application of commercial sampling for lobster, crab, shrimp, scallops, and squid in Newfoundland are reviewed. Sampling efforts in recent years have taken a more systematic approach aimed at representing the catch of each species. Although sampling intensity is very low relative to the total catch for each species, the data obtained are considered valuable in estimating catch composition and providing information on various biological parameters.

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Le rapport présente un aperçu de l'historique, du succès et de l'application de l'échantillonnage commercial du homard, du crabe, de la crevette, du pétoncle et du calmar à Terre-Neuve. Au cours des dernières années, les efforts d'échantillonnage sont devenus plus méthodiques, visant une meilleure représentation des prises de chaque espèce. Même si l'intensité de l'échantillonnage est très peu élevée par rapport aux prises totales de chaque espèce, les données obtenues sont utiles pour évaluer la composition des prises et recueillir de l'information sur les divers paramètres biologiques.

Introduction

The Invertebrates Section of Fisheries Research Branch, Fisheries and Oceans in St. John's, Newfoundland focuses research on five species or groups of species: lobster (*Homarus americanus*), crab (*Chionoecetes opilio*), shrimp (*Pandalus borealis* and *P. montagui*), scallops (*Placopecten magellanicus* and *Chlamys islandica*), and squid (*Illex illecebrosus*). Fisheries for these species have existed for varying periods. Lobsters and squid have been sampled from commercial catches since the 1930s while crab, shrimp, and scallops only became commercially important during the 1970s.

This paper outlines the history of commercial sampling for each of these species (groups), describes present performances, and evaluates the data obtained from the various sampling programs.

History of Sampling and Description of Sampling Area

LOBSTER

Sampling of commercial catches of lobsters in Newfoundland goes back to 1931 when sampling was done at three localities in Placentia Bay and at two in Fortune Bay on the south coast (Fig. 1). In 1935, sampling was done at six localities in Placentia Bay, two in Fortune Bay, nine along the south coast west of Fortune Bay, and three in St. George's Bay and Port au Port Bay. A summary of this sampling is reported in Whiteley (1936). Templeman and Tibbo (1945) reported sampling at 26 localities from Grand Bruit on the southwest coast, northward along the west coast to St. John Island in 1938; at 28 localities along the south coast in Bay d'Espoir, Hermitage, Fortune, and Placentia bays in 1939; at 12 localities in Notre Dame Bay on the northeast coast in 1940; and at five localities in St. Mary's Bay on the southeast coast in 1941. The foregoing can be referred to as phase 1 of lobster commercial catch sampling in Newfoundland.

Following a 20-yr lapse, what can be referred to as phase 2 began in 1961. Between 1961 and 1965, annual sampling was done in Port au Port Bay and a number of samples were obtained in St. George's Bay and from the Outside Shore (between Cape St. George and Long Point) of the Port au Port Peninsula. One area in Bay of Islands was sampled in 1964 and two different areas in 1965. In 1966, nineteen localities from Bonne Bay to Pistolet Bay (along the northwest coast) were sampled, as were, in 1967, nine (some the same as in 1966) along part of the same coast. Also in 1967, sampling was done in nine areas in Notre Dame Bay. In 1968 and 1969, 12 areas in Bonavista Bay and in 1969 nine areas in Placentia Bay were sampled. One area in Bonavista Bay, 11 in Placentia Bay, and four in Fortune Bay were sampled in 1970. Summaries of most of the phase 2 sampling are provided in

[1]First author was responsible for collating individual contributions. Remaining authors are in alphabetical order.

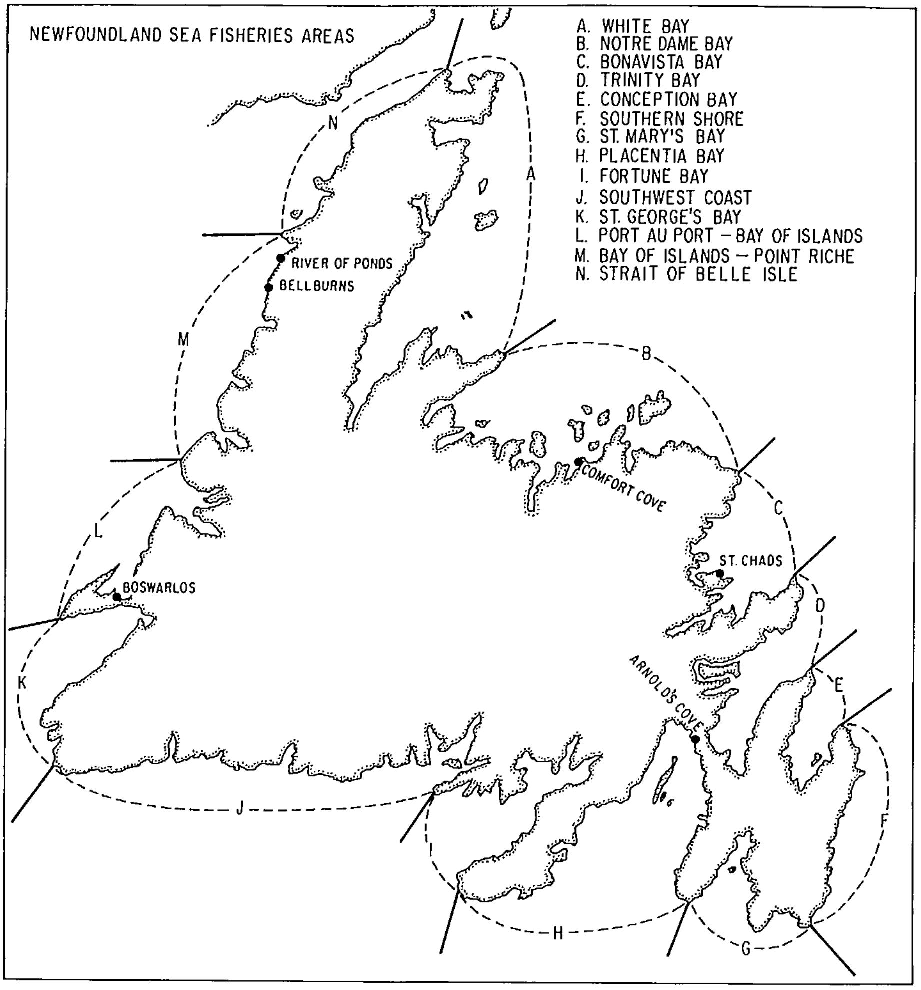

FIG. 1. Newfoundland sea fisheries areas and sampling ports for lobster.

Annual Reports of the St. John's Biological Station (Anon. 1961–70), Squires (1970), Squires et al. (1971, 1974), and Ennis (1971).

Phases 1 and 2 were similar in that emphasis was placed on obtaining samples from many different sites. In only a few were samples obtained in more than 1 yr. The third or current phase of lobster commercial catch sampling in Newfoundland began in 1971 when it was decided to sample annually in a few selected areas. In 1971, sampling was done in the St. Chads–Burnside area of Bonavista Bay (3La)[2], at Arnold's Cove, Placentia Bay (3PSc) and at Comfort Cove, Notre Dame Bay (3Ki). Sampling was started at Boswarlos, Port au Port Bay (4Rc) and in the Bellburns–River of Ponds area (4Rb) in 1975 and 1976, respectively. Annual sampling has continued uninterrupted in each of these five areas (Fig. 1) since it was initiated.

CRAB

Although a commercial snow crab fishery began in Newfoundland in 1969, it was not until 1979 that commercial sampling was carried out on a sustained basis. The fishery is divided into management areas (Fig. 2) partly based on stock units. Although no rigid sampling schedule has been implemented in these areas, efforts are made to obtain commercial samples from areas 26 to 14 on a monthly basis and from areas 36 to 28 on a bimonthly basis. The efficacy of this program has been largely dependent on weather conditions, manpower constraints, and processing plant production schedules. Due to fishing intensity and volume of landings, sampling has been concentrated in the southern areas of the province (26–14), which by far are the most productive.

SHRIMP

Commercial fishing for shrimp (*Pandalus borealis*) in

[2]Fisheries and Oceans statistical areas.

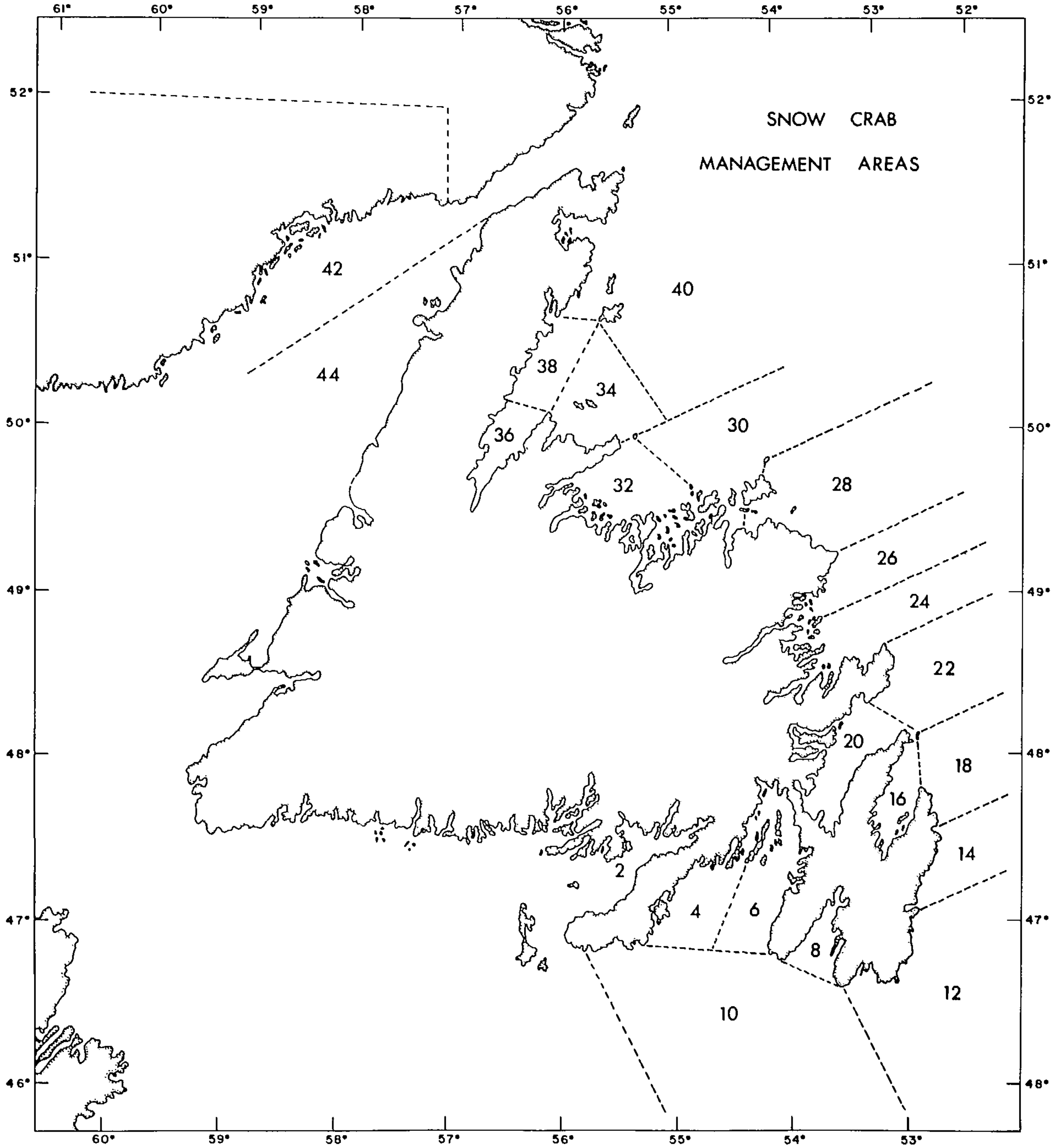

FIG. 2. Snow crab management areas in Newfoundland (Miller, unpublished data).

Newfoundland is new, relative to fisheries directed at the more "traditional" species of fish and shellfish. Although the occurrence of concentrations of the pink or northern shrimp has been known in the Esquiman Channel in the Gulf of St. Lawrence (Fig. 3) since the late 1950s, commercial exploitation only began in 1970 and is based at Port au Choix on the Great Northern Peninsula (Sandeman 1978a). Sampling of the commercial landings by season and/or month has been conducted for this fishery since its inception.

During the mid-1970s, concentrations of this species were discovered in deepwater channels off the coast of

Labrador. In 1976, some exploratory fishing occurred and by 1977 a commercial operation was in place, exploiting shrimp "stocks" in the Hawke, Cartwright, and Hopedale channels (Sandeman 1978b). Sampling of the commercial catch has been intensively pursued through cooperation with the Department's Observer Program providing information from all months of the fishing season.

The offshore northern shrimp fishery in subareas 0 and 1 has been fished by various countries since the early 1970s (Atkinson et al. 1982) and has increased substantially since then. In 1978, Canada was allocated 1000 t in this area but no effort was expended. Canada's allocation increased to 2000 t in 1979, and 2500 t in 1980 attracting participation from industry. In 1981, a total allowable catch of 5000 t in Canadian waters (subarea 0) was reserved for Canadian licensed vessels. Sampling of the catch has been accomplished in each year through the intensification of the observer program in the area, providing details of the catch in most months of the fishery.

Concentrations of a closely related species, *Pandalus montagui* (the striped pink shrimp), were found in the Ungava Bay and eastern Hudson Strait areas in the late 1970s (Anon. 1978; Parsons et al. 1981). In 1980, some commercial fishing was permitted in these areas and samples of the catch and details of fishing were collected by observers.

Scallops

Sampling is conducted on two species of scallops harvested commercially in the Newfoundland region, particularly where significant fisheries occur. Sampling effort is directed at inshore giant scallops (*Placopecten magellanicus*) in Port au Port Bay and St. George's Bay and nearshore Iceland scallops (*Chlamys islandica*) in the northeastern Gulf of St. Lawrence and at the mouth of the Bay of Islands. The fishery takes place from about April to November. A considerable proportion of catches, especially of the larger giant scallop, comes from numerous localities scattered along the coast. Placentia Bay, St. Mary's Bay, and Fortune Bay along the south coast, and St. John Bay and St. George's Bay on the west coast (Fig. 4) are principal areas of production. An offshore fishery for giants occurs on St. Pierre Bank from time to time, but as only maritime-based vessels participate, all catches are landed in Nova Scotia and are consequently sampled by the Scotia-Fundy region.

No systematic annual sampling of scallops occurred prior to 1976 and, consequently the data base on past stock characteristics is fragmented and, at best, incomplete. Sampling effort has been more formalized with the hiring of a full-time scallop scientist. Manpower constraints have precluded sampling of the commercial catch of Iceland scallops in Labrador.

Squid

The squid fishery in the Newfoundland area is predominantly an inshore jigger fishery conducted from small open boats. Sampling localities are selected to represent the entire northeast and south coasts of insular Newfoundland. The fishery is carried out mainly in these regions, although a small proportion of the catch comes from the west coast. Only small and varying catches come from the Grand Bank, as the Canadian offshore otter trawl fishery for squid is prosecuted mainly on the Nova Scotian Shelf.

Representative sampling of the commercial catch has not been achieved until recently due to inadequate seasonal and areal coverage as well as scarcity of squid in inshore areas during part of a year or even for a series of years. During 1930–35, sampling was conducted at Bay Bulls and Holyrood (Fig. 5). However, during this period there was no sampling on a regular basis throughout the season. During 1951–53, research sampling by bottom trawl was conducted on the Grand Bank during May or June. Regular monthly samples were collected at Holyrood throughout the inshore season (July–November). However, only occasional samples were collected at other inshore localities.

Between 1964 and 1975, sampling was conducted at more localities, usually Holyrood in Conception Bay and Rencontre West in Hermitage Bay. Less frequently, samples were taken at Placentia Bay, Fortune Bay, Trinity Bay, and White Bay (Fig. 5). This period coincided with a period of low abundance of squid in inshore areas during 1968–74. Thus, sampling throughout the season was generally incomplete. Also for some years (1968–71, and 1973) sampling was restricted to one locality, and for other years (1972 and 1974) no inshore sampling was conducted.

With the increase in inshore availability of squid, regular seasonal sampling at Holyrood was resumed in 1975. This continued until 1978 when sampling localities were selected to represent the various regions of Newfoundland, which coincide with NAFO divisions. Thus, during 1978–79, sampling was conducted at Holyrood (Div. 3L), Twillingate (Div. 3K) and Hermitage (Div. 3Ps) (Fig. 5). Frequency of sampling was also increased, and samples were collected bimonthly throughout the season. In 1980, the number of sampling localities was increased to include other sites within these NAFO divisions. Thus, in 1980 and 1981, sampling was also conducted at La Scie (Div. 3K) and Arnold's Cove (Div. 3PS). These additions resulted in increased sampling intensity in some regions and better seasonal and areal representation during periods when squid are not available in some areas.

Methods

Lobster

During the earliest years (phase 1) of commercial lobster catch sampling, measurements (to the nearest centimetre) were obtained for total length from the tip of the rostum to the distal end of the telson for males and females separately. Subsequent to phase 1, carapace length (not total length) was measured using vernier calipers to the nearest millimetre (distance from the eye socket to the

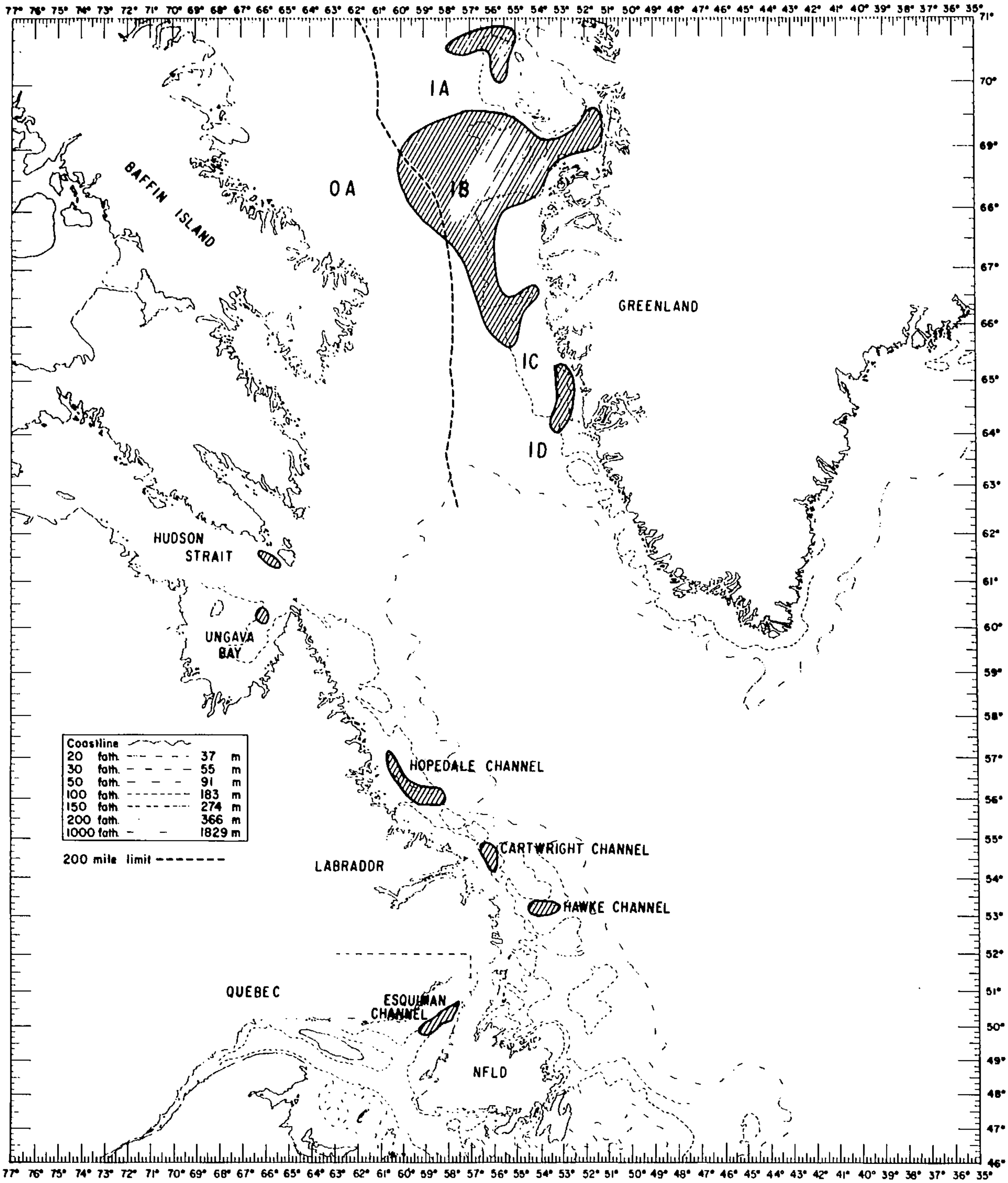

FIG. 3. Locations of northern shrimp fisheries in the Northwest Atlantic monitored by the Newfoundland region.

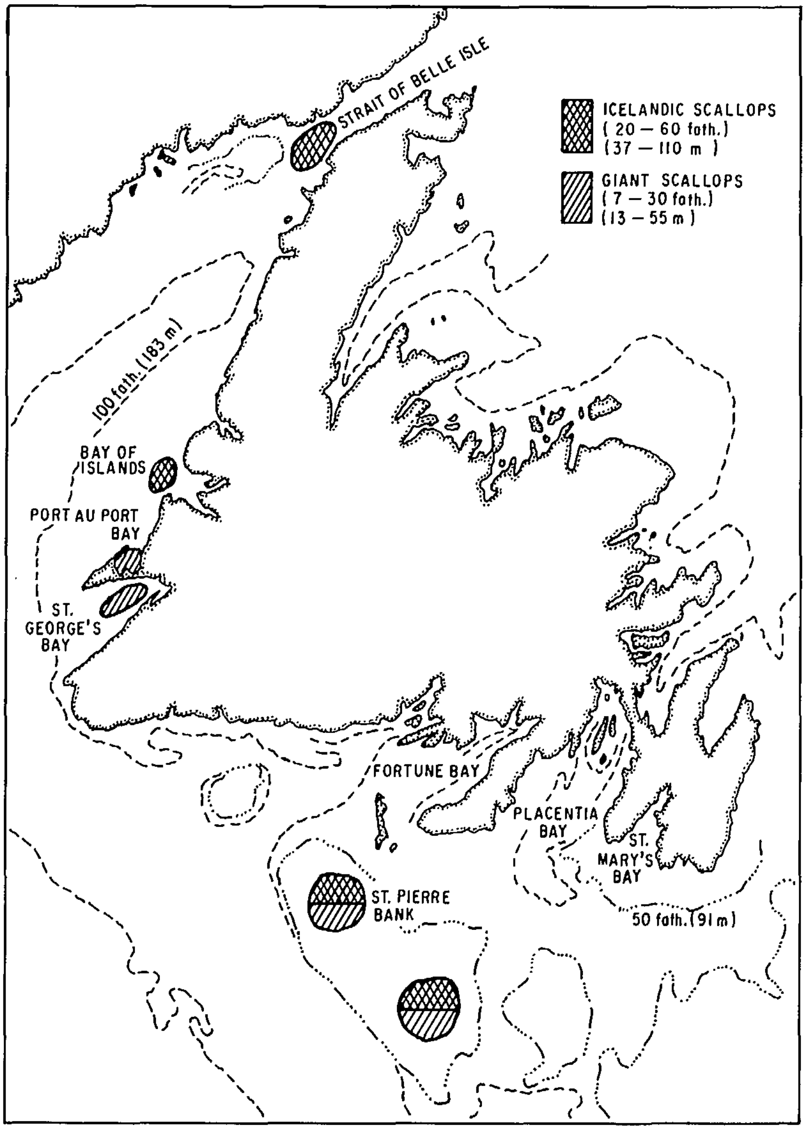

FIG. 4. Locations of scallop fishing areas around Newfoundland.

posterior edge of the carapace parallel to the middorsal line).

Current sampling practice involves visiting a representative number of fishermen in each of the five areas, usually once a week during the fishing season (various opening and closing dates from April 20 to July 15). Whatever commercially legal lobsters are on hand at the time (provided they represent the total commercial catches for a given period, i.e. quantities have not been removed for sale) are sampled for sex and carapace length. Fishermen are required, by law, to release undersized (81 mm carapace length) and berried (i.e. ovigerous) female lobsters as soon as they are removed from the traps; consequently, only the commercially legal portion of the catch is sampled.

CRAB

Sampling is conducted either at the holding facilities of processing plants or on board commercial fishing vessels during fishing operations.

At the processing plants each vessel's daily catch is held separately until processed. As a plant may purchase crab from several management areas on any given day, this segregation of vessel catches is fortuitous in that the management area from which the catch originated can be determined by examination of the vessel's log book (mandatory) for any given day. From 250 to 300 animals are randomly sampled from each vessel's catch. Crabs are measured (maximum carapace width) with vernier calipers to the nearest millimetre and their shell conditions deter-

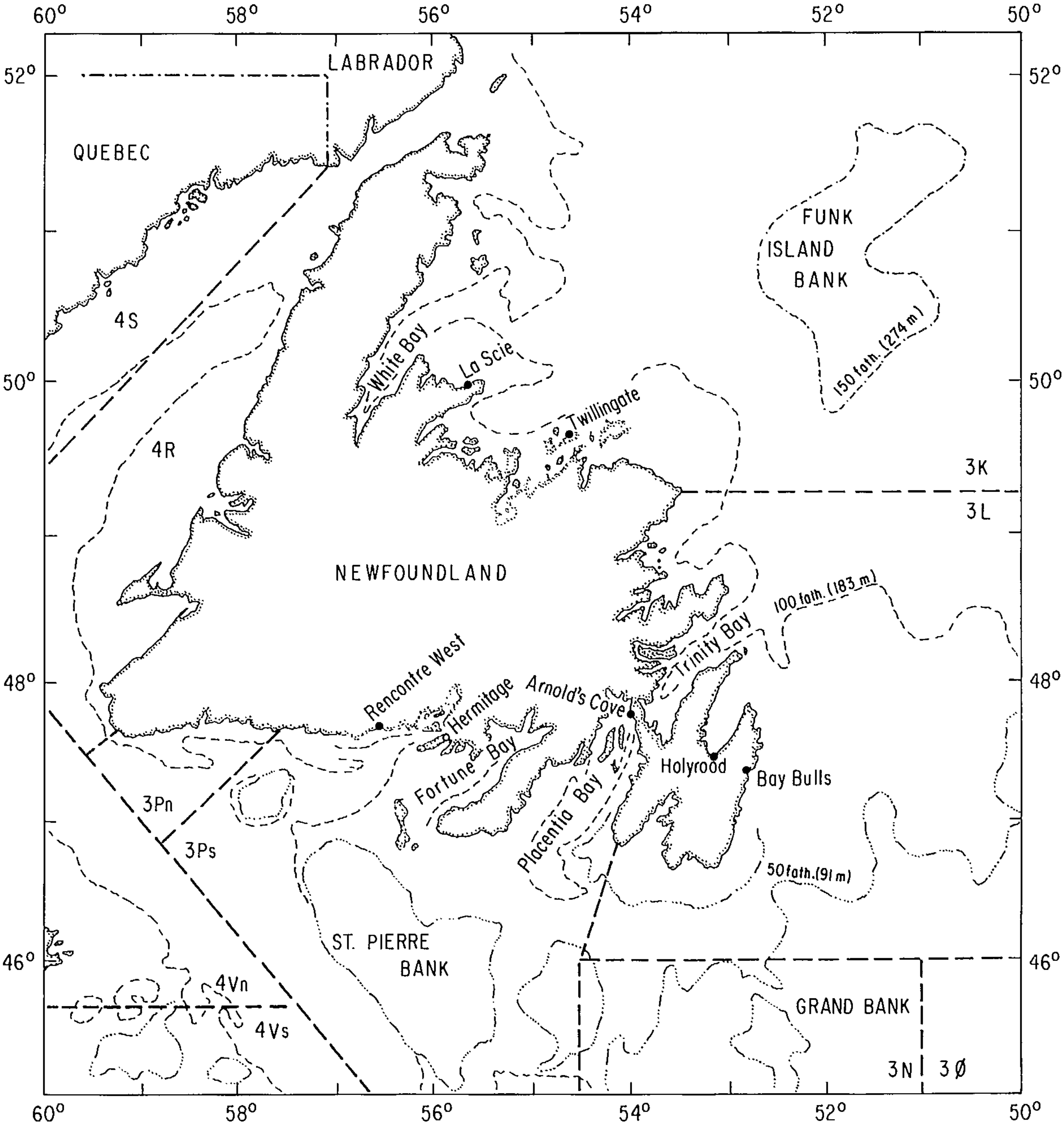

FIG. 5. Locations of squid sampling areas around Newfoundland, 1930–81.

mined. The catches of randomly selected crab traps are measured on board commercial fishing vessels. Sampling is carried out during the whole fishing season (usually from March to December).

SHRIMP

Commercial catch sampling is essentially the same for all shrimp stocks exploited in Newfoundland. In the Esquiman Channel (northern Gulf of St. Lawrence), samples of the catch from selected vessels are often supplemented by samples of landings from the processing plant at Port au Choix. For all other areas only catches are sampled.

Sampling for length requires a random sample of the catch consisting of 250–300 animals. The oblique carapace length (measured from the posterior part of the orbit to the posterior middorsal margin of the carapace) is measured using vernier calipers and recorded to the nearest 0.5 mm (below). Animals are separated into ovigerous and nonovigerous categories.

Prior to 1981, the inshore Gulf fishery, centered at Port au Choix, was sampled on a monthly basis, when manpower permitted. Two to three days were spent at sea in each month, sampling the catches from each fishing set from as many vessels as possible. In 1981, sampling was conducted seasonally due to manpower shortages.

Shrimp fisheries outside the Gulf employ large offshore trawlers which stay at sea up to 60 d. Commercial sampling for length (described above) was conducted by observers trained by staff of Research and Resource Services in St. John's. The observers were instructed to sample as many sets as possible, ensuring that the sampling scheme adequately reflected the daily catch and was not biased by disproportionate sampling during only certain hours of the day. (Availability of shrimp to trawls is generally less during hours of darkness.)

By-catches of various finfish species (e.g. cod, redfish, and Greenland halibut) occur in all northern shrimp fisheries, and the main species involved are sampled intermittently. Shrimp discarding has been a recurring problem in fisheries outside the Gulf of St. Lawrence and observers have been instructed to take representative length samples of the discarded animals as well.

Efforts have also been made to obtain preserved samples of length, weight, fecundity, sex, and maturity for detailed examination at the laboratory. Such samples have been relatively easy to obtain from the inshore fishery at Port au Choix but are rare for larger offshore trawlers. Transport of specimens preserved in alcohol and formaldehyde presents a potential hazard to public transit systems as well as the fishing vessels.

SCALLOPS

Catches, particularly from the Strait of Belle Isle, are sampled monthly either at ports of landing (for shucked meats) and/or at the processing facility where the mollusc is landed in the shell (Naidu et al. 1982). Shell-height frequencies based on about 50 kg round (about 500 scallops) are tallied. In addition, a biological sample consisting of about 100 animals is examined each time commercial shell-height frequency data are collected. Meat count per kg is also calculated from a sample of about 20 kg of meat (approximately 2000 meats).

Numbers and type of dredges used are identified for each licensed boat (over 40 ft). No attempt has yet been made to incorporate vessel horsepower to either total catch or catch per unit of effort.

SQUID

At all five sampling localities, samples are collected at the plants at bimonthly intervals, and are immediately frozen. All samples are captured using jigging devices, usually the Japanese mechanical jigger. Although size selectivity is not known, it is possible that smaller animals present in the fishing area may not be adequately sampled using this gear. Samples are collected in all areas by plant personnel so that no method of randomizing is used. This probably does not pose any problems of bias in sampling for size distribution since specimens do not vary greatly in size. Each sample is taken at random from a single boat's landings. At each locality, samples are usually taken weekly when squid are landed. Two weekly samples, when available, were combined to produce a single large sample for each 2-wk period.

Sampling intensity varies considerably between and within bimonthly periods and localities due to severe fluctuations in abundance and/or availability of squid to the fishery and the resultant fluctuations in catches. Sample size, however, is not proportional to catch due in part to a time lag in the reporting of catch statistics which makes it impossible to monitor fluctuations in landings in each area and regulate sampling intensity. Bimonthly samples generally provide 300–350 specimens which are subsequently measured at the laboratory for the purposes of length-frequency distribution by sex composition and maturity. A subsample of 50 animals is examined for more detailed biological characteristics including total weight, stomach, and caecum fullness and contents, as well as parasite burden. Nidamental gland length in females is also recorded.

Current Sampling Performance

LOBSTER

Numbers of lobsters sampled during a fishing season have ranged from 387 to 3952 (Table 1) for a given area. These are very small samples in relation to total Newfoundland landings and in relation to landings in the statistical areas (Fig. 1) in which the sampling areas are located. Landings data are not available for small localized areas but for the Comfort Cove sampling area landings have been estimated from estimates of standing stock and exploitation rate. For those years for which these estimates were obtained, the samples represent from 13 to 27% of the landings.

This commercial catch sampling can only be considered representative of the areas in which it is being done. In Newfoundland waters, lobsters are generally distributed along a narrow band of rocky bottom close to shore, and their movements tend to be restricted to very localized areas. Given sections of coastline are usually fished by fishermen from one or two communities, and because of different concentrations of effort resulting in different exploitation rates, it is common to find very different size compositions in samples of lobsters examined.

CRAB

Examination of Table 2 indicates that the number of animals sampled from processing plants and vessels combined represents a very small proportion of the commercial catch for each area. Although it is realized that greater sampling intensity is probably desirable, operational constraints will make the achievement of this goal very difficult.

An objective of the 1982 snow crab research program is to reduce effort expended on research cruises and increase commercial sampling, especially on board commercial fishing vessels, in order to obtain the maximum amount of information for management areas.

Shrimp

Numbers of shrimp sampled in certain areas in some years appear high (Table 3) but when sample weight and total catch weight are compared, the extremely small proportions become more obvious.

Observer coverage for shrimp fisheries in northern waters has increased sharply since 1978 as reflected in sampling totals for the Hopedale Channel Division 0A and Subarea 1. As long as these fisheries remain politically high-profiled both nationally and internationally, the continuation of sampling at or near levels recorded in recent years should continue. However, observers' sampling duties are only a part of their total work load, and as priorities switch to other fisheries it can be expected that eventually the observer coverage will diminish and commercial sampling will drop to unacceptable levels.

Commercial sampling in the Gulf of St. Lawrence (Port au Choix) has been considerably less than in the northern waters due solely to limitations of manpower. However, vessels in the Gulf usually fish at depths of between 180 and 250 m whereas in Labrador, fishing can range between 200 and 600 m and deeper. In addition, most of the Gulf catch is taken during daylight hours and problems of 24-h fishing noted previously are not so pronounced. Therefore, levels of sampling obtained during the late 1970s probably reflect, with reasonable accuracy, the characteristics of the actual catch provided they are spaced evenly over the fishing season.

Scallops

Less than 0.01% of the total annual catch was sampled over the last 2 yr (1980, 1981) (Table 4). Vessel logs (voluntary) and tags are collected when port sampling is carried out.

Catches from St. Pierre Bank landed in maritime ports are not reported as Newfoundland commercial landings. The proportion of giants to Icelandics taken from St. Pierre Bank remains unknown.

Squid

During 1975–80, sampling by the methods described above would have provided minimum sampling intensity of at least 200 measurements per 1000 t for 85% of samples. However, sampling intensity was usually greater than this in that there were approximately 400 measurements per 1000 t for 80% of samples. Sampling intensity was higher in 1981 than for the previous 2 yr due to the lower catch (approximately 18 000 t in 1981, 32 000 t in 1980, and 86 000 t in 1979). In recent years (1978–81), the percentage of the catch sampled, in number of animals, was less than approximately 0.005%. Except for occa-

TABLE 1. Numbers of lobsters sampled from commercial catches in selected areas in Newfoundland, landings in kg for statistical areas in which sampling areas are located, and total Newfoundland landings, 1970–81.

Year	St. Chads-Burnside	Area C	Arnold's Cove	Area H	Comfort Cove	Area B	Boswarlos	Area L	Bellburns-River of Ponds	Area M	Total Nfld.
	No. sampled	Landings (kg)	No. sampled	Landings (kg)	No. sampled	Landings (kg)	No. sampled	Landings (kg)	No. sampled	Landings (kg)	landings (kg)
1970	1276	103 874	743	51 710							1 462 732
1971	2262	69 681	998	46 846	1695	211 892					1 379 992
1972	1850	46 400	944	50 224	2385	203 588					1 237 568
1973	2618	49 091	1632	88 316	1877	164 341					1 263 101
1974	865	48 550	2305	209 010	1022	149 020					1 326 385
1975	2813	80 872	2129	268 306	1777	303 324	426	157 508			1 663 205
1976	2913	102 396	3346	390 584	2511	380 582	412	206 463	1396	370 879	2 253 893
1977	2699	104 439	3870	349 885	2579	472 712	387	155 591	2802	306 464	2 096 724
1978	3349	143 027	1744	322 686	2858	624 476	1123	141 091	1796	360 302	2 470 756
1979	3952	172 033	2355	410 820	2963	572 591	970	161 803	422	321 001	2 591 578
1980	2795	137 771	2765	360 434	3688	565 621	1028	160 159	1119	276 885	2 452 029
1981[a]	3114	161 913	2465	293 415	2767	564 995	1327	196 056	2098	290 252	2 376 070

[a] 1981 landings are preliminary.

TABLE 2. Sampling performance for snow crab (*Chionoecetes opilio*) in Newfoundland 1979–81.

Area	No. sampled			Landings (kg)		
	1979	1980	1981	1979	1980	1981[a]
8	—	—	—	8 498.5		
10	—	—	—			
12	—	—	256		304 158.6	
14	1 138	—	276	776 606.4	120 861.0	
16	611	1318	231	349 224.8	868 695.2	
18	14 976	6796	5372	6 975 419.2	4 982 996.1	
20	—	—	—	66 790.1	58 698.5	
22	2 289	600	1767	566 010.2	493 112.5	
24	2 838	2462	1469	819 757.9	1 264 855.0	741 006.6
26	830	1091	631	744 428.5	651 196.7	634 968.5
28	—	—	—	—	—	—
30	—	—	—	—	—	—
32	—	1030	754	416 314.8	327 405.2	584 048.3
34	—	412	1034	141 045.5	95 569.6	276 513.1
36	268	937	230	155 379.9	157 898.2	320 142.3

[a]Preliminary figures.

sional periods of high catch, especially in years of unusually high squid abundance, this level of sampling is probably adequate for describing length, sex, and maturity. However, even this rather inconsistent level of sampling intensity cannot be maintained on a yearly, seasonal, and areal basis due mainly to severe and unpredictable fluctuations in squid availability. In some years, samples may sometimes be small or may not be available for some bimonthly periods. In other years, no samples may be collected at certain localities due to the absence of squid from a large region of coastal Newfoundland.

The number and location of sampling sites are probably representative of the area of catch since this species undergoes extensive movements around the coast (Hurley and Dawe 1980). Sampling intensity may also be adequate for the purposes of describing biological characteristics of the catch. However, there are possible sources of bias which include uncertainty as to the success of jigging devices in sampling the entire size range of the population. Further, a sample is often taken from a single squid school which may not be representative since, based on observations while jigging within a day, schooling seems to be size dependent to some extent. Frequently, when squid availability is sporadic within a day, the general size of squid may vary considerably among periods of peak availability to jigging devices.

Application of Sampling Data

LOBSTER

The commercial catch sampling of lobsters in the five localized fishing areas is part of a comprehensive, ongoing study of lobster population dynamics and the fishery in these areas. Population parameters such as standing stock, recruitment, annual growth, and exploitation rate are being estimated for each year as a basis for the understanding of the causes of annual fluctuations in landings and identifying resource management options which might be employed to develop greater stability in the fishery. Size and sex composition of the commercial catches are used in generating some of these estimates (see Ennis 1981a, b for details). Characteristics of the fishery, such as size composition, catch rates, etc. in each area are being monitored to provide a basis for identifying trends and continuing evaluation of the impact on the Newfoundland fishery generally, of changes in regulatory measures, etc.

CRAB

Commercial sampling data are used in compiling yearly size-frequency tables for each management area. Changes in these data from year to year may indicate whether fishing pressure is significantly affecting the mean size of commercial-sized (≤95 mm carapace width) crabs. At sea, sampling of commercial fishing vessels enables us to monitor the incidence of soft-shelled and undersized (prerecruits) crabs in an area.

SHRIMP

Size composition of the shrimp catch from the various fisheries forms an important part of the data base for resource management. As well as monitoring changes in the stocks between years, sampling for length permits preliminary evaluation of the relative strength of fully recruited age groups and recruitment prospects. More importantly, the shrimp length frequencies are the only source of information on the age composition of the catch. Therefore, it is vital to obtain representative length frequencies from all components of the fishery since they will be used in analytical population models when these techniques are refined.

Subsampling for sex, maturity, fecundity, and weight provides comparisons between years which might indicate changes in shrimp stocks due to fishing or environmental changes. Maturity samples, especially for females, provide the data that are used to break down the accumula-

TABLE 3. Performance of shrimp (*Pandalus borealis* and *P. montagui*) sampling by the Newfoundland region in recent years.

Year	Hopedale Channel				Cartwright Channel				Hawke Channel			
	No. measured	Weight measured (kg)	Observed catch (kg)	Total catch (kg)	No. measured	Weight measured (kg)	Observed catch (kg)	Total catch (kg)	No. measured	Weight measured (kg)	Observed catch (kg)	Total catch (kg)
1977	11 031	105.98	84 954	1 550 000	8 674	76.32	68 959	1 179 261	302	2.95	116	~37 000
1978	71 491	519.80	455 475	1 847 000	10 004	77.34	85 494	1 413 000				<10 000
1979	45 011	347.47	535 892	2 991 100	24 644	214.96	66 597	1 105 300	503	4.05	62	<10 000
1980	254 249	2166.77	1 428 748	3 988 000	8 596	73.05	35 235	145 000	330	4.11	60	<10 000
1981	283 223	2115.49	1 403 540	3 394 000	2 277	14.79	7 549	8 000	6 266	41.89	18 585	132 000
	Discards				Discards							
1980	3 594	25.55	3 890		209	1.63	75					
1981	12 939	55.76	9 838									
	Div. 0A				Subarea 1				Ungava Bay[b]			
1979					903	11.87	2 070	1 813 000[a]	847	8.55	679	<10 000
1980	13 101	112.84	48 604	274 000	264 481	2374.14	1 001 445	2 363 000	1 497	11.49	2 190	<10 000
1981	173 816	1638.08	677 918	4 331 000								
	Discards				Discards							
1980	83	0.59	260		23 613	132.37	22 566					
1981	7 280	35.10	2 767									
	Hudson Strait[b]				Port au Choix (vessels)				Port au Choix Plant			
1977					10 473	71.73	8 628	1 199 000	2 667	18.27		1 199 000
1978					12 650	78.70	15 399	2 082 000	931	5.79		2 082 000
1979					10 565	69.00	12 689	2 721 000	706	4.61		2 721 000
1980	9 685	81.80	88 330	236 000	7 675	52.57	15 831	1 865 000				1 865 000
1981					1 301	10.40	1 858	2 079 000	284	2.27		2 079 000

[a]Total landings for 0 + 1.
[b]*Pandalus montagui.*

TABLE 4. Frequency and intensity of commercial sampling in the northeastern Gulf of St. Lawrence Iceland scallop fishery.

Date	Mean shell height measurements	Meat counts weight (kg)	Numbers	Monthly landings kg (round)
1980				
April	—	—	—	31 166
May 29	923	7.3	843	159 105
June 17	1187	55.9	6 000	199 333
July 2	1707	36.7	4 000	233 416
July 30	386	4.4	500	
Aug. 28	863	19.1	2 000	180 512
Sept. 27	614	34.6	4 000	101 222
Oct. 16	515	32.2	4 000	112 436
November	—	—	—	4 389
	6195	190.2	21 343	1 021 578
1981				
April 9	406	—	—	52 514
May 12	577	19.4	2 000	312 873
June 13	506	16.6	2 000	270 335
July 7	523	16.8	2 000	227 288
July 29	1404	16.3	2 000	
August	—	—	—	196 937
September	—	—	—	210 492
Oct. 5	615	20.5	2 000	109 307
	4031	89.6	10 000	1 379 746

tion of female age groups in the last prominent mode in the length frequencies into its two major components. The same type of data can be used to interpret mortality for females between years.

Sampling discarded shrimp provides basic data concerning the fishery, and additional information on the younger age groups. It has also been shown that these samples provide valuable details for estimating the parameters of the normal distributions of the youngest age groups (Fréchette and Parsons 1983). Discarding, at times, has been shown to be indiscriminate and on one occasion, at least, a fishing captain adjusted his sorting machines after it was demonstrated that he was throwing away shrimp of acceptable sizes.

By-catches are also monitored closely in the shrimp fisheries, especially those considered to be important predators of shrimp (i.e. cod and Greenland halibut). Monitoring the abundance and size distribution of these species through research and commercial sampling enables prediction of changes in shrimp mortality due to marked changes in abundance and/or size of predators (Bowering and Parsons 1981).

SCALLOPS

While past stock characteristics are somewhat speculative, the present sampling strategy may identify the need for better management regulations. Meat count regulations to maximize yield per recruit and closure of areas to reduce effort and help preserve stocks are some management strategies contemplated. Socioeconomic considerations may also be considered in limiting the total effort directed at this fishery.

SQUID

The sampling of squid described previously is used to document seasonal variation in such biological characteristics as length-frequency distributions, sex composition, and maturity. These data are not used in routine stock assessments, but a good time series of these data may eventually be useful in forming models for squid growth or inshore abundance. Sampling of more detailed biological characteristics is also performed, but on a more limited basis. Of recent particular interest is stomach analysis aimed at elucidating relationships between squid and its prey. Examination of stomach contents of squid and collection of retained otoliths may help determine the influence of predation by squid on commercial fish stocks.

Discussion and Conclusions

Sampling of commercial catches of invertebrates in Newfoundland requires radically different techniques depending on the species being considered. Lobster sampling, for example, can hardly be expected to be representative of the catch from all areas when the fishery is characteristically localized. Sampling of shrimp in areas outside the Gulf of St. Lawrence should represent the catch with acceptable accuracy as long as the observer coverage is maintained at present levels. Squid abundance fluctuates substantially between years, seasons, and areas, making representative sampling seem more difficult to achieve. Characteristics of crab and scallop fishing provide conditions that allow for a representative sampling program, but a diversity of "stocks" (especially for crab), priorities, and consequential manpower distribution, limits the amount of sampling that can be maintained both within and between years.

Nevertheless, information obtained from these sampling programs do provide data necessary for the evaluation of the status of the various stocks in terms of maturity, growth, recruitment, year-class strength, and mortality. Therefore, the sampling programs for the various species now in place must continue, with long-term objectives to improve sampling levels, ensure that the more important components of the individual fisheries are represented, and use the data in analytical assessments of the stocks.

Summary

Early periods of commercial catch sampling of lobsters in Newfoundland (i.e. 1931–41 and 1961–70) concentrated on obtaining a single sample from many different localities around the island. Since 1971, sampling has concentrated on obtaining annual samples in a small number (currently five) of selected areas considered to be representative, in general terms, of the Newfoundland fishery. Sampling standards as such have not been defined. Although sample sizes are highly variable from area to area

and year to year, for a variety of reasons, it is considered that they adequately represent the localized areas from which they were obtained. Landings in these areas, however, are a very small proportion of total Newfoundland landings.

The current sampling program is part of ongoing studies of lobster population dynamics and the fishery in each of the five areas. These studies provide the basis for advice on the "optimum" combination of minimum legal size and exploitation rate (through effort control) which are the key management tools used in lobster fisheries. If properly applied, these tools can achieve the same basic objectives as managing a fishery by an annual quota.

Obtaining representative samples of snow crab catches is a difficult task faced with limited manpower to cover numerous management areas. Sampling in recent years has been focused on the southern areas of the island where production is highest. Although it is recognized that present sampling levels are likely insufficient, the data provide valuable information on the effects of the fishery on the stocks and recruitment prospects.

Shrimp fisheries, outside the Gulf of St. Lawrence, are new and, since they are of political interest, command a high percentage of observer coverage. Sampling levels thus obtained should be reasonably representative of the actual catch, even though ratios of shrimp sampled to those caught are very low. Sampling in the Gulf of St. Lawrence on a monthly basis has been satisfactory in past years and these levels should be maintained. Commercial sampling for length and subsampling for biological detail are important sources of information, and since resource assessment techniques for shrimp are very general (insufficient time series data being a major problem), they are depended upon heavily in evaluating changes in the stocks.

Sampling commercial catches of two species of scallop is complicated due to the numerous landing localities. Prior to 1976, no systematic sampling scheme existed, but since that time most important areas of production are sampled regularly. Manpower constraints limit the amount of sampling to less than 0.01% but even these levels indicate the need for better management regulations through yield per recruit analyses.

Inshore commercial sampling from the jigger fishery for squid was discontinuous until the 1970s and most sampling was conducted at Holyrood. In 1978, sampling at bimonthly intervals was initiated at several localities on the northeast and south coasts of Newfoundland. Despite an increase in sampling localities, sampling intensity is considered to be low, but it is probably adequate for the purpose of describing biological characteristics of the catch.

Problems of sampling for length, sex, and maturity include possible bias due to gear selectivity. Sampling intensity varies greatly due to lack of immediate reporting of catch statistics, yearly variation in catch magnitude, and manpower limitations. Discontinuity of sampling and variation in sample size are due to unpredictable fluctuations in availability of squid to the fishery.

More detailed sampling on a limited basis examines such biological characteristics as weight, stomach analysis, and parasite fauna. Stomach analysis may elucidate the effect of predation by squid on commercial fish stocks.

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Sampling of Commercial Catches of Invertebrates and Marine Plants in the Scotia-Fundy Region

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Invertebrate and marine plant resources are of major importance to the Scotia-Fundy region, constituting roughly 45% of total landed value in the fisheries. Commercial catch sampling practices for these species groups are highly varied as a consequence of great biological, stock, and fisheries differences. Landings and other data from statistical and vessel log systems provide major inputs to the understanding of stock status for these species and to the provision of management advice. Biological catch sampling began around 1900 and expanded rapidly in the mid-1970s. For most species, the basic sampling strategy has been to direct sampling effort at "key" ports in the major fishing areas and to sample minor ports as the possibility arises. Level of sampling, when measured as percentage of total landings, ranges from 0.002 to 4.59, with most sampled at levels of 0.03% and above. Precision, as measured by variance in the parameters being sampled, has generally not been assessed. Sufficient data now exist for a number of fisheries to evaluate the level and precision of sampling required.

ROWELL, T. W. 1983. Sampling of commercial catches of invertebrates and marine plants in the Scotia-Fundy region, p. 52–60. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Les invertébrés et les algues marines, qui contribuent pour environ 45 % à la valeur totale des pêches au débarquement, sont d'une importance primordiale pour la Région Scotia–Fundy. Les méthodes d'échantillonnage des prises commerciales de ces deux groupes varient beaucoup à cause de grandes différences relatives à la biologie, aux stocks et aux pêches. Les chiffres sur les débarquements et les autres données provenant d'ensembles statistiques et des journaux de bord aident beaucoup à comprendre l'état des stocks de ces espèces et à formuler des avis de gestion. L'échantillonnage biologique des prises a débuté vers 1900 et s'est rapidement développé vers le milieu des années 1970. Pour la plupart des espèces, la stratégie de base pour l'échantillonnage consiste à orienter les efforts vers des ports "clés", dans les principales pêcheries, en plus d'un échantillonnage occasionnel dans les petits ports. Le taux d'échantillonnage, mesuré en pourcentage des débarquements totaux, varie de 0,002 à 4,59; dans la plupart des cas, les taux s'élèvent à 0.03 % ou plus. La précision, quantifiée par la variance des paramètres échantillonnés, n'a en général pas été évaluée. Pour un certain nombre de pêches, il existe maintenant assez de données pour déterminer le taux et la précision de l'échantillonnage nécessaire.

Introduction

The purpose of this paper is to provide a general background on historical and current commercial catch sampling practice for invertebrates and marine plants within the Scotia–Fundy region. It broadly reviews the history of commercial catch sampling, the scope and nature of the fisheries, the type of data sought, current practice and level of sampling, and some of the difficulties in applying currently available models.

Because of their importance as short-term indicators of stock status in many invertebrate and marine plant fisheries, landings and other data compiled through statistical and vessel log systems are also given consideration as integral components of catch sampling.

The invertebrate and marine plant resources are of major significance to the Scotia–Fundy region, domestic landings of these species being valued at $104 million in 1980 (Table 1; Fig. 1) and representing 45% of total landed value for all species. Foreign landings of squid, if given a value based on the inshore Newfoundland price of $720 per tonne, amounted to an additional $23 million. Because of wide variations in the market price for squid, the value per tonne may in some years be considerably higher than this. In descending order, the value of landings for the main species or species groups was: scallops — $65.1 million; lobster — $31.1 million; shrimp — $3.9 million; clams — $1.7 million; marine plants — $0.9 million; crab — $0.8 million; squid — $0.2 million; and oysters — $0.05 million. If foreign landings for squid are considered, that species ranked third in 1980 and, in some years, would undoubtedly be our second most valuable species.

Because the fisheries are prosecuted largely in the inshore waters along the entire coast of Scotia–Fundy, there are

TABLE 1. 1980 Scotia–Fundy region landings (t) and values ($,000) for invertebrates and marine plants.

Statistical district	Molluscs								Crustaceans						Marine plants		Total	
	Scallop		Clam		Squid		Oyster		Lobster		Shrimp		Crab					
	(t)	($)	(t)	($)	(t)	($)	(t)	($)	(t)	($)	(t)	($)	(t)	($)	(t)	($)	(t)	($)
1					13	2			372	1 211			485	257			870	1 470
3																		
4	19	20			141	25	65	43	143	541			22	16			390	645
6	22	22			31	4			129	478	623	1 184	59	34			864	1 722
7	111	113	3	4	27	6	6	4	317	1 271			422	241			886	1 639
8									14	64			121	81			135	145
9	3	3			66	15			11	55			8	6			88	79
14	21	22			128	19			16	65			17	65			182	171
15	5	6			176	25			23	104							204	135
16									3	18	714	1 654					717	1 672
17	1	1	23	10					14	60							38	71
18									2	15							2	15
19	15	15							40	195							55	210
20			2	1					24	130							26	131
21					3	1			12	12	306	1 019					321	1 032
22					1				5	49							6	49
23									7	58							7	58
24									8	46							8	46
25	4	5			29	5			6	36							39	46
26	40 355	38 915			33	3			5	43							40 393	38 961
27									24	124							24	194
28	4 270	4 088			7	3			101	590			5	3			4 383	4 684
30	25	25			5	2			129	747							159	774
31	65	62			11	4			516	2 098							592	2 164
32	18	16	4	3	6	4			1 128	7 662					6 784	474	7 940	8 159
33									780	5 385					2 557	359	3 337	5 744
34	5 597	5 411							700	4 811			4	1	207	29	6 508	10 252
35									7	40							7	40
36	8 127	7 829	51	34					121	742							8 299	8 605
37	498	508			5	1			209	1 497							712	2 006
38	5 929	6 395	1 013	673	1				15	94							6 958	7 162
39	85	84	451	306	53	14			14	85							603	489
40									8	60					1	4	9	64
41									3	17							3	17
42			43	25													43	25
43			560	369					6	34							566	403
44	27	33							6	43					1	1	34	77
48									25	149							25	149
49									41	259							41	259
50	1 205	1 363			1				232	1 437					26	55	1 464	2 855
51	75	80			97	15			34	248			5	1			211	344
52	79	88	487	231	3				21	125							590	444
53	2	3	165	91	5	1			37	248			102	62			311	405
81									13	70							13	70
Scotia–Fundy Total:	66 558	65 107	2 802	1 747	[a] 842	149	71	47	5 321	31 086	1 643	3 857	1 250	767	9 576	922	88 063	103 682
Maritimes Total:	68 239	66 797	3 871	2 217	871	155	1 509	1 445	16 069	63 950	4 562	8 252	13 517	7 791	27 920	3 100	136 558	153 707

[a]NOTE: Total foreign catch in NAFO SA4 = 32 033 t @ $720/t = $23 063 760

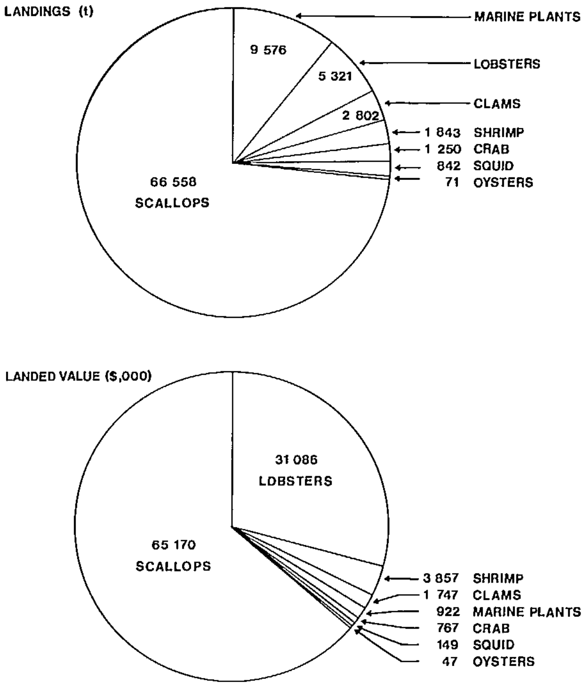

FIG 1. Relative importance of individual species or species groups to Scotia-Fundy invertebrate and marine plant fisheries.

many landing points, and for some species, such as lobsters, a very large number of fishing units (Table 2). The large number and wide range in size of fishing units, coupled with the great biological diversity of the species groups involved, present an unusual variety of requirements and difficulties in the establishment of commercial sampling regimes.

Hancock (1979), in a paper on the population dynamics and management of shellfish stocks, summarizes the difficulties of applying current theory to molluscs and crustacea. He points out that the assumptions and generalizations inherent in the theory and equations developed for finfish by Baranov, Russel, Schaefer, Beverton, Holt, Ricker, and others, are often not valid, since complications in the biology of the species are not readily accommodated in the models. He also presents a checklist of species and fishery characteristics important to the development of such models.

Since commercial sampling provides the basic data inputs for the development and application of mangement theory, Hancock's summary of species and fisheries characteristics is equally relevant to its consideration.

History of Commercial Sampling

Landing statistics, generally recorded as weights per unit time per area, comprise the most fundamental element of commercial fisheries sampling. On their own, they provide a long-term index of present relative to past production

TABLE 2. Fishing units and landing points for invertebrate and marine plant fisheries in the Scotia-Fundy region (1980).

Number of units	Scallop	Clam	Squid	Oyster	Lobster	Shrimp	Crab	Marine plants	Total[e]
Fishermen[a]	3257 (1212 offshore)	250-500 (est.)	240 (75 offshore)	73	3689 (148 offshore)	107 (64 offshore)	332	831	8779-9029
Total ports[a]	192	14 (producing area)	25	9 (producing area)	435	12	37	12	736
Major ports[b]	5	8 (major prod. area)	5	3 (major prod. area)	40	3	5	5	74
Vessels <35′[b]	528		2	73	2171	1	61	831	3667
Vessels 35-50′[b]	231		19		1335	1	70		1656
Vessels 50-65′[b]	74		26		8	8			116
Vessels 65-90′[b]	1 (offshore)		—		4 (offshore)				5
Vessels >90′[b]	71 (offshore)		3 (offshore)		4 (offshore)	3 (offshore)			81
Total vessels[b]	905		50	73	3522	13	131	831	5525
Foreign vessels[c]			88[d]						88

[a]Figures obtained from individual responsible biologist.
[b]Figures obtained from Limited Licence and Personal Licence statistics.
[c]Figures obtained from FLASH statistics.
[d]Bulgaria — 2 Poland — 1
Cuba — 7 Portugal — 9
France — 4 Spain — 19
Japan — 18 USSR — 28
[e]Totals do not account for multifishery involvement of some fishermen, vessels, and ports.

for most fisheries and, assuming changes in effective effort are limited, allow some projection of short-term future production. For most of the invertebrate species having historically high unit values, such as scallops, lobsters, and oysters, landings have been recorded since the late 1800s. Similar early data likely exist for most invertebrate and marine plant fisheries; and certainly, since at least the turn of the century, landings data of variable quality have been recorded for most species of commercial significance.

Biological catch sampling and recording of effort data of Scotia–Fundy fisheries have been sporadically conducted since about the turn of the century for a number of these species, the type and extent of sampling reflecting the relative importance of the species/stocks, their associated management problems, and often the particular predilections of fisheries biologists of the time.

The department responsible for management of Canada's fisheries underwent a major reorganization in 1976. This date, therefore, presents a logical dividing point for the periods of historical and current sampling practice.

For the period up to 1976, I have chosen to present only information on commercial sampling of scallops and lobsters. Because of their long commercial history and relative importance, these species can probably be considered representative in terms of the early development of commercial catch sampling in the region.

Scallops

Fisheries statistics of Canada first recorded scallop landings from Mahone Bay, N.S., in 1886 and from the Maces Bay to the Lepreau, N.B. area in 1895 (Bourne 1964). The early documentation of the Bay of Fundy fishery off Digby, N.S., was carried out by Stevenson (1936) and Brannen (1952) throughout the 1930s, followed by Dickie (1955) in the mid-1940s. These investigators relied almost entirely on sampling of commercial vessels and processing plants for their biological collections and catch statistics. Catch and effort statistics were compiled from National Sea Products Company records from 1965 to 1956 (Dickie 1955) and commercial logs were introduced to this fishery by George Sullivan in 1949 (R. A. Chandler, Department of Fisheries and Oceans, St. Andrews Biological Station, St. Andrews, N.B. E0G 2X0, personal communication). These logs have, with a few lapses, been collected ever since. Caddy (1979), in a study of long-term trends and production cycles in the Bay of Fundy fishery, made use of fishery officers' reports, Canadian Customs records, and licence records to develop catch and effort data for the period 1922–72. Commercial sampling of Digby scallops was largely neglected during the 1960s; but with the consideration by Caddy of meat counts as a possible management tool for the Bay of Fundy in the early 1970s, several sea trips were made to determine the feasibility of this measure. Observations on shell heights, ages, and meat yields were made; and additionally, in-plant meat counts were made by fishery officers throughout the 1970s. Since the mid-1970s, regular sampling of commercial vessels has been conducted for shell-height distribution, meat yield, and condition index studies (R. A. Chandler, personal communication).

For the offshore scallop fishery, centered on Georges Bank, logs were introduced to the Canadian fleet by Sullivan in 1957. Caddy (1975) provides a summary, based on Canadian and U.S. statistics, of landings and CPUE (t/d) for the period 1944–71. From 1957 forward, occasional biological samples were also taken from vessel catches. L. M. Dickie carried out shore sampling of an offshore scalloper in 1946 (1946 Report of the Atlantic Biological Station) and at-sea sampling of a Georges Bank scalloper in the late 1940s, collecting information on fishing practices and biological characteristics of the catch (1947 Report of the Atlantic Biological Station). At least five such trips were made between 1962 and 1964 by N. F. Bourne, J. S. MacPhail, and R. A. Chandler (R. A. Chandler, personal communication). Routine port sampling of the offshore scallop fleet was initiated by J. F. Caddy in 1970, again in relation to the possible use of meat count regulations as a management option. Meat samples, and occasional shell-height samples, were, and continue to be, collected regularly at Lunenburg, Riverport, Yarmouth, and Saulnierville.

Lobster

Data on Maritimes lobster landings were recorded as early as 1869, although it was not until 1892 that landings were segregated by county, thereby allowing monitoring of production changes and trends for smaller geographic areas (Annual Report of Department of Marine and Fisheries, cited by Robinson 1979). Data collected as early as 1873 (Venning 1910) and 1890 (Annual Report of Department of Marine and Fisheries, cited by Robinson 1979) give some record of average weights and percentages of catch in particular size-classes.

Further information extracted from Annual Reports of the Department of Marine and Fisheries and successor departments by Robinson (1979) provide statistical information on Maritimes lobster fisheries between 1890 and 1944, giving a historical measure of effort for all major fishery areas. Effort data, in the form of traps per man, were available for SE Nova Scotia and the southern Gulf of St. Lawrence since 1910.

It was D. G. Wilder who initiated the first extensive commercial sampling program on lobsters, beginning with the collection of catch and effort data from 1933 to 1938 in Lobster District 6A, SE Cape Breton, and continuing after 1944 until the late 1950s and early 1960s with the collection of catch and effort, size distribution, and general biological sampling along with tag return and trap evaluation studies in virtually all Maritimes lobster districts. Since 1975 and 1976, sampling has been resumed throughout these areas.

Current Sampling Practice

Following the 1976 reorganization, fisheries research activities were rapidly expanded and new instruments such as the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) were created for the vetting of biological advice on fisheries management. At this time, invertebrate and marine plant research began to focus on assessmentoriented studies. It was quickly recognized that the field capability to collect the essential data on area-specific catch and effort, catch composition, growth, mortality, fecundity, and other biological and fisheries practice information necessary to assessments was lacking. Accordingly, port sampling activities were initiated between 1976 and 1978, with primary emphasis given to the lobster and scallop fisheries and less effort being directed to the marine plant, crab, and shrimp fisheries. Because of the large volume of sampling necessary to sample the numerous and diverse fishing units, a large number of samplers have been deployed each summer, using various provincial and other nonbudgeted and nondepartmental staff (approximately 12 man-years in 1980). Sampling of offshore squid has been carried out under the International Observer Program. Along with increased sampling activity, considerable effort has been expended on compilation and analysis of historical data bases, both statistical and biological.

Data Sources

Current practice in commercial sampling is highly varied, both among the species and the various components of the fisheries on each. The sampling data derived can be partitioned into two distinct types: that obtained from secondary or indirect sources, and that obtained by direct field observation and measurement.

Indirect — The first, summarized in Table 3, is obtained indirectly from statistical systems, vessel logs, and inter-

TABLE 3. Commercial sampling data available from statistical systems, vessel logs, interviews, and other indirect sampling.

Fishery		Data source	Data derived
Crustaceans:			
Lobster	Inshore	Purchase slips	Boat name, landings, gear type, port fish landed.
		Supplementary purchase slips — A & B	Vessel name, landings, gear type, port fish landed.
		Interviews	Boat name (or fisherman's name), landings (number and/or weight by market category and private sale weight), port, depth, trap number set and hauled, soak days, men, number of berried females, port fish landed.
	Offshore	Purchase Slips	Boat name, gear type, port fish landed.
		Vessel logs	Vessel name, trip landings, daily catch, gear type, hour set (soak time), depth, location fished, bait used, fish buyer's name (fish landed).
Crab	Inshore	Purchase slips	Boat name, landings, gear type, port fish landed.
		Vessel logs	Vessel name, trip landings, gear type, hour set, depth, location fished, port fish landed.
Shrimp	Offshore	Purchase slips	Boat name, landings, gear type, port fish landed.
		Groundfish logs	Vessel name, trip landings, catch/day and by-catch/day, tows/day, gear type, depth, location fished, port fish landed.
Molluscs:			
Scallop	Inshore	Purchase slips	Boat name, landings, gear type, port fish landed.
		Vessel logs	Vessel name, trip landings, gear type, time/tow, depth, bottom type, location fished, port fish landed.
	Offshore	Purchase slips	Boat name, landings, gear type, port fish landed.
		Vessel logs	Vessel name, trip landings, gear type, time/tow, depth, bottom type, location fished, port fish landed.
Squid	Inshore	Purchase slips	Boat name, landings, gear type, port fish landed.
		Supplementary purchase slips — A & B	Vessel name, landings, gear type, port fish landed.
	Offshore	Purchase slips	Boat name, gear type, port fish landed.
		Vessel logs	Vessel name, landings, gear type, time/tow, depth, by-catch, location fished, port fish landed.
	Foreign	International fishing logs	Vessel name, side number, Canadian licence number, landings (catch/set and by-catch/set and discards), gear type, time/tow, depth, location fished.
Clam	Inshore	Purchase slips	Boat name (or fisherman's name), landings, gear type, port (location) fish landed.
Oyster	Inshore	Purchase slips	Boat name (or fisherman's name), landings, gear type, port (location) fish landed.
		Supplementary purchase slips — A & B	Vessel name, landings, gear type, port (location) fish landed.
		Return of operation (leases)	Lessee's name, file number, landings, effort, lease location.
Marine plants:			
	Inshore	Purchase slips	Boat name (or fisherman's name), landings/tide/man, location fished, gear type, port plants landed.

views with fishermen. These data depend on the fisherman, buyer, or fishery officer for both their completeness and accuracy and ultimately their usefulness to the biologist. Where interviews are used, the skill and thoroughness of the interviewer are also important in deriving complete and accurate data.

For the indirectly obtained data, there has been some effort over the last few years to upgrade the data received and improve its timeliness. Vessel logs were introduced into the Cape Breton snow crab fishery in 1978, and the biologist responsible for that fishery is currently attempting to refine the data inputs — in particular, more precise locational information on grounds fished, which is critically important to the interpretation of CPUE changes as utilized in the Leslie analysis for biomass determinations. Timeliness of receipt of offshore vessel logs for scallops has also been improved, permitting somewhat more responsive assessment of resource status. Monitoring of the "leasehold" component of the oyster industry was also upgraded considerably between 1978 and 1980 with the development of a computer-based lease management system and improved recording of catch, effort, biological, and area-specific data on the annually submitted Return of Operations form.

Direct — The second type of data, obtained by direct observation and measurement in landing ports and at sea with commercial vessels, is summarized in Table 4. The accuracy and completeness of these data are more certain, assuming adequate sampling design and conscientious field observation.

Port sampling and at-sea sampling have been markedly increased since 1976. The level of sampling effort has, however, been highly variable from year to year, being dependent on availability on nondepartmental staff. Despite problems in effective deployment of samplers, a reasonably comprehensive data base on some of the more important fisheries such as scallops and lobsters has been developed. Sampling of the lobster fishery, with its approximately 40 major ports and 3500 vessels, has been expanded to include a large number of areas either not previously or, in the past, only rarely sampled. For squid, at-sea sampling of the foreign fleet was initiated in 1977 with the inception of the International Observer Program. This program continues to be the main source for data on the commercial fishery, since the inshore squid fishery in Scotia-Fundy is relatively underdeveloped and only sporadically active.

For species such as clams and oysters, there has been

TABLE 4. Commercial sampling data derived by direct sampling in ports and at sea.

Fishery			Data derived
Crustaceans:			
Lobster	Inshore	Port	Length frequency, sex ratio, moult stage, port.
		At sea	Boat name (or fisherman's name), location and depth fished, total catch/trip, number of traps set and hauled, soak time, lath space, hoop size, trap sequence, surface and bottom temperature, men, length frequency, sex ratio, moult stage, number of berried females, egg stage, crabs by species, sea urchins, port.
	Offshore	Port	Essentially the same as for inshore lobster.
		At sea	Essentially the same as for inshore lobster.
Crab	Inshore	Port	Boat name, trap type, location fished, total catch/trip, number of traps, soak time, width frequency, shell condition, mortality, port.
		At sea	Essentially the same as port, with addition of sex ratio, number of berried females, and egg stage.
Shrimp	Offshore	Port	Boat name, location and depth fished, total catch, length frequency, sex, growth stage, port.
		At sea	Essentially the same as port, with addition of time of day fish caught.
Molluscs:			
Scallop	Inshore	Port	Vessel name, location and depth fished, total catch/day, number of drags, individual meat weights, shell height/meat weight, sex, maturity, psp samples, port.
		At sea	Vessel name, location and depth fished, shell height frequency, age structure, cull size, port.
	Offshore	Port	Vessel name, location and depth fished, individual meat weights for each third of trip, shell height/meat weight, port.
		At sea	Vessel name, location and depth fished, shell height frequency, age structure, cull size, port.
Squid	Inshore	Port	Vessel name, gear type, location and depth fished, length frequency, weight, sex maturity, food and feeding, parasites, port.
	Offshore	At sea	Vessel name, Canadian licence number, country of registration, gear type, set number, depth and time/start and end of set, surface and bottom temperature, by-catch/set, length frequency, weight, sex, maturity, food and feeding, parasites.
Clam	—	—	—
Oyster	—	—	—
Marine plants:			
	Inshore	Port (buyer)	Species composition, by-catch, reproductive state, size frequency, port.

no effort at port sampling or direct sampling of the harvesting units.

Sampling Strategies

The sampling strategies chosen for the various species have been adaptive to, and reflect, the year-to-year uncertainty of available sampling manpower. For most, there has been no formal statistical study on the required sample sizes or sampling design, although, in 1980, an unpublished in-house report was prepared outlining basic port sampling requirements for these species. This study attempted to define the types of data required, the time frame over which the collection activity would likely continue, resolution, sampling effort, and seasonality of requirements. Although the study served to clarify the basic sampling requirements and define what an appropriate distribution of sampling effort might be, it has only been used as a guide, since the required manpower has remained unavailable. The basic strategy chosen for most species has therefore been to direct sampling effort at "key" or "representative" ports in the major fishing areas and sample the more minor ports as manpower resources permit. Port and at-sea sampling activities on Cape Breton snow crab, as described by R. W. Elner (Department of Fisheries and Oceans, St. Andrews, N.B. E0G 2X0, personal communication), serve to illustrate this strategy.

In the Cape Breton snow crab fishery, the following plan should be followed throughout the 9-wk fishing season. For each of the seven Cape Breton Snow Crab Areas, two to three representative ports are chosen (these ports are as far apart as possible along the coastline). Landed catches at each port are sampled twice per week and one at-sea sample is obtained for each Area every week.

At-sea samples consist of going out on a fishing boat for a day and measuring carapace width and shell condition of all male and female snow crabs in every second or third trap hauled. Given a trap limit of 30 and present CPUE levels, approximately 1500 crabs will be sampled per sea trip — approximately 50% of the boat's catch after culling.

Port samples consist of measuring the carapace widths and shell condition of three boxes (150–250 kg) of landed, culled male snow crab for three to four boats for one port on one day. This constitutes approximately 12% of the landed catch for each boat.

Sampling data for each Area are pooled to provide (1) *monthly* size-frequency histograms for both at-sea samples and port samples; and (2) *weekly* soft-shell frequencies for both at-sea samples and port samples.

The objective is to assemble representative catch samples for each area for defined intervals throughout the fishing season, that may be used both to support interpretation of the logbook data-derived Leslie analysis of biomass and to independently monitor the condition of the stocks.

To date, manpower resource levels have been insufficient to allow even one port sampler per month in each of the seven areas. Rather, sampling effort has been directed into key ports in the three major Areas (1, 5, and 7) in an attempt to obtain at least weekly port samples and monthly at-sea samples.

The strategy for inshore lobster is similar to that for snow crab, with the exception that, because of the very large number of geographically dispersed landing points, an attempt is made to sample not only key ports in each Lobster District but also secondary ports, deemed to be generally representative, at 10–20 mi intervals along the coastline. For lobster fisheries such as that in Lobster District 4, with a 6-mo season extending through a midwinter period of poor weather conditions and low water temperatures during which both effort and catchability are reduced, sampling is concentrated on the first and last few weeks of the season when most of the landings are made. Sample sizes greater than 400 animals are obtained where possible since this usually provides variances sufficiently small to allow seasonal and geographic comparisons of catch curves with reasonable accuracy.

For offshore and Bay of Fundy scallops, the strategy is again to sample the key or major ports, and in recent years an arbitrary level of 10% of the year's commercial scallop trips was designated for sampling. This has amounted to roughly 100 offshore and 500 Bay of Fundy trips being sampled each year.

The strategies for shrimp, offshore lobster, and inshore squid are very similar to those described for the above fisheries.

The strategy for marine plants differs in that the sample source is the buyer's bin rather than the harvesting unit or fishermen, and the samples cannot be attributed to specific beds, only to general harvest areas. There is no regular at-sea sampling of marine plants. The data derived do not allow prediction of yield. Rather, sampling is directed at determining the percentage of by-catch species (by-catch may range from 10 to 40% of harvest and affects carrageenan yield), reproductive state profile (of importance in carrageenan yield and loss of biomass after fruiting), size frequency of fronds (rough measure of age structure), and frequency of holdfasts (rough measure of gear impact).

Offshore squid are sampled, under the International Observer Program, with roughly 60% coverage of the foreign fishing effort. Sampling is directed at obtaining daily length frequencies on each vessel sampled as well as twice-per-trip samples for morphometric analysis and general biological sampling.

Level of Sampling

In an attempt to evaluate the level of direct port and at-sea sampling, I have, in Table 5, compared the total weight of samples to the total weight of landings for a number of the fisheries and their components. The data on weights sampled were in most cases supplied by the biologist responsible for the fishery. The percentage of landings sampled varies widely, from 0.002 for marine plants to 4.59 for the offshore component of the lobster fishery, with most fisheries and components being sampled at levels of 0.03% and above. The data, as presented, do not show the wide range in sampling level for a particular fishery or fishery component when individual areas, seasons, or other factors are considered. For example, sampling of inshore lobster varied from 0.20% (6.51 t sampled out of

TABLE 5. Percentages of landings directly sampled (port and at sea) in 1980.

Fishery	Weight sampled (t)	Total landings (t)	Percentage of landings sampled
Scallops			
Offshore	1.47	5 221	0.03
Digby	0.24	714	0.03
Squid			
Offshore	9.74	32 033	0.03
Lobster			
Offshore	24.57	535	4.59
Inshore[a]	13.63	4 760	0.29
Snow crab[b]	10 507 (animals)	1 208 550 (animals)	0.87
Shrimp	0.05	985	0.01
Marine plants[c]	0.12	5 769	0.002

[a]Based only on port sampling. Weight of offshore samples unavailable at time of writing.
[b]Based on 1981 sampling and landings.
[c]*Chondrus* only.

3199 t landed) in Lobster District 4 to 1.46% (0.95 t sampled out of 65 t landed) in Lobster District 3. Similar variations in sampling level are evident for most of the fisheries examined.

The variation in sampling level between fisheries, fisheries components, areas, seasons, etc. may, in some cases, be indicative of poor sampling design and less than optimal placement of sampling effort. Further analysis, in which the level of sampling activity is examined in relationship to the data being sought and its range of variability, are necessary to determine the adequacy of sampling. For most of the fisheries, a sufficient data base has now been developed to permit the required analysis.

It should be recognized that the more general fishery data collected at the time of port or at-sea sampling, by direct observation or interview, will be proportional to the biologically defined (weight sampled) level of sampling described above. For some of these data, the level of sampling necessary may be quite different from that required for particular biological parameters. In some crustacean and molluscan fisheries, changes in grounds fished may occur rapidly, with reflected changes in CPUE, size of animals captured, etc. For a fishery such as the Cape Breton snow crab, where Leslie analysis has been used to monitor year-to-year changes in biomass and to establish TACs, small changes in area fished may be sufficient to render the analysis useless. Sampling methods must be sufficiently precise for the biologist to recognize both that change has occurred and the nature of the change.

Discussion and Conclusion

Commercial sampling of invertebrates and marine plants, while generally directed at collecting the same sort of data and carried out in support of the same types of management objectives as for finfish, is greatly complicated by the highly diverse assemblage of organisms involved and by the huge range in scale of the fisheries to be sampled. Although the management objectives may be similar, the applicability and usefulness of existing models vary greatly and, in many cases, the required inputs for such models have not been developed or are of insufficient precision.

Despite the problems posed in commercial sampling of invertebrates and marine plants, the most basic requirements are essentially the same as for finfish: catch curves, representative catch and effort data, knowledge of area fished, distribution of catch in size-classes or age-classes, percentage by-catches, gear performance and its impact on sampling, reproductive state, fecundity, seasonal factors influencing yield, etc. However, because of their biological, stock, and fisheries characteristics, invertebrates and marine plants in general are managed very differently than marine finfish. The management regimes utilized tend by their nature to require greater dependence on statistical and log-derived data than on biological catch sampling. Most are managed through some form of effort control and often, as in the case of Leslie analysis for snow crab, statistical and log data are critical to assessment.

In recent years, there has been considerable research into the adaptation, development, and application of modeling techniques to invertebrate stocks and in 1976, a special ICES meeting was convened on the population assessment of shellfish stocks (Thomas 1979). The contributions to the meeting provide an excellent review of current application of management theory to crustaceans and of the commercial sampling data inputs required.

For a number of invertebrates, such as oysters, scallops, and lobsters, there has been a long history of commercial sampling, extending from the mid- to late 1800s to the present. Initially, the data were primarily landings summaries for particular geographic areas, but by the turn of the century some data on effort and on particular biological characteristics such as size frequencies were being recorded.

The level of commercial sampling increased considerably between the 1940s and mid-1970s and then quite dramatically up to the present.

In Scotia–Fundy, the strategies currently being applied to commercial sampling reflect the need to gather information on previously unsampled or undersampled species and stocks and to accommodate this requirement within the manpower sources available. Gulland (1966) notes that in the majority of fishery programs the amount of sampling done is rarely decided by statistical criteria, but rather by the availability of manpower and funding. This is a less-than-adequate approach to longer-term sampling requirements and leads to gross disparities in disposition of sampling effort.

While I have attempted to look at the level of sampling as a measure of adequacy in the disposition of sampling effort, it is obvious that this information is, in itself, of little use. To be useful, the level of effort must be examined in direct relation to the variability of the parameters being sampled. Gulland (1966) and Holden and Raitt (1974) describe the basic sampling strategies and the means of evaluating the level of sampling necessary to obtain the precision required. They point out the degree to which variance in the parameters being sampled can be reduced through appropriate stratification of the sampling regime. Sampling of inshore lobster stocks in particular, with their wide geographical spread and high number of landing points and fishing units, would benefit from such a statistically validated stratified sampling program.

With the sampling data accumulated in recent years, it should now be possible to evaluate the level of sampling required and design a more adequate sampling program than that now operating.

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Revue de l'échantillonnage des captures commerciales d'espèces marines par la province de Québec

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LUSSIAÀ-BERDOU, J. P., R. COURTOIS, P. DUBÉ, J. FRÉCHETTE, P. LAMOUREUX ET C. TREMBLAY. 1983. Revue de l'échantillonnage des captures commerciales d'espèces marines par la province de Québec, p. 61–76. *Dans* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Des renseignements sur l'historique, les objectifs, les méthodes et les volumes des échantillonnages des captures commerciales sont donnés pour la morue, le sébaste, le flétan du Groenland, les plies, le hareng, le homard et la crevette nordique. Les activités d'échantillonnage au débarquement des stocks de poissons démersaux, entreprises dans le cadre des recommandations de la CIPANO ont souffert entre 1966 et 1974 d'un changement de priorité dans les activités de recherche en pêche de la province de Québec. En conclusion générale on souligne l'importance, en particulier pour la crevette nordique et les poissons démersaux, de la liaison entre récolte de statistiques sur l'effort de pêche et l'échantillonnage au débarquement. Ces deux activités sont menées de front par des techniciens présents, en permanence, durant la saison de pêche dans les principaux ports de débarquement.

LUSSIAÀ-BERDOU, J. P., R. COURTOIS, P. DUBÉ, J. FRÉCHETTE, P. LAMOUREUX ET C. TREMBLAY. 1983. Revue de l'échantillonnage des captures commerciales, d'espèces marines par la province de Québec, p. 61–76. *Dans* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Data are presented on the history, objectives, methods, and volumes of commercial catch samplings of cod, redfish, Greenland halibut, plaice, herring, lobster, and pink shrimp. Sampling of demersal fish at landing, initiated following ICNAF recommendations, has suffered from a change of priority in fisheries research activities in Quebec between 1966 and 1974. The importance, especially for pink shrimp and demersal fish, of the link between the gathering of statistics on the fishing effort and sampling at landing, is stressed. These two activities are tackled by technicians permanently present in the main landing ports during the fishing season.

Introduction

Ce document a pour but de donner un aperçu de l'échantillonnage des captures commerciales réalisées jusqu'à présent par la province de Québec.

Historiquement, les échantillonnages les plus anciens concernent le hareng, le homard et la morue. Le homard, en particulier aux Îles-de-la-Madeleine, a été l'objet d'assez nombreuses études qui ont nécessité soit l'échantillonnage des débarquements, soit celui des captures, au cours des années cinquante.

L'échantillonnage des espèces démersales, entre 1958 et 1968, pour répondre aux recommandations de la CIPANO, a principalement concerné la morue. À cette époque les stations de biologie marine dépendant du Gouvernement du Québec étaient les seuls laboratoires gouvernementaux effectuant de la recherche dans le domaine de la biologie des pêches au Québec, ceci contrairement aux Provinces maritimes et à Terre-Neuve où il existait des laboratoires dépendant du Gouvernement fédéral canadien. À la suite d'un changement d'orientation dans le domaine de la recherche sur les pêches entre 1961 et 1969, entraînant la fermeture des laboratoires de la Tabatière, puis des Îles-de-la-Madeleine et de Grande-Rivière, il y eut une diminution importante dans les activités d'échantillonnage au débarquement pour toutes les espèces, sauf la crevette nordique, une réduction dans la participation aux activités scientifiques de la CIPANO, et dans l'étude des grands stocks migrateurs pour se consacrer plus spécialement à des espèces plus côtières.

À partir de 1974, une volonté de s'impliquer de nouveau dans l'évaluation des stocks de poissons démersaux a conduit au développement d'un système de collecte, dans les principaux ports, et de traitement de données, concernant l'effort de pêche, les captures et les lieux de pêche des chalutiers québécois, parallèlement au système administratif de statistiques existant, géré par le bureau de la Statistique du Québec. À partir de 1978, profitant de l'implantation stable de techniciens saisonniers dans les principaux points de débarquement des chalutiers pour les sta-

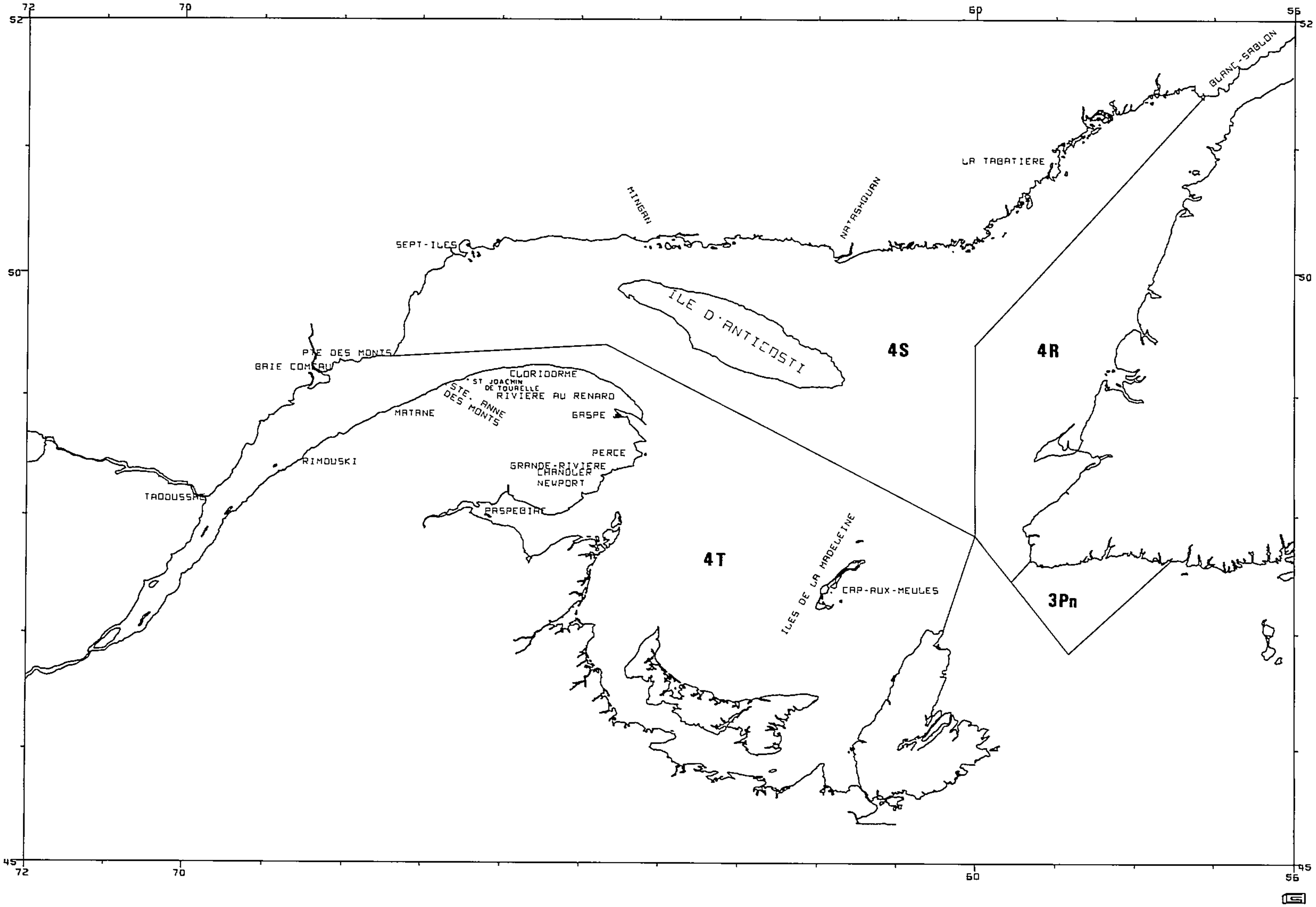

FIG. 1. Principaux points de débarquement de la pêche commerciale québécoise.

tistiques, le programme d'échantillonnage des poissons démersaux débuté en 1974 sur une petite échelle fut amplifié de façon significative.

La crevette nordique dont la pêche a commencé au milieu des années soixante a été l'objet d'une attention particulière depuis ses débuts. Ceci fait qu'un programme d'échantillonnage au débarquement s'est maintenu régulièrement et n'a pas souffert du changement d'orientation temporaire de la fin des années soixante. Il en est de même pour la pêche du crabe des neiges, plus récente, qui s'est développée avec rapidité ces dernières années.

Bien que les objectifs particuliers des échantillonnages au débarquement aient varié au cours du temps, le but principal a toujours été une meilleure connaissance des stocks exploités. Actuellement les objectifs généraux sont : l'évaluation de l'importance relative des générations dans les captures et son évolution, de suivre certaines caractéristiques biologiques des captures, d'évaluer l'importance des recrutements en parallèle avec les données récoltées au cours de croisières scientifiques d'évaluation, ceci afin de fournir des données primordiales ou d'appoint aux structures gouvernementales de gestion biologique des stocks comme le CSCPCA, ou internationales comme l'OPANO.

La morue (*Gadus morhua*)

INTRODUCTION

La pêche de la morue, au Québec, est extrêmement ancienne, comme le long de toute la côte atlantique canadienne.

Les pêcheurs québécois exploitent principalement deux stocks de morue; le stock dit de 4T4Vn, à partir de la Gaspésie et des Îles-de-la-Madeleine, et le stock dit 4RS3Pn (fig. 1).

Le chalutage s'est développé en Gaspésie au début des années cinquante et la pêche traditionnelle à la dandinette et à la palangre a été en partie remplacée par la pêche aux filets maillants dans les années soixante. Depuis 1980 on observe un retour à l'utilisation des palangres.

Le long de la Côte-Nord (Pointe des Monts, Blanc-Sablon), les méthodes de pêche traditionnelle, trappe, dandinette et palangre, ont encore une grande importance et n'ont été remplacées qu'en partie par des filets maillants depuis quatre à cinq ans. Ce changement s'accompagne d'un accroissement de la taille des embarcations. Les deux principaux ports chalutiers du Québec sont Newport et Rivière-au-Renard. Leur pression de pêche s'exerce principalement sur la morue de 4T4Vn, mais un développement de la pression de tous les types de pêche sur le stock de 4RS3Pn a lieu depuis les quatre dernières années.

Les premiers échantillonnages de débarquements de morue ont été effectués dès 1951 (tableau 1) à partir de la station de biologie marine de Grande-Rivière (Corbeil 1952; Jean 1953). En 1953 des otolithes ont été récoltés. À partir de 1958 un échantillonnage régulier de la morue de 4T4Vn a été instauré, à la suite des recommandations de la CIPANO, et s'est maintenu jusqu'en 1968. Le poids des échantillons n'était pas enregistré. Quelques échantillonnages de captures faites à l'aide de trappes et de palangres dans la région de la Tabatière aux dépens de la morue de 4RS3Pn, ont été effectués en 1960 et 1961. Tous ces échantillonnages ont été réalisés sous la direction de Marcotte (1960) et Boulanger. L'échantillonnage de la morue de 4T4Vn a cessé en 1968 avec la fermeture presque totale de la station de biologie marine de Grande-Rivière.

TABLEAU 1. Nombre de morues mesurées au débarquement par la province de Québec de 1951 à 1981 par stocks et par engins.

	4T4Vn					4RS3Pn				
Année	CM[a]	CC[a]	FM[a]	P[a]	T[a]	CM	CC	FM	P	T
1951	502			660						
52			20	867						
53	538			808						
54										
55	Il n'y a pas de renseignements disponibles de 1954 à 1957.									
56										
57										
58	1739			1375						
59	1668			1563						
1960	2773			1883					3000	7545
61	1046		509	2025	718	3413		1420	3935	3037
62	1331		819	951		1958				
63	4213		368	1104		1462				
64	2374			1271		777				
65	3628			545						
66	920		985			367				
67	1334		317	196		136				
68	423		755							
69										
1970										
71										
72										
73										
74										
75	205					148				
76	562					309		292		
77										
78	2029		197			1082	1321	555		
79	1360	613	300			2894	2393	378		
1980	2573	177				1285	3855		640	
81	4690			1436		1464	8047			

[a]CM Chalutiers à morue; CC Chalutiers à crevette; FM Filets maillants; P Palangres; T Trappes.

Une reprise de l'échantillonnage au débarquement a eu lieu en 1975–1976 à l'aide d'une équipe mobile formée d'étudiants engagés pour l'été. Cependant, ce programme a été abandonné à cause des maigres résultats. En 1978 le programme actuel a été mis en place. Il utilise comme ressource humaine des techniciens en place dans les ports, dont la tâche originelle était de récolter des statistiques d'efforts et de captures auprès des pêcheurs et des usines de transformation.

BUTS ET TECHNIQUES ACTUELS DE L'ÉCHANTILLONNAGE

Les objectifs visés actuellement par la DRST (Direction de la Recherche scientifique et technique) ne sont pas les mêmes pour les deux stocks exploités par les pêcheurs québécois :

Pour la morue de 4T4Vn on n'a recherché qu'à maintenir un échantillonnage des longueurs pour pouvoir retransmettre des données de base à d'autres organismes.

Pour la morue de 4RS3Pn, il s'agit d'un échantillonnage plus intensif comprenant le prélèvement d'otolithes, afin de suivre l'évolution de la structure d'âge dans les captures, de la comparer aux structures d'âge obtenues à partir de croisières scientifiques d'évaluation des stocks par chalutage, d'établir des courbes de captures et d'être capable de construire un tableau des captures par génération pour les débarquements québécois provenant de ce stock. L'échantillonnage a principalement lieu à Newport et accessoirement à Grande-Rivière pour la morue de 4T4Vn. Celui de la morue de 4RS3Pn est surtout réalisé à Rivière-au-Renard mais aussi à Matane et Mingan. Aucun échantillon n'est actuellement prélevé dans les débarquements faits le long de la Basse Côte-Nord (Natashquan, Blanc-Sablon).

L'échantillonnage des longueurs individuelles est réalisé sur une base mensuelle. Pour un stock donné, un port donné, et un engin donné, il doit comprendre de 300 à 500 individus et provenir d'au moins trois débarquements différents. Cette dernière exigence n'est pas toujours remplie en particulier pour les engins fixes. Suivant le cas, le poids de l'échantillon est mesuré à l'aide d'une balance présente sur les lieux de débarquement ou estimé. Depuis 1981 dans le cas d'une estimation, on recalcule le poids de l'échantillon à l'aide d'une relation longueur-poids du type $P = aL^b$. La longueur mesurée est la longueur totale au centimètre le plus proche. Le tableau 1 récapitule les quantités échantillonnées depuis 1951.

Normalement le prélèvement d'otolithes n'est effectué que sur des morues provenant du stock 4RS3Pn. De 1978 à 1980, l'objectif fixé était un échantillonnage sur une base approximativement trimestrielle (mars à mai, juin à août, septembre à décembre). En 1981, devant les difficultés à atteindre cet objectif, à cause d'une saison de pêche vraiment active qu'entre la mi-mai et la mi-novembre, la cueillette a été redéfinie sur une base semestrielle (mai–juillet et août–novembre). Il s'agit d'un échantillonnage stratifié indépendant des engins de pêche, de 4 otolithes par classe de 1 centimètre. On note la longueur totale au milimètre près, et le poids individuel, à l'aide d'une balance électronique depuis 1981. Le tableau 2 résume le nombre de morues sur lesquelles ont été prélevés des otolithes au débarquement entre 1978 et 1981.

En 1981, pour certains débarquements, il existait un tri en plusieurs catégories de longueurs. Dans la mesure du possible le technicien essayait de réaliser son échantillonnage avant ce tri. Lorsque cela n'était pas possible, il échantillonnait chaque catégorie en notant les poids débarqués.

La collaboration des usines où s'effectue l'échantillonnage est en général bonne; cependant, il peut y avoir des difficultés en particulier en début et fin de saison de pêche où le poisson peu abondant est immédiatement utilisé et dans les lieux où le débarquement du poisson est fortement mécanisé.

TABLEAU 2. Nombre de morues sur lesquelles ont été prélevés des otolithes au débarquement par la province de Québec de 1976 à 1981 par stock.

	Année					
Stocks	1976	1977	1978	1979	1980	1981
4T4Vn						174
4RS	257			273	171	333

TECHNIQUES DE STOCKAGE ET DE TRAITEMENT PRIMAIRE DES DONNÉES

Les échantillons de longueur sont regroupés manuellement par stock, par engin de pêche, et par mois. Les échantillons provenant des chalutiers sont regroupés quelle que soit la taille du bateau, mais l'on tient compte des différences de maillage qui existent entre les chalutiers à crevette et les chalutiers à morue. Dans le cas où l'échantillonnage a été effectué sur un débarquement trié en deux catégories, on reconstitue un échantillon composite avant de l'intégrer aux autres à l'aide de la formule :

$$N_i = n1_i \times \frac{P1}{P2} \times \frac{p2}{p1} + n2_i$$

N_i : nombre d'individus dans la classe de longueur i pour l'échantillon composite.

$n1_i$: nombre d'individus dans la classe de longueur i mesurés dans l'échantillon provenant de la catégorie 1 de longueurs.

$n2_i$: nombre d'individus dans la classe de longueur i mesurés dans l'échantillon provenant de la catégorie 2 de longueurs.

$P1$: poids total de la catégorie 1.

$P2$: poids total de la catégorie 2.

$p1$: poids de l'échantillon de la catégorie 1.

$p2$: poids de l'échantillon de la catégorie 2.

Les échantillons regroupés sont stockés dans des fichiers APL. Il existe un fichier spécifique que la morue. Les échantillons ainsi stockés peuvent être inventoriés en mode interactif à l'aide de tris hiérarchisés, suivant l'année, l'engin de pêche, le mois, une division ou une subdivision NAFO, le sexe, l'intervalle de profondeur de capture. Si on le désire, on peut extraire du fichier les échantillons inventoriés, effectuer des regroupements suivant différents pas de longueurs (1, 2 et 3 cm) et calculer des distributions en pourcentage. Une fois les âges établis à partir des otolithes récoltés, ils sont stockés dans un fichier APL, différent de celui utilisé pour les échantillons de longueur, avec des données complémentaires (poids et longueurs individuels). Il est possible de trier les échantillons d'âges suivant le même type de hiérarchie que pour ceux des longueurs et de les extraire du fichier si on le désire. Il est alors possible de calculer les longueurs moyennes ou les poids moyens pour un âge donné, ou encore de construire une clé longueur-âge et de calculer des distributions de fréquence d'âge. Les diverses fonctions APL nécessaires pour ce genre de travaux sont disponibles auprès des auteurs.

Discussion

La couverture des débarquements provenant du stock de 4T4Vn est en général plus faible, en particulier pour les filets maillants. Cette faiblesse de l'échantillonnage des filets maillants est due au fait que le technicien responsable aussi des statistiques de pêche, est surtout appelé à Newport où débarquent principalement des chalutiers. Les débarquements des filets maillants sont géographiquement très dispersés.

Dans le cas de la morue de 4RST qui est l'objet d'une plus grande attention, il y a eu une amélioration dans la régularité de l'échantillonnage de 1978 à 1981. L'échantillonnage des engins fixes est insuffisant. Ceci s'explique en partie par le développement récent de la pêche de la morue aux filets maillants sur la Basse Côte-Nord où jusqu'à récemment nous n'avions pas de technicien. Les trappes pêchant la morue de 4RS3Pn sont toutes implantées le long de la Basse Côte-Nord. L'échantillonnage des crevettiers est beaucoup plus important que dans le cas des autres types de pêche. On retrouve ce phénomène pour tous les autres poissons démersaux échantillonnés. Ceci est dû à la grande importance accordée à la pêche de la crevette par la DRST.

Cela a impliqué une présence plus grande dans les ports où débarquent des crevettiers (Matane, Mingan, Rivière-au-Renard). De plus, dans ce dernier port où débarquent aussi des chalutiers dirigeant leur pêche vers les poissons de fond, les méthodes de débarquement font qu'il est en général plus aisé d'échantillonner le poisson débarqué par les crevettiers (tableau 1). Pour tous les types de pêche et les deux stocks, l'échantillonnage en début et en fin de saison de pêche est moindre qu'au milieu. À ces périodes, les volumes débarqués sont faibles et sont immédiatement traités par les usines.

Le sébaste (*Sebastes mentella*)

Introduction

La pêche de cette espèce au Québec a débuté au milieu des années cinquante. Son véritable essor a eu lieu à partir de 1963 et les débarquements ont culminé entre 1967 et 1973 aux environs de 30 000 t. Ce sommet a été suivi d'une chute abrupte à cause de la raréfaction de la ressource, mais une légère reprise s'est amorcée en 1981 faisant remonter les débarquements à 11 000 t après un minimum de 4000 t en 1976. La majeure partie des débarquements proviennent du stock de sébaste de 4RST. Cependant, en fin ou en début de saison, certains débarquements faits à Cap-aux-Meules proviennent de 3P ou de 4V.

À la suite des recommandations de la CIPANO, un échantillonnage de faible envergure du sébaste, pour les longueurs, a été réalisé à la Tabatière entre 1958 et 1961 avant la fermeture du laboratoire. Ni le sexe des poissons, ni le poids des échantillons n'ont été enregistrés.

Jusqu'au début des années soixante-dix, le sébaste ne faisait pas partie des espèces étudiées par la DRST. À partir de 1975 un programme d'étude des poissons démersaux a été envisagé, et comme pour la morue un programme d'échantillonnage a été mis en place. À cause des difficultés évoquées dans le chapitre sur la morue, il a été remplacé par le programme actuel.

Buts et techniques actuels de l'échantillonnage

Les objectifs de l'échantillonnage établi en 1978 sont :
1) de suivre l'évolution de l'abondance des classes de longueur et des classes d'âge dans les captures
2) d'évaluer les paramètres de la croissance
3) de réaliser des courbes de capture et d'établir des matrices de captures par génération afin de suivre l'évolution de la mortalité par la pêche
4) de comparer les compositions en longueurs et en âges des captures avec celles obtenues au cours des croisières scientifiques d'échantillonnage à l'aide d'un plan de chalutage stratifié aléatoire.

Comme pour la morue, le programme d'échantillonnage du sébaste au débarquement est basé sur la présence de techniciens saisonniers situés dans les principaux points de débarquements des chalutiers pour la récolte des statistiques concernant l'effort de pêche et les captures durant la saison de pêche.

Le principe de l'échantillonnage et les données récoltées pour cette espèce sont les mêmes que pour la morue (environ 500 longueurs par mois et par engin, provenant d'au moins trois débarquements). Pour cette espèce, le sexe des individus est déterminé. Depuis 1980 la majeure partie de l'échantillonnage (tableau 3) se fait à Cap-aux-Meules où ont lieu les débarquements les plus importants, mais aussi à Rivière-au-Renard, Matane et Mingan.

L'échantillonnage des otolithes se fait à Cap-aux-Meules et Rivière-au-Renard. Ils ont été prélevés sur 600 individus en 1980 et 771 en 1981. Il consiste à prélever, sur une base semestrielle, 10 paires d'otolithes par classe d'un centimètre et par sexe, indépendamment des engins de pêche.

Tableau 3. Nombre de sébastes mesurés au débarquement par la province de Québec de 1958 à 1981, par engins.

Année	Chalutier[a] à sébaste	Chalutier à crevette	Palangre	Filet maillant
1958	1969			
1959				
1960	2880			
1961	8695			
1975	157			
1976	808			
1977				
1978	363	2621		242
1979		3411		671
1980	3858	4032	640	
1981	4744	4075		

[a]Comprend les chalutiers de toute taille utilisant des chaluts de fond ou semi-pélagiques ou pélagiques pêchant le sébaste avec une maille d'environ 89 mm.

Méthodes de stockage et de traitement primaire des données

La façon de stocker les échantillons de longueurs et d'âges de sébaste est la même que pour la morue. Les traitements primaires possibles sont les mêmes. La seule différence est que les échantillons sont séparés par sexe.

Discussion

L'échantillonnage des chalutiers de 40 m des Îles-de-la-Madeleine qui sont responsables de plus de 50 % des débarquements de sébaste au Québec, n'est devenu effectif qu'en 1980. Ce n'est qu'à cette date qu'un technicien a été chargé de recueillir des statistiques de pêche auprès des chalutiers de 40 m. Auparavant, ce travail était fait par du personnel ne dépendant pas de la DRST.

Les débarquements des crevettiers de la péninsule gaspésienne, ou de Mingan, ont été échantillonnés de façon régulière depuis 1978. L'échantillonnage du sébaste pêché par des engins fixes est irrégulier (tableau 3). Les captures de sébaste par les engins fixes représentent un faible volume et sont des prises accidentelles de la pêche aux engins fixes du flétan du Groenland.

Flétan du Groenland
(*Reinhardtius hippoglossoides*)

Introduction

Les premières statistiques de débarquement du Flétan du Groenland remontent à 1957, où les captures n'atteignèrent alors que 500 kg. Les débarquements de cette espèce demeurèrent relativement faibles par la suite, et ce n'est que vers les années 1975 et 1976 que cette pêche pris de l'importance. À l'origine, la plupart des débarquements étaient constitués des prises accessoires des chalutiers à crevette mais depuis 1978, il s'est développé au Québec une pêche côtière au filet maillant dirigée vers cette espèce et responsable de plus de 80 % des débarquements depuis 1979 (Tremblay et Axelsen 1981).

Jusqu'en 1979, près de la moitié des débarquements de flétan du Groenland ont été effectués dans la région de Rivière-au-Renard. L'autre moitié des débarquements provenait des régions de Rimouski et Matane jusqu'en 1976, et en moindre importance de la Côte Nord de la péninsule gaspésienne (Ste-Anne des Monts à Cloridorme) ainsi que de la Moyenne Côte Nord (Sept-Îles à Natashquan). Depuis 1978, avec le développement d'une pêche côtière importante à l'embouchure de l'estuaire maritime du Saint-Laurent, les débarquements se sont concentrés principalement dans les régions de Matane et St-Joachim de Tourelle, ainsi que dans d'autres petites localités sises le long de la côte nord de la péninsule gaspésienne (Tremblay et Axelsen 1978).

Buts et techniques actuels de l'échantillonnage

C'est en 1978 qu'a débuté l'échantillonnage au débarquement du Flétan du Groenland au Québec. Les objectifs poursuivis par cet échantillonnage constitué d'une récolte de données biologiques et biométriques, sont les suivants :

1) étude de l'évolution temporelle des structures de taille et d'âge
2) accumulation de données historiques nécessaires à la création de tableaux de capture à l'âge utilisé dans les modèles de dynamique de population et nécessaire aux avis de gestion
3) récolte de données sur la maturité sexuelle afin d'évaluer le taux de reproduction
4) estimation de la croissance et la mortalité
5) séparer le stock du golfe de celui de l'extérieur du golfe.

Le flétan du Groenland du golfe du Saint-Laurent (division 4RST) est considéré comme un stock unique et a été échantillonné comme tel. Au départ, cet échantillonnage, constitué de la récolte de données de longueur et d'otolithes, s'effectuait à partir de Rivière-au-Renard et provenait des trois principaux engins de pêche capturant du flétan du Groenland soit : les chalutiers à crevette, les chalutiers à morue et les filets maillants. En 1979, cette récolte de données s'intensifie et s'étend à Matane et Mingan.

À partir de 1980, on ajoute St-Joachim de Tourelle comme point d'échantillonnage. De plus, le plan général de cueillette de données devient beaucoup plus structuré. En effet, en plus des données de longueur, s'ajoute un échantillonnage stratifié pour les otolithes, accompagné d'une prise du poids individuel des individus échantillonnés. À partir de septembre, on prélève mensuellement un échantillon d'individus mâles et femelles où on y effectue une évaluation des stades de maturité. Enfin, la récolte des données se concentre sur les deux principaux engins de pêche responsables des captures : le chalutier à crevette et le filet maillant.

Le volume théorique d'échantillonnage des longueurs est de 300 à 500 individus par mois, par sexe et par type d'engins de pêche provenant de trois débarquements différents. Cet échantillonnage est effectué par les techniciens responsables de la récolte des statistiques de pêche et situés dans les ports de Rivière-au-Renard, Matane et Mingan. Lors de la cueillette des données plus spécifiques (otolithes, stades de maturité, poids individuels), les techniciens sont aidés par une équipe volante constituée de deux personnes provenant du laboratoire de Québec. La fréquence d'échantillonnage des otolithes est effectuée sur une base semestrielle pour l'ensemble du territoire au rythme de trois otolithes par classe d'un centimètre par sexe et par semestre. Enfin, le volume d'échantillonnage lors de l'évaluation des stades de maturité est de 100 à 151 individus par sexe et par mois.

L'échantillonnage s'effectue d'une façon aléatoire et la méthode utilisée est la suivante : le poisson est débarqué dans des bacs dont le volume peut varier suivant le port où s'effectue l'échantillonnage, par la suite on prend au hasard, ou selon les disponibilités, le nombre de bacs nécessaire pour obtenir le volume d'échantillonnage désiré.

Après avoir prélevé l'échantillon, on y détermine le sexe de tous les individus présents. Par la suite la longueur totale est enregistrée au cm le plus près, et le poids de

TABLEAU 4. Principales données[a] biométriques et biologiques récoltées lors de l'échantillonnage au débarquement du flétan du Groenland de 1978 à 1981 en 4RS.

Année	Données sur la longueur: Chalutier à crevette	Filet maillant	Chalutier à morue	Otolithes	Stade de maturité et rapport gonosomatique: Mâles	Femelles
1978	823	919	1501	133		
1979	3296	1530	147			
1980	7446	1370	—	389	450	499
1981	9348	1717	—	446	313	174

[a]Nombre d'individus échantillonnés.

l'échantillon (glace enlevée) est déterminé au kilogramme près pour les mâles et les femelles séparément. Lors de la récolte des otolithes, la longueur du poisson est prise au mm près et le poids individuel est déterminé au gramme près. La prise du poids individuel sert également à établir une relation longueur-poids du type $P = aL^b$ qui est utilisé pour estimer le poids de l'échantillon lorsqu'il n'a pu être obtenu lors de l'échantillonnage. Enfin, l'évaluation des stades de maturité est faite par un examen macroscopique ou par détermination du rapport gonosomatique. Le tableau 4 montre les principales données biologiques et biométriques recueillies depuis 1978 sur le stock de flétan du Groenland du golfe du Saint-Laurent.

TECHNIQUES DE STOCKAGE ET DE TRAITEMENT PRIMAIRE

Ce sont les mêmes techniques qui ont été uniformisées et qui sont utilisées pour tout l'échantillonnage au débarquement des poissons démersaux. Elles ont été décrites dans la section « Morue ».

DISCUSSION

Le volume théorique d'échantillonnage mensuel d'environ 500 individus par sexe et par engin est difficilement observable étant donné les contraintes rencontrées dans les ports de débarquement telles que vitesse des débarquements, priorité de tranchage de certaines espèces, déchargement simultané de bateaux possédant des engins de pêche différents, etc.

Les chalutiers à crevette subissent un effort d'échantillonnage supérieur aux autres types d'engins de pêche. Ce suréchantillonnage s'explique par le fait que dans deux des trois principaux ports de débarquement où nous pratiquons de l'échantillonnage, soit Matane et Mingan, la presque totalité des débarquements proviennent des chalutiers à crevette. De plus, il est très difficile d'échantillonner la pêche côtière (filet maillant) puisque celle-ci est très irrégulière et dispersée le long de la côte. À cela s'ajoute le fait que les prises sont acheminées très tôt le matin vers les usines de transformation où elles sont traitées presqu'immédiatement. Enfin, c'est volontairement que les chalutiers à morue ont été délaissés étant donné les faibles quantités de flétan du Groenland débarquées.

Un autre problème rencontré lors de cet échantillonnage, est le manque de régularité dans le prélèvement de nos données au cours de la saison de pêche puisqu'on observe un sous-échantillonnage en début et fin de saison de pêche. Au début de la saison de pêche, ce sous-échantillonnage est occasionné par le manque de ressource humaine. En effet, les techniciens dans les ports sont saisonniers et ne sont pas toujours en poste au moment où débute la saison de pêche. De plus, comme leur mandat est de s'occuper principalement de la cueillette de statistiques des chalutiers à crevette et que cette pêche est très active à cette époque, ils n'ont plus beaucoup de temps pour échantillonner le poisson provenant des débarquements des différents types de chalutiers et encore moins pour celui provenant de la pêche côtière.

En fin de saison, le problème de sous-échantillonnage est de tout autre nature. En effet, ce problème est provoqué par des débarquements peu nombreux et très irréguliers. En conséquence, les captures sont rapidement transformées laissant peu de chance au technicien de prélever son échantillon.

Plie canadienne (*Hippoglossoides platessoides*) et plie grise (*Glyptocephalus cynoglossus*)

INTRODUCTION

Au Québec, les débarquements de plie grise et de plie canadienne sont compilés sous le terme général de « plies » puisque ces deux espèces ne sont pas séparées lors de la transformation. Les statistiques de débarquements sont transmises à l'OPANO sous forme de débarquements de plie canadienne et de plie grise. Pour ce faire, le Bureau de la Statistique du Québec identifie l'espèce de plies en tenant compte de l'espèce principale débarquée ainsi que de la distribution bathymétrique des deux espèces de plies.

Les premières statistiques de débarquements de plies au Québec remontent à 1947 où les captures enregistrées n'étaient que de 138 tonnes. Les captures ont augmenté jusqu'au milieu des années soixante et se maintiennent depuis lors entre 3500 et 5000 t. Dans le golfe du Saint-Laurent, on distingue deux stocks de plie canadienne, celui du nord (division 4RS) et celui du sud (division 4T), et un stock de plie grise, celui du nord (division 4RS).

La plie canadienne et la plie grise n'ont jamais été des espèces recherchées au Québec, sauf au début des années soixante où une pêche dirigée vers la plie canadienne s'était développée aux Îles-de-la-Madeleine, mais elle ne dura que quelques années (1962 à 1964). Il y eut de plus en Gaspésie, de 1976 à 1978, une pêche dirigée vers la plie canadienne mais elle se pratiquait à la fin de la saison lorsque les contingents de morue étaient atteints. De façon générale les captures de plies proviennent des prises accessoires des chalutiers à morue et à crevette.

La plie canadienne, dont le volume débarqué est le plus important, est principalement capturée dans les divisions 4T et 4RS de l'OPANO par les chalutiers à morue depuis les années cinquante. Une autre proportion des débarquements provient des prises accessoires des chalutiers à crevette pêchant dans le nord-ouest du golfe (4RS) depuis 1965. Les principaux ports de débarquement pour la plie canadienne sont : Newport, Grande-Rivière, Rivière-au-Renard et les Îles-de-la-Madeleine pour les chalutiers à morue, et Rivière-au-Renard, Matane et Mingan pour les chalutiers à crevette. Enfin, dans plusieurs petites localités de la Gaspésie, il se débarque de légères quantités de plie canadienne provenant de la pêche côtière (filets maillants).

Les captures de plie grise proviennent surtout du nord-ouest du golfe (4RS) et sont constituées des prises accessoires des chalutiers à crevette débarquant à Rivière-au-Renard, Matane et Mingan, ainsi que des captures provenant des chalutiers à morue débarquant à Rivière-au-Renard. Enfin, les statistiques révèlent qu'une part infime des débarquements de plie grise provient des chalutiers à morue pêchant dans le sud du golfe (4T).

Il n'y a pratiquemment jamais eu d'échantillonnage au débarquement sur les plies avant 1978. Seul un échantillon de 525 plies canadiennes avait été récolté en même temps qu'un échantillonnage de morue, sur des chalutiers à morue ayant pêché en 4RS et 4T en 1961. Les principales données recueillies lors de l'échantillonnage au débarquement de la plie canadienne de 4RS et 4T et de la plie grise de 4RS, depuis 1978, sont présentées aux tableaux 5 et 6.

Buts et techniques actuels de l'échantillonnage

C'est en 1978, lors de la mise en marche d'un programme d'échantillonnage sur les poissons démersaux à Newport, Rivière-au-Renard, Matane et Mingan que débutèrent les premières récoltes de données biologiques et biométriques provenant de débarquements de plie canadienne et de plie grise des chalutiers du Québec. L'objectif visé par cet échantillonnage était d'accumuler, en profitant de la disponibilité de techniciens dans les ports, des données historiques de longueurs et d'âges afin de pouvoir construire ultérieurement des tableaux de captures à l'âge par année. Ces données ont été recueillies également dans le but de pouvoir déterminer certaines caractéristiques biologiques de ces stocks, telles que la mortalité et la croissance, dans l'éventualité d'une mise en marche de programmes de recherches sur ces espèces.

TABLEAU 5. Principales données[a] biométriques et biologiques récoltées lors de l'échantillonnage au débarquement de la plie canadienne de 1978 à 1981 dans 4RS et 4T.

Année	Données de longueur: Chalutier à morue		Données de longueur: Chalutier à crevette		Récolte d'otolithes	
1978	1976	1552	—	186		
1979	127	389	1768	—	326	—
1980	661	4516	3013	498	149	585
1981	1455	4731	2563	—	395	202

[a]Nombre d'individus échantillonnés.

TABLEAU 6. Principales données[a] biologiques et biométriques récoltées lors de l'échantillonnage au débarquement de la plie grise de 1978 à 1981 dans 4RS.

Année	Données de longueur: Chalutier à morue	Données de longueur: Chalutier à crevette	Récolte d'otolithes
1978	455	1411	—
1979	143	1032	128
1980	121	2831	375
1981	1096	3066	448

[a]Nombre d'individus échantillonnés.

Les techniques d'échantillonnage utilisées sont les mêmes que celles décrites pour les autres poissons démersaux (morue, flétan du Groenland, sébaste). Les principales données récoltées sont les suivantes :

1) le sexe
2) la longueur au cm près
3) le poids total des mâles et des femelles échantillonnés
4) échantillonnage stratifié d'otolithes au rythme de cinq otolithes par classe de 1 cm, par sexe et par semestre, accompagné de la longueur au mm près du poisson
5) depuis 1980, détermination du poids individuel au gramme près pour les poissons ayant servi à la récolte des otolithes.

Ces échantillons sont prélevés, chez les deux espèces de plies, au rythme de 300 à 500 individus par mois, par engin de pêche et provenant de trois débarquements différents.

Techniques de stockage et de traitement primaire

Ce sont les mêmes techniques qui ont été uniformisées et qui sont utilisées pour tout l'échantillonnage au débarquement des poissons démersaux. Elles ont été décrites dans la section « Morue ».

Discussion

L'objectif d'échantillonnage d'environ 500 individus par sexe, par engin, par mois, est difficilement respecté dans le cas de la plie canadienne et de la plie grise. En effet, cette récolte de données est assujettie, lors du débarquement, aux mêmes contraintes physiques qui ont été discutées dans la section traitant de l'échantillonnage du flétan du Groenland. De plus, étant donné que l'échantillonnage des plies est une récolte de données complémentaires lors de l'échantillonnage d'autres poissons démersaux et des crevettes, il est le premier à être affecté en terme de volume échantillonné lorsque surgissent des contraintes de temps ou de ressources humaines.

Étant donné que les deux espèces de plies sont débarquées sans être préalablement triées et qu'elles sont échantillonnées simultanément, on observe les mêmes problèmes d'échantillonnage chez chacune d'elles. Ces problèmes sont similaires à ceux observés lors de l'échantillonnage des autres poissons démersaux, et consistent en un sous-échantillonnage en début et fin de saison ainsi qu'en un léger sur-échantillonnage des débarquements des chalutiers à crevette pêchant dans 4S. Ces problèmes ainsi que leurs causes ont été discutés dans la section traitant de l'échantillonnage du flétan du Groenland.

Enfin, on note une absence complète d'échantillonnage provenant de la pêche côtière. Cette situation est occasionnée par le faible volume des prises débarquées ainsi que par les difficultés à échantillonner un type de pêche caractérisée par des débarquements très irréguliers et dispersés sur un territoire très vaste.

Le hareng de l'Atlantique (*Clupea harengus harengus*)

INTRODUCTION

Traditionnellement au Québec, la pêche du hareng s'effectue à l'aide d'engins côtiers (trappes, fascines, filets maillants). De 1959 à 1979, les captures québécoises de hareng rapportèrent en moyenne 17 815 t/an. Jusqu'à 1969, la majorité des captures (15 810 t/an) provenait des Îles-de-la-Madeleine et de la Gaspésie (2518 t/an). La pêcherie a toutefois été grandement modifiée suite à l'introduction d'une flotte mobile (seineurs surtout) en 1967 aux Îles-de-la-Madeleine; cette flotte débarqua plus de 9000 t/an de 1967 à 1970. Après cette date, les débarquements de la flotte mobile chutèrent rapidement et furent concentrés à Gaspé et Paspébiac, rapportant dès 1970 plus de 37 000 t de hareng dans ce comté. Les débarquements des seineurs ont par la suite diminué de façon constante et sont très sporadiques depuis 1976.

Au cours des dernières années, les débarquements gaspésiens paraissent s'être rétablis à leur niveau normal mais ceux des Îles-de-la-Madeleine demeurent pratiquement dix fois inférieurs à ce qu'ils étaient au cours des années soixante. Par contre, la Côte-Nord a vu ses débarquements passer de 79 t/an au cours des années soixante à plus de 430 t/an en moyenne de 1969 à 1979.

Les premiers échantillonnages de hareng ont été effectués au Québec dans le cadre de la "Canadian Fisheries Expedition" de 1914–15 (Hjort 1915). Le ministère de l'Industrie et du Commerce du Québec a par la suite contribué à la réalisation des travaux de Jean en 1942–43 (Jean 1967) et en 1952–53 (Jean 1956). Ces études visaient à acquérir des données sur la biologie générale de l'espèce et sur la délimitation des stocks. L'office de recherche sur les pêcheries du Canada effectua également, entre 1946 et 1948, des travaux pour la délimitation des stocks de hareng québécois (Day 1957a, b).

Ce n'est toutefois qu'à partir de 1975 que furent investis des efforts d'échantillonnage plus systématiques. Jusqu'en 1977 ceux-ci furent concentrés dans la région de l'Île Verte et autour de la péninsule gaspésienne. Des données biologiques (longueur, poids, sexe, etc.) méristiques (rayons des nageoires, branchicténies, scutelles osseuses) et morphologiques de l'otolithe ont été recensées sur les échantillons permettant ainsi la distinction des trois stocks majeurs fréquentant la péninsule gaspésienne (hareng de printemps de l'Île Verte, hareng de printemps et d'automne de la péninsule gaspésienne (Côté et al. 1980).

En 1978 un travail similaire d'identification de stocks a été entrepris sur la Basse Côte-Nord et poursuivi en 1979 et 1980. Parallèlement aux travaux d'identification des stocks, des échantillons ont été récoltés aux Îles-de-la-Madeleine à partir de 1978 tandis que les échantillonnages déjà entrepris dans la Baie des Chaleurs et sur la Basse Côte-Nord se sont poursuivis. Ceux-ci visaient soit à suivre l'évolution des populations ou encore à atteindre des objectifs strictement biologiques (périodes et zones de frai en relation avec d'autres formes d'exploitation, possibilités d'extension de la pêche, etc.).

BUTS ET TECHNIQUES ACTUELS D'ÉCHANTILLONNAGE

Les échantillonnages actuels visent principalement à suivre l'évolution des structures de taille et d'âge des populations soumises à l'exploitation sur la Côte-Nord et aux Îles-de-la-Madeleine.

Les débarquements de hareng sont répartis sur toutes les côtes maritimes québécoises et des captures sont enregistrées dans la majeure partie des ports échelonnés le long des côtes. Le choix des lieux d'échantillonnage dépend donc des buts visés par l'étude de la disponibilité des prises au moment de l'échantillonnage. Le choix du bateau est également fait en fonction de ces critères en tenant compte également de la fiabilité du pêcheur et de l'engin utilisé par ce dernier. Les échantillons comptent généralement 200 individus achetés hebdomadairement directement du pêcheur.

L'examen des spécimens se fait au laboratoire humide; la longueur est mesurée au millimètre près puis, ramenée au centimètre inférieur pour la confection des distributions de fréquences. Le poids corporel est enregistré au gramme près et le poids des gonades au dixième de gramme. Le sexe et le stade de maturité sexuelle sont évalués selon une échelle relative adaptée de Boyar (1968) (Courtois et al. 1983). Le gras coelomique (présence ou absence) de même que le degré de réplétion de l'estomac sont déterminés de façon visuelle. Les otolithes de tous les spécimens sont prélevés et montés dans des treillis de plastique puis lus dans l'éthanol à 95 %. En plus de ces données, les caractères méristiques suivants peuvent être dénombrés lorsque des objectifs de délimitation de stock sont visés : rayons de nageoires dorsales, pectorales et anales, branchicténies et scutelles osseuses.

TECHNIQUES DE STOCKAGE ET DE TRAITEMENT PRIMAIRE

De 1975 à 1980, les données étaient stockées sur bandes magnétiques au Bureau Central d'Informatique (BCI) du Ministère des Communications du Québec, et traitées à l'aide de l'utilitaire EXTRACTO de ce ministère et du logiciel SPSS.

Depuis 1981, les données sur le hareng sont stockées sur disques magnétiques à l'Université Laval et traitées par l'intermédiaire d'un terminal léger situé à Grande-Rivière en Gaspésie. Le traitement s'effectue à l'aide d'une série de programmes APL (Courtois et al. 1983). Les traitements statistiques sont habituellement faits à l'aide des utilitaires de l'Université Laval.

Discussion

L'échantillonnage au débarquement s'avère difficile pour un certain nombre de raisons. La multitude et la dispersion des points de débarquement le long de la côte rend onéreuse la cueillette des échantillons. En plus, certains ports tels que ceux de la Basse Côte-Nord, sont difficiles d'accès.

La gestion efficace de cette ressource demande en premier lieu la délimitation claire des unités de stock. Parallèlement à cette recherche, il faudra se pencher attentivement sur les méthodes d'échantillonnage réalistes, susceptibles de fournir l'image la plus conforme possible de l'état de ces stocks.

Homard d'Amérique (*Homarus americanus*)

Introduction

Bergeron (1967a) note qu'au Québec, c'est dans la Baie des Chaleurs, dans les années 1870, que débute la pêche du Homard dans les secteurs de Gaspé et des Îles-de-la-Madeleine. Cette pêche se développe à la même époque, tandis que sur la Côte-Nord, elle commence environ 10 ans plus tard. Dans les districts de Gaspé et de Bonaventure, cette activité connaît une expansion rapide les cinq premières années et les débarquements deviennent alors aussi importants que ceux qu'on observe aujourd'hui. Aux Îles-de-la-Madeleine, la pêche connaît une progression beaucoup plus lente, et c'est seulement à partir de 1912 que les captures atteignent un niveau comparable aux prises actuelles.

Les premiers travaux scientifiques accomplis sur le homard pêché au Québec sont ceux de Templeman (1935), qui en 1931 et 1932 effectue des travaux d'étiquetage aux Îles-de-la-Madeleine en même temps qu'à l'Île-du-Prince-Édouard. Le premier échantillonnage recensé fut effectué à Grande-Rivière à l'automne de 1939 (Tremblay et al. 1941). À partir de cette date et jusqu'en 1947, un important programme d'échantillonnage s'est poursuivi principalement dans les districts de Gaspé et de Bonaventure, à partir de 10 aires d'échantillonnage, et d'une façon moins intensive aux Îles-de-la-Madeleine et à l'Île d'Anticosti. L'échantillonnage en Gaspésie avait pour but de caractériser les populations de homard de cette région, et de mettre en évidence les traits qui le différencient de celui des Îles-de-la-Madeleine et de l'Île d'Anticosti. Après cette période, les principaux travaux vont se dérouler aux Îles-de-la-Madeleine. À partir de 1950 et jusqu'en 1967, un échantillonnage annuel est effectué à partir de différents sites dont le nombre varie de 7 à 13; la subdivision du territoire en sous-régions d'échantillonnage est alors artificielle et ne repose sur aucun critère d'ordre biologique. On distingue alors deux types d'échantillonnage :

1) échantillonnage des captures complètes; le pêcheur rapporte au quai tous les homards capturés (tailles commerciales, non commerciales et les femelles œuvées) afin d'être mesurés.
2) échantillonnage des captures commerciales; seuls les homards de taille légale (mesurant plus que 76,2 mm de céphalotorax) sont mesurés. De façon générale, on vise à effectuer trois échantillonnages de chaque type et dans chaque sous-région au cours d'une saison. Les statistiques de captures et d'efforts de pêche sont cumulées à partir des mêmes sous-régions. Le but visé était alors de suivre l'évolution des rendements de pêche et des captures en tenant compte des structures de population. Bergeron (1967b) effectue une analyse de l'échantillonnage réalisé entre 1950 et 1959. Après 1967, les travaux systématiques d'échantillonnage sont interrompus jusqu'en 1979; le travail accompli depuis est décrit à la section suivante. Le tableau 7 donne le nombre de homards examinés pour chaque année entre 1939 et 1981.

Buts et techniques actuels d'échantillonnage

En 1981, la DRST décidait d'interrompre l'échantillonnage des captures commerciales et de poursuivre ses activités d'échantillonnage en mer (Lamoureux et al. 1983). La technique décrite ici ne portera donc que sur l'échantillonnage des captures complètes réalisées à bord de bateaux de pêche.

Buts et objectifs

Cet échantillonnage vise de façon générale à obtenir pour une zone donnée, une image de la structure des populations avant et après la saison de pêche. Il permet ainsi de mesurer l'effet de la pêche sur la population et de suivre d'année en année l'état des stocks, de caractériser les régions au niveau du sexe-ratio ainsi que de l'abondance du homard pré-recru et des femelles œuvées. Il permet aussi l'évaluation de certains paramètres, comme la mortalité par la pêche.

Nature des données récoltées

— Identification du pêcheur, du port et débarquement, et date
— Longueur du céphalothorax, sexe, stade et quantité des œufs
— Position et nombre de casiers levés
— Poids de la capture (homard commercial)
— Température de l'eau en surface et au fond.

Les longueurs du céphalothorax sont prises au 1/10 de mm. Les œufs sont classés en trois catégories :
— vert foncé, noir et opaque, rond
— brun, une partie de l'oeuf est translucide
— rose, rouge translucide.

TABLEAU 7. Nombre de homards examinés au cours des échantillonnages entre 1939 et 1981.

Année	Gaspé	Bonaventure	Îles-de-la-Madeleine	Île d'Anticosti
1939	356			
1940	286			
1941	456			
1942	673			
1943	785			
1944	4 172			3 838
1945	5 235	3 214	2 508	
1946	2 976	966		
1947	2 048	2 076		

Zones de pêche[a] — Îles-de-la-Madeleine

	1		2		3		4		Total	
	A[b]	B[b]	A	B	A	B	A	B	A	B
1950		1 580		1 656		484				3 720
1951	988		1 528	1 103		1 450			2 516	2 553
1952	370		1 243	633		332	236	368	1 849	1 133
1953	860	451	2 033		740	308	621	218	4 254	933
1954	2 026	1 513		2 206		1 035		1 632	150	6 386
1955				1 218						1 218
1956		454		1 269						1 723
1957		123	302	188					302	311
1958	1 158		2 993	301					4 151	301
1959	3 087	955	3 394	559					6 481	1 514
1961		621		1 999		927				3 547
1963	3 240	2 953	3 311	2 016	1 955	1 565	523	1 096	9 047	7 630
1964[c]	4 939		5 208		2 444		3 041		15 632	
1965[c]	2 380		3 129		1 084		1 694		8 337	
1966[c]	4 833		4 702		980		1 895		12 410	
1967[c]	1 237		2 579		3 424		1 052		6 292	
1979	3 360	1 680	1 308	722	1 376	1 070	757	1 133	6 801	4 605
1980	2 374	1 591	1 461	848	884	1 299	692	1 365	5 411	5 103
1981	3 069		1 866		830		553		6 318	

[a]Voir figure 2.
[b]A: Capture complète, B: Capture commerciale.
[c]De 1964 à 1967 les échantillonnages effectués au débarquement n'ont pas été compilés.

Description de l'échantillonnage pour les Îles-de-la-Madeleine en 1982

Choix des sites : six aires seront échantillonnées, trois dans la zone de gestion nord : Grosse-Île, Étang du Nord, Millerand, et trois dans la zone sud : Grande-Entrée, Hâvre-aux-Maisons, Île d'Entrée. Leur répartition assure une bonne représentativité autour de l'archipel et leur choix tient compte des différences régionales que nous avons observées lors des échantillonnages précédents. De plus, ces sites sont parmi les plus importants en terme de volume des captures.

Choix des bateaux : étant donné que l'échantillonnage se fait à bord des navires, nous sommes donc limités dans ce choix; certains capitaines se montrent réticents à embarquer un observateur.

Périodes et fréquence d'échantillonnage : aux Îles-de-la-Madeleine la saison de pêche commence le 10 mai et se termine le 10 juillet. Pour chaque site, deux échantillonnages seront effectués au début de la saison de pêche, entre les 10 et 25 mai, et deux autres à la fin entre le 28 juin et le 10 juillet.

TECHNIQUES DE STOCKAGE ET DE TRAITEMENT PRIMAIRE

Les mensurations sont notées sur papier aquafuge, et elles sont ensuite compilées sur une fiche standard. Ces données sont saisies sur informatique en APL, sous forme de trois vecteurs, représentant la distribution de fréquence des mâles, des femelles et des femelles œuvées. Les informations complémentaires concernant la date d'échantillonnage, le poids de la capture, etc..., sont codées et gardées en mémoire.

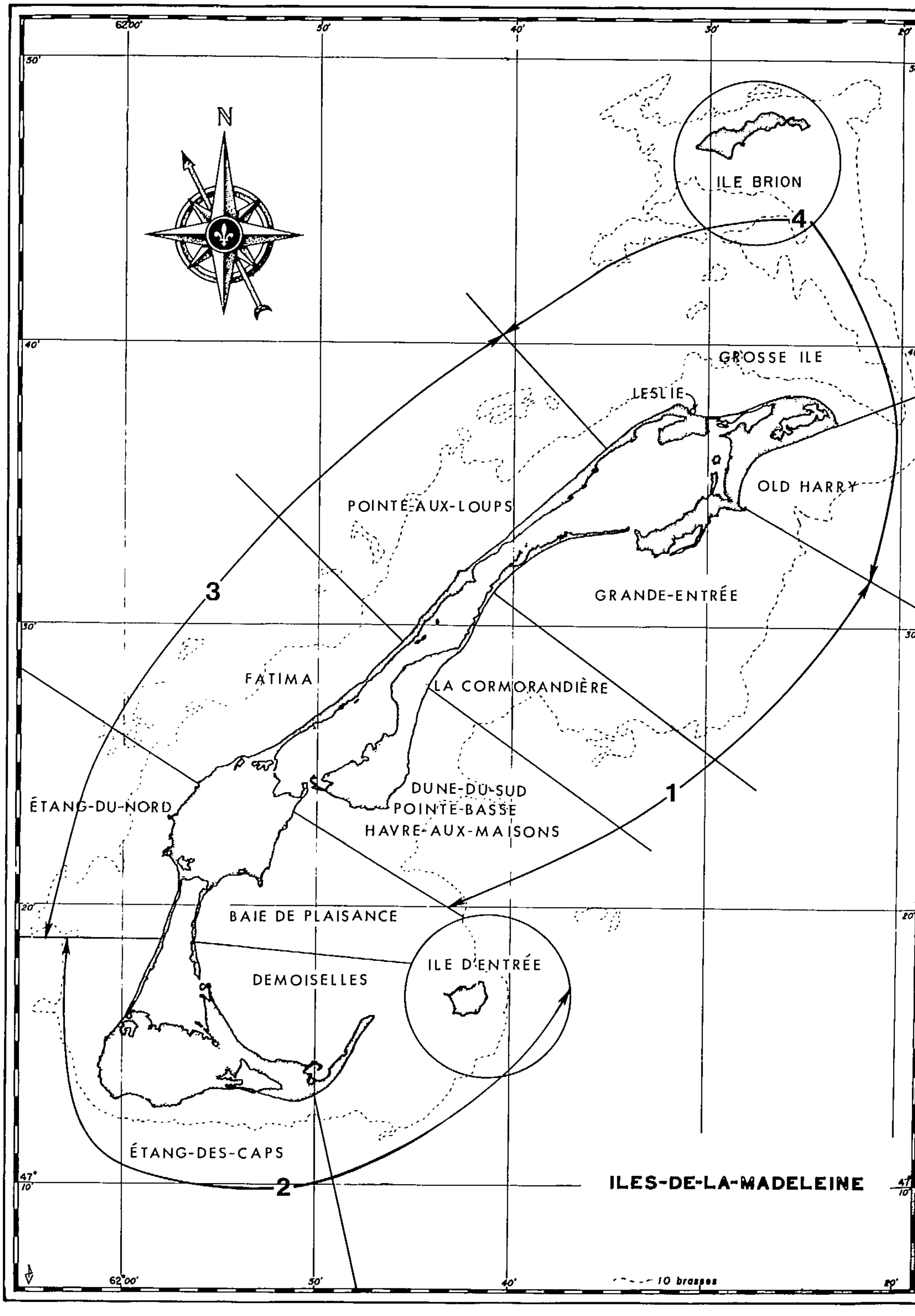

FIG. 2. Carte indiquant les différentes aires de pêche où l'échantillonnage est regroupé (d'après Bergeron 1976b).

Discussion

Le tableau 8 rapporte, pour 1979 et 1980, le pourcentage en poids du homard échantillonné par rapport au total des prises dans les quatre zones illustrées à la figure 2. Bien que ce pourcentage soit faible, le tableau 7 montre que le nombre correspondant de homards mesurés par zone, au cours des saisons de pêche de 1979 et 1980, varie entre 700 et 3 300 individus; les distributions de taille qui en résultent sont, dans la plupart des cas, représentatives pour chacune de ces quatre zones. Cependant, nous avons décidé, à partir de 1982, d'effectuer deux sorties au lieu d'une seule par période, pour chacune des six aires d'échantillonnage identifiées plus haut. La détermination de ces six aires tient compte des différences régionales qu'on observe dans les structures de population et ces aires sont situées dans les zones qui sont les plus importantes en terme de débarquements.

TABLEAU 8. Rapport en poids du homard échantillonné par rapport au homard débarqué dans quatre zones[a] des Îles-de-la-Madeleine en 1979 et 1980.

Année	1979			1980		
Zone	Captures (kg)	Poids échantillonné (kg)	%	Captures (kg)	Poids échantillonné (kg)	%
1	500 495	1 527	0,3	459 445	1 079	0,2
2	347 660	595	0,2	268 651	664	0,2
3	166 038	625	0,4	131 600	402	0,3
4	200 739	344	0,2	166 944	314	0,2

[a]Voir figure 2.

La crevette nordique (*Pandalus borealis*)

Introduction

La pêche à la crevette, *Pandalus borealis*, a débuté en 1965, année qui marque le début de pêches exploratoires qui ont été menées par la Station de Biologie Marine de Grande-Rivière, particulièrement dans la partie nord-ouest du golfe du Saint-Laurent. Suite à ces pêches d'exploration qui se continuèrent en 1966, les débarquements de crevettes au Québec ne cessèrent de croître avec l'implantation à Matane d'une usine de transformation. Deux phases sont bien distinctes dans l'évolution de cette pêcherie au Québec : une période d'accroissement lent de 1965 à 1972, caractérisée par une augmentation constante de l'effort de pêche et du nombre d'unités de pêche, une période d'accroissement rapide de cet effort à partir de 1973, causé par l'ouverture d'une deuxième usine de transformation à Rivière-au-Renard, puis d'une troisième en 1974 à Mingan sur la Côte Nord. Parallèlement à l'augmentation du potentiel de transformation de cette espèce, on note durant cette période une augmentation explosive de l'effort de pêche et des débarquements.

La figure 3 présente les territoires de pêche à la crevette dans le golfe du Saint-Laurent, exploités actuellement par les crevettiers québécois ainsi que les points de débarquements de la crevette au Québec. Historiquement, les crevettiers ont surtout exploité la partie nord-ouest du Golfe (secteur de Sept-Îles) étant donné la situation du seul point de débarquement disponible à Matane. Avec l'apparition d'autres points de débarquements moins éloignés des territoires de l'est du Golfe (chenal d'Anticosti, chenal d'Esquiman), l'augmentation des captures s'est effectuée par l'expansion de l'effort de pêche vers des secteurs non exploités traditionnellement par le Québec; cette situation se réflète bien en 1980, année où l'on observe une diversification importante des secteurs de pêche (fig. 3).

L'importance grandissante des captures de crevettes par le Québec dans le golfe et leurs importances économiques ont justifié la mise en place d'un système d'échantillonnage des captures qui puisse fournir les données nécessaires à la gestion rationnelle de l'exploitation de cette espèce.

Ce système d'échantillonnage a été mis en place dès 1965 par le Gouvernement du Québec et couvre les périodes de 1966 à 1968, et de 1972 à nos jours.

Durant la première période, des échantillons étaient recueillis à intervalles réguliers et traités afin d'analyser la variation annuelle dans la structure du stock et l'évolution du rapport des sexes (Couture 1969).

Buts et méthodes actuels d'échantillonnage

Plusieurs objectifs de recherche justifient cet effort de cueillette de données et sont reliés à un objectif global de gestion des stocks de crevettes présents le long des côtes du Québec.

1) Étude de l'évolution saisonnière des tailles et du rapport des sexes au cours de la pêche commerciale.
2) Identification des groupes d'âge et estimation de leurs abondances par la séparation des classes modales présentes sur les distributions de fréquence de taille.
3) Estimation de la croissance et de la mortalité.
4) Suivi de la composition des captures au cours de la pêche commerciale pour fins d'information aux pêcheurs, producteurs et gestionnaires.

C'est à partir de 1972 que s'est développé un système permanent d'échantillonnage qui au départ consistait à demander aux pêcheurs eux-mêmes de faire l'échantillonnage en mer et qui maintenant est fondé sur un échantillonnage au hasard.

Le système d'échantillonnage utilisé couvre toute la période de pêche d'avril à décembre, période divisée en sous-unités de temps égales (un mois). À l'intérieur de ces périodes mensuelles un effort légal d'échantillonnage est appliqué; pour chacune des usines de transformation, trois échantillons sont prélevés selon un calendrier préétabli. Au total près de 48 échantillons d'environ 300 crevettes sont recueillis chaque année. Suite à l'expansion de l'effort de pêche vers d'autres territoires, des échantillons ont aussi été recueillis pour les secteurs de pêche non traditionnelle.

Pour chacun des échantillons recueillis, les données suivantes sont recueillies : longueur du céphalothorax (0,1 mm près), sexe, maturité sexuelle, nombre de cre-

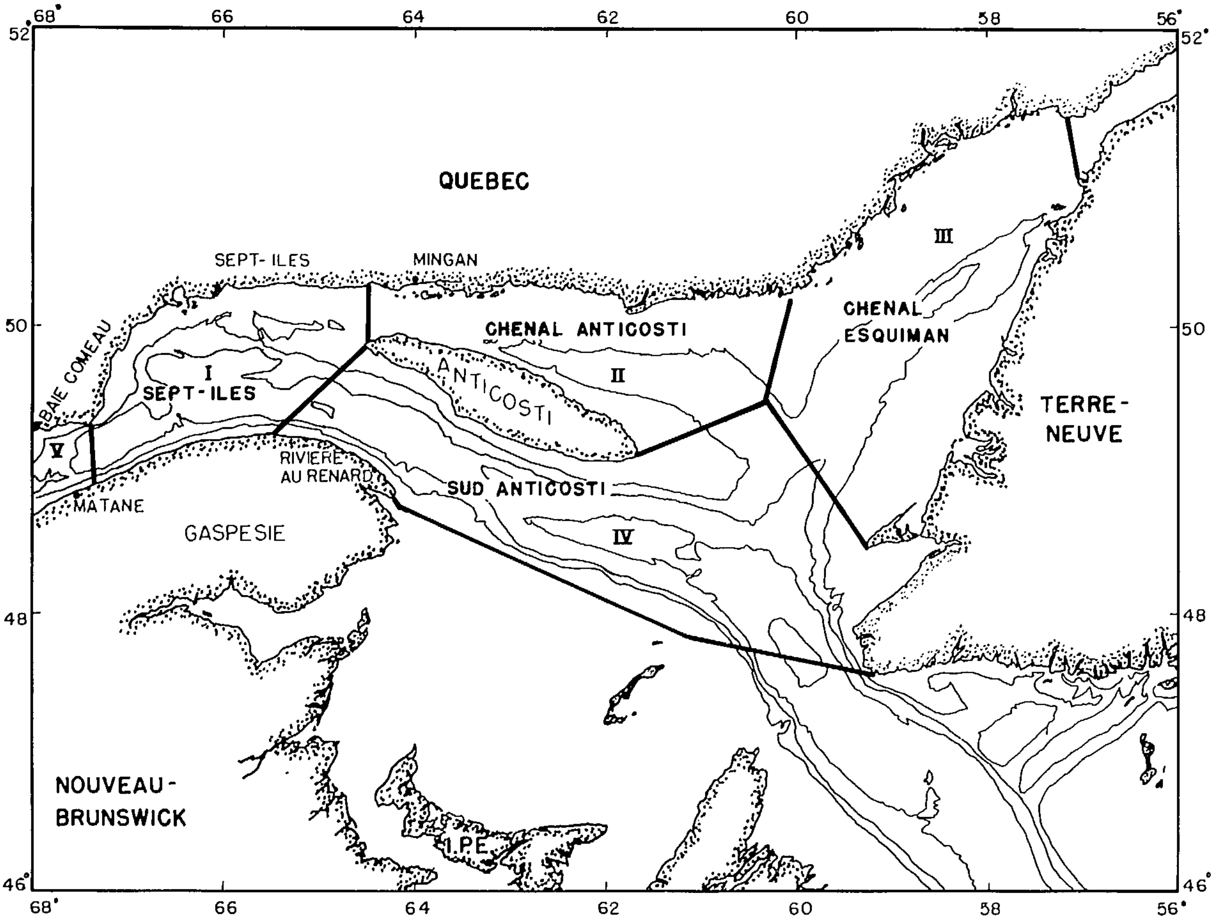

FIG. 3. Limites des différentes zones de pêche de la crevette nordique, visitées par les chalutiers québécois.

vettes et poids de l'échantillon par sexe. La précision de mesure de longueur permet de combiner les données avec différents intervalles de classe; cette possibilité est très importante chez *P. borealis* puisque la détermination de l'âge dépend en dernier ressort de la séparation des classes modales à partir des distributions de fréquences de taille. Le choix possible de différents regroupements des données améliore à ce niveau la mise en évidence des modes.

TECHNIQUES DE STOCKAGE ET DE TRAITEMENT PRIMAIRE

Les distributions de fréquence de taille sont par la suite transformées usuellement en classes de taille de 0,3 mm sur lesquelles une moyenne mobile de 3 est par la suite appliquée. Ce traitement diminue de façon sensible l'importance des pics secondaires et facilite la détermination des classes modales identifiées chez cette espèce comme des groupes d'âge. L'application des méthodes permettant de séparer chacun des groupes d'âge sur les distributions de fréquence de taille constitue la dernière étape du traitement qui nous permet d'acquérir pour chacun des groupes d'âge identifiés, la longueur moyenne ainsi que l'abondance relative de chacun de ceux-ci. Ces abondances estimées permettent la détermination de paramètres biologiques, telle la croissance (Simard et al. 1975).

DISCUSSION

Le tableau 9 présente l'intensité annuelle d'échantillonnage pour la crevette de 1979 à 1981. Parmi les principaux territoires de crevettes du Golfe, l'effort d'échantillon-

TABLEAU 9. Nombre total de crevettes mesurées au débarquement, de 1979 à 1981, pour les principaux territoires de pêche (voir figure 3).

Année	Sept-Îles (I)	Chenal Anticosti (II)	Chenal Esquiman (III)	Sud Anticosti (IV)	Estuaire maritime (V)
1979	11 280	1 072	—	—	—
1980	12 995	4 199	479	—	2593
1981	12 283	4 723	511	201	1838

nage est surtout concentré dans la partie nord-ouest (Secteur de Sept-Îles et le chenal d'Anticosti) où est localisé en majeure partie l'effort de pêche des chalutiers québécois. La nécessité de couvrir toute la saison de pêche justifie l'ampleur d'échantillonnage dans cette région. Il existe en effet, au niveau des stocks de crevettes, des variabilités saisonnières et régionales qui doivent être prises en considération. D'une part, le cycle de reproduction relativement synchrone chez les individus exige que l'échantillonnage s'étende sur toute la saison si un des objectifs est l'étude de ce cycle. D'autre part, face à l'objectif d'étude de l'abondance relative des classes d'âge, les variations observées dans les distributions de fréquences de taille en fonction de la profondeur, du secteur de pêche, du temps et des sites de pêche des pêcheurs, justifient une très bonne couverture spatio-temporelle de l'échantillonnage. Notons de plus, que l'exploitation récente d'autres territoires par les crevettiers, a nécessité une augmentation globale de l'effort d'échantillonnage.

Le système actuel d'échantillonnage rencontre de façon satisfaisante les objectifs. Cependant, l'analyse des données recueillies pose encore des problèmes concrets spécialement face à l'estimation de paramètres biologiques tels la croissance et la mortalité par la pêche. Le principal problème demeure l'interprétation des distributions de fréquences de taille en terme de groupes d'âge; ces distributions provenant d'échantillonnages de prises commerciales présentent parfois des décalages des modes qui rendent très difficile toute cumulation des données. Nos efforts de recherche visent actuellement à solutionner ces problèmes d'analyse.

Les autres espèces

La DRST a effectué dans le cadre de ses programmes de recherche d'autres activités d'échantillonnage de captures commerciales. En particulier, il existe un important programme d'échantillonnage du crabe des neiges, débuté en 1975, et traité par Lamoureux et al. (1983).

Depuis 1979 un échantillonnage mensuel des captures de pétoncle aux Îles-de-la-Madeleine a été mis en place. Il consiste à relever les poids individuels des muscles contenus dans un échantillon d'environ 1 kg par bateau. La distribution de fréquences des poids est convertie en une distribution de fréquences de taille des coquilles à l'aide d'une clef établie à partir d'échantillonnages de recherche. Cet échantillonnage est réparti entre deux gisements distincts. Un des gisements est actuellement mal représenté dans les échantillons, la pêche y étant rare à cause des faibles rendements.

Un échantillonnage des captures commerciales d'anguilles a eu lieu entre 1970 et 1972 dans la région de Québec, en rapport avec la teneur en mercure de ces poissons. Il a été repris depuis 1979 pour essayer de suivre l'évolution de la structure de taille des captures. La récolte d'otolithes entreprise en 1979 a été abandonnée à cause du coût d'achat des anguilles.

Nous échantillonnons aussi depuis 1979 les captures d'esturgeon noir (longueurs) dans la région de Québec. Les captures de cette espèce ont repris récemment après une longue interruption et un changement dans les habitudes de pêche. Ce travail a pour but de vérifier s'il y eut une augmentation de l'abondance, ou si la nouvelle pêche ne s'exerce pas sur un reliquat de la population. Pour la détermination des âges un échantillonnage des pectorales est aussi réalisé depuis 1980 sur cette espèce.

Entre 1959 et 1973 la DRST a régulièrement échantillonné, pour les longueurs, les espèces les plus abondantes dans les captures d'une pêche fixe de type commercial. Cette pêche est installée sur la rive sud du Saint-Laurent à Québec et sert à approvisionner l'aquarium de cette ville.

Conclusion

L'échantillonnage des captures commerciales réalisé actuellement par la province de Québec est articulé suivant deux grands axes :

- un échantillonnage au débarquement couvrant les poissons démersaux et la crevette nordique qui s'effectue dans les principaux ports de débarquements des chalutiers et s'appuie sur le personnel saisonnier mis en place pour la récolte des statistiques d'efforts de pêche.
- un échantillonnage en mer à bord des bateaux de pêche pour le homard et le crabe des neiges (Lamoureux et al. 1983).

Le premier axe représente une bonne solution en ce qui concerne la crevette qui n'est débarquée que par des chalutiers et dont les échantillons, peu encombrants, peuvent être transportés et conservés facilement avant analyse. Par contre, en ce qui concerne les poissons démersaux, il comporte certains défauts. Il y a un échantillonnage insuffisant en début et en fin de saison. La couverture des engins fixes et côtiers débarquant dans des ports secondaires est insuffisante. Le second axe exige une organisation plus complexe et plus lourde. Il faut trouver des embarquements pour les observateurs. Ceci réduit la fréquence et la distribution géographique des échantillons. Par contre, les renseignements recueillis sont plus nombreux et plus complets. En particulier, ils permettent d'avoir des renseignements sur le recrutement sans avoir à organiser des missions onéreuses en mer.

L'échantillonnage des poissons démersaux devrait s'améliorer dans la mesure où le programme de cueillette de données statistiques de la DRST s'oriente maintenant de plus en plus vers la pêche côtière. Cette évolution devrait avoir aussi des conséquences bénéfiques pour l'échantillonnage de captures de hareng dont la problématique est proche de celle de l'échantillonnage des captures de poissons démersaux par les engins côtiers. En 1975 et 1976 des tentatives d'échantillonnage à l'aide d'équipes mobiles ont été faites pour les poissons démersaux. Les difficultés rencontrées pour se trouver le bon jour dans le bon port pour échantillonner le bon engin et la bonne espèce, ont été très grandes. En effet, la base de départ de l'équipe, Québec, était très loin des points de débarquements et les horaires prévus par les usines souvent modifiés. Le développement de laboratoires régionaux pouvant envoyer rapidement une personne pour aider le technicien présent dans le port, devrait permettre l'amélioration de l'échantillonnage au tout début et à la toute fin de la saison de pêche quand les usines traitent très rapidement le poisson débarqué.

Au fur et à mesure que l'expérience des techniciens présents dans les ports s'améliore, on devrait assister à une plus grande implication de leur part dans l'échantillonnage en mer, en particulier pour le crabe des neiges, et ainsi aboutir à une réduction du coût de ce programme.

Pour finir, il nous semble important de souligner sur le plan organisationnel et fonctionnel, l'avantage de la présence dans les lieux de débarquements de techniciens à la fois chargés de récolter des statistiques de pêche suivant des exigences de qualités convenables pour les chercheurs, et de réaliser l'échantillonnage de base au débarquement ou en mer sur des bateaux de pêche. Ils représentent un maillon très important dans les relations entre la recherche et les pêcheurs par le fait qu'ils sont capables, en plus de leurs fonctions principales, de véhiculer rapidement des informations de toute nature dans les deux sens.

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A Review of the Sampling of Snow Crab (*Chionoecetes opilio*) Catches in the Southwestern Gulf of St. Lawrence

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BAILEY, R. F. J. 1983. A review of the sampling of snow crab (*Chionoecetes opilio*) catches in the southwestern Gulf of St. Lawrence, p. 77–81. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publl. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

This paper summarizes the sampling effort and coverage of the New Brunswick snow crab fishery in the southwestern Gulf of St. Lawrence. The results of a 5-yr (1977–81) sampling program are examined in terms of standards set by ICNAF for desirable levels of sampling in a commercial fishery.

BAILEY, R. F. J. 1983. A review of the sampling of snow crab (*Chionoecetes opilio*) catches in the southwestern Gulf of St. Lawrence, p. 77–81. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Ce document donne un aperçu de l'effort et de la couverture d'échantillonnage de la pêcherie au crabe des neiges pratiquée par le Nouveau-Brunswick dans le sud-ouest du Golfe Saint-Laurent. Les résultats de ce programme d'échantillonnage quinquennal (1977–81) sont comparés aux normes établies par la CIPANO pour un niveau souhaitable d'échantillonnage d'une pêcherie commerciale.

Introduction

The exploitation of snow crab (*Chionoecetes opilio*) in the southwestern Gulf of St. Lawrence started in 1967. From a marginal fishery, it has rapidly grown to be one of the most lucrative fishing activities in the area. The resource has always been abundant and management controls have been minimal, aiming at ensuring a sufficient brood stock and the economical viability of the industry.

Fishing effort is limited by a restricted number of fishing licences and a maximum number of traps allowed per boat. There is no closed season or catch limitation, other than limits enforced sometimes by the industry for economical purposes. The catch is thus largely a function of the availability of the resource and of the fishing capacity of the fleet. Only males with a carapace width of 95 mm and more are permitted for landing. Females are smaller than 95 mm and have no commercial value; they are thus totally protected for breeding. Males are all mature at about 70 mm (Watson 1970) and can mate with several females in a season (Watson 1972). Since males are not recruited to the fishery until they reach 95 mm, it is believed that the reproductive potential of the population is virtually unaffected by exploitation. This is confirmed by the observation that nearly all mature females are egg bearing (Bailey, unpublished data).

Growth and recruitment of snow crab are periodic and occur during a molting season, generally in midsummer. Molting results in the appearance in the catch of soft-shell animals which are not suitable for processing. Under the current conditions of intense exploitation and strong recruitment, the high percentage of soft-shell crabs creates a serious seasonal problem for the industry. Consequently, to solve this problem, other management regimes will have to be considered. Suggested alternatives are a summer closed season and a total allowable catch. This last alternative could be based on a crustacean-adapted analytical model and would require good knowledge of growth and of the size composition of snow crab in the catches. Better understanding of the behavior of the size composition with time and area would also allow monitoring of changes in recruitment and exploitation rates.

This paper presents the results of a 5-yr sampling program, from 1977 to 1981, which is a first attempt at compiling information on the size composition of snow crab in New Brunswick commercial catches. Sampling was carried out in the three ports of landing, Shippegan, Lamèque, and Caraquet, all within 30 km of each other. An independent sampling program has also been organized by the Quebec department of fisheries since 1975, covering catches of snow crab made by Quebec fishermen in the southwestern Gulf, and landed in Grande-Rivière, Ste-Thérèse-de-Gaspé and Gascons on the Gaspé Peninsula, and in the Magdalen Islands. Information on this program was presented at this workshop (Lamoureux et al. 1983).

Materials and Methods

The exploited population of snow crab is distributed from Chaleur Bay to the Magdalen Islands, and is restricted by the deep Laurentian Channel to the north (Fig. 1). Snow crabs prefer muddy substrates where the

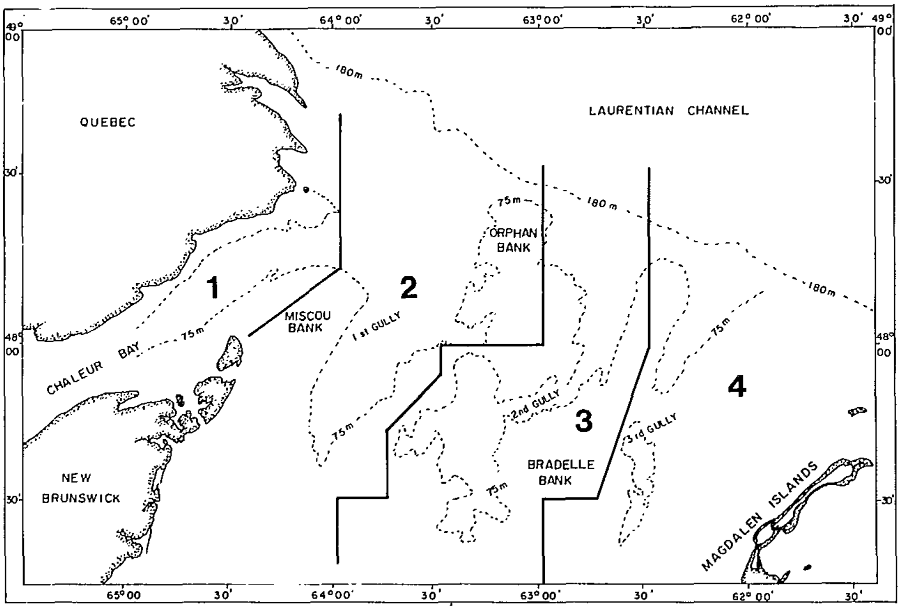

Fig. 1. Subdivision of snow crab fishing grounds in the southwestern Gulf of St. Lawrence into four subareas.

temperature is generally less than 2°C year long. In the southwestern Gulf, most of the ocean floor deeper than 75 m is a suitable habitat. As a result, the distribution of the stock, and consequently that of the fishing effort, is subdivided into four subareas. The first subarea is Chaleur Bay, partially isolated from the next subarea by Miscou Bank. The three other subareas are deepwater gullies separated by Orphan Bank and Bradelle Bank.

Boats from New Brunswick and Québec participate in the fishery. The fleet has more than 100 units, of which 77 were registered and landing in New Brunswick in 1980 and 1981. The major portion of the landings are made in that province although Québec increased its share from 21% in 1977 to 29% in 1980. Most Gaspé fishermen fish in Chaleur Bay and in the first gully, while New Brunswick fishermen fish mostly in the three gullies, and Magdalen Islands fishermen fish the gully near their islands.

The fishing season usually starts in April, when ice conditions permit, and finishes in October–November, depending on resource abundance and weather conditions. The fishing trips are 1 or 2 d long, three in a week on the average, for a potential of some 75 trips per boat per season. This means that approximately 5775 individual landings of snow crab can be made in New Brunswick during a season.

Some sampling of the catches was done at sea on commercial boats, but most of the effort was concentrated onshore. Allocation of sampling effort among the three ports of landing was roughly on the basis of the volume landed in each one. More effort was put in Shippegan than in Lamèque and Caraquet where fewer boats are landing. Fishing area is generally independent of the port of landing.

Once samplers were in a given port, they selected a processing plant from those where boats were waiting to unload. This selection was based on several factors such as the number of boats waiting at each plant, their relative importance in terms of production, and the latest date of previous sampling. Usually, two or three boats could be sampled in a day from that particular plant. The following day, a different plant was selected, sometimes in a different port.

Three types of sample were collected in port and one type at sea. This last type of sample consisted in measuring all individuals of both sexes from individual traps, noting the maturity stage of females. This was repeated for several traps hauled during a fishing trip. The first type of port sample was done for size measurements only. It consisted of two or three boxes (approx. 30 kg or 70 crabs each) selected randomly as a boat catch was unloaded. The sampling team usually tried to get one box from the beginning, middle, and end of a load. The second type of port sample was taken for size and shell hardness, an index of the molting stage of the crabs. These samples consisted of 50 individuals taken from a randomly selected box in a crab load. To establish size–weight relationships, a few samples of a third type were measured for individual size and weight.

To estimate the level of precision achieved by different efforts of sampling, the average percent frequency and the coefficient of variation of the average frequency in different size-classes were calculated with different numbers of samples. The samples came from subarea 3

TABLE 1. Monthly landings and sampling effort of the New Brunswick snow crab fishery from 1977 to 1981.

Year	Month	Landings (*t*)	No. of samples of each type[a] 1	2	3	4	No. of samples[b] per 1000 t landed	No. of individuals per sample[b]
1977	April	2	0	0	0	0	0	—
	May	457	1	1	0	0	2.2	242.0
	June	2 122	12	9	0	15	5.7	246.8
	July	2 062	32	31	0	14	15.5	236.2
	August	1 869	36	36	0	52	19.3	265.1
	September	756	11	11	0	33	14.6	251.6
	October	71	2	1	0	0	28.2	241.0
	November	2	0	0	0	0	0	—
	Total	7 331	94	89	0	114	12.8	250.6
1978	May	977	11	10	1	0	11.3	181.3
	June	2 405	9	8	1	0	3.7	204.6
	July	2 239	0	0	0	0	0	—
	August	1 467	5	0	5	0	3.4	108.0
	September	421	0	0	0	0	0	—
	October	422	0	0	0	0	0	—
	November	4	0	0	0	0	0	—
	Total	7 935	25	18	7	0	3.2	175.0
1979	April	14	0	0	0	0	0	—
	May	1 289	0	0	0	0	0	—
	June	2 202	0	0	0	0	0	—
	July	2 809	8	8	0	0	2.8	186.9
	August	2 673	4	4	0	0	1.5	204.8
	September	1 457	0	0	0	0	0	—
	October	498	0	0	0	0	0	—
	November	8	0	0	0	0	0	—
	Total	10 950	12	12	0	0	1.1	192.8
1980	April	19	0	0	0	0	0	—
	May	3 037	46	46	6	0	15.1	224.4
	June	3 259	31	31	7	18	9.5	247.0
	July	2 125	40	40	4	1	18.8	210.6
	August	1 154	32	32	0	0	27.7	170.9
	September	290	0	0	0	0	0	—
	October	107	0	0	0	0	0	—
	November	3	0	0	0	0	0	—
	Total	9 994	149	149	17	19	14.9	213.9
1981	April	1 716	0	0	0	0	0	—
	May	4 749	5	4	0	0	1.1	243.2
	June	3 977	34	34	0	4	8.5	177.6
	July	1 738	16	16	0	9	9.2	256.9
	August	715	2	2	0	0	2.8	223.5
	September	382	0	0	0	0	0	—
	October	390	0	0	0	0	0	—
	Total	13 667	57	56	0	0	4.2	207.2

[a]Type 1 are samples for size only; type 2 are samples for size and shell hardness; type 3 are samples for size and weight; and type 4 are individual traps sampled at sea.
[b]Samples of types 1 and 2 only; combined when coming from the same load of crabs.

(Fig. 1) only, and the calculations were made on two series of 20 samples collected in May 1980 and June 1981. The calculations were first made with five samples selected randomly, then recalculated with five more samples for a total of 10. The procedure was repeated with 15 and 20 samples. The coefficients were calculated as:

$$\text{C.V.} = s_{\bar{x}} / \bar{x}$$

where $\bar{x}$ is the average percent frequency in a size-class, and $s_{\bar{x}}$ is its standard error.

Results

The landings were generally sampled intensively from May to August in all years, except for July 1978 and May–June 1979 (Table 1). April and September–November landings were not sampled from 1978 to 1981; they were usually low compared to the summer landings. On a monthly basis, only 0.06% of the landings (those of April and November) were not sampled in 1977, while 38.9% in 1978, 50.0% in 1979, 4.2% in 1980, and 18.2% in 1981 were not. In 1977, 0.14% of all crabs landed in New Brunswick were sampled. This is estimated from the average weight of a crab (443 g) multiplied by the total number of individuals measured during the year, and compared to the total landings. Similar calculations give a level of sampling for all individuals landed of 0.02% in 1978, 0.01% in 1979, 0.14% in 1980, and 0.04% in 1981.

The annual averages of sample size ranged from 175 to 251 individuals (Table 1), after combination of type 1 and 2 samples taken from the same loads. In each year, an average of more than one sample for every 1000 t landed was taken. In each month since 1977, when landings were sampled, more than one sample per 1000 t were taken. As mentioned above, not all months in which there were landings have been sampled. For instance, in July 1978, in May, June, and September 1979, and in April 1981, more than 1000 t of crabs were landed without a sample taken.

There is a general reduction in the coefficients of variation of the average percent frequencies in the size-classes as the sample number increases from 5 to 20 (Table 2). With a sample number of 15, a coefficient of variation (C.V.) of 0.13 or less is obtained for all legal size-classes ≤ 120 mm. With a number of 20 samples, the maximum C.V. is only reduced to 0.11 for the same size range. Over 96% of all crabs were smaller than this size in the last 2 yr.

Discussion

The series of data obtained from this sampling program is the first information collected on snow crab size composition in the southwestern Gulf of St. Lawrence on such spatial and time scales. Except for the data of Lamoureux et al. (1983), earlier sampling of snow crab was restricted to a few thousand individuals measured during the summer in the late 1960s (Powles

TABLE 2. Average frequencies ($\bar{x}$) in percentages and their coefficients of variation (ratio of standard error on the average) for different cumulative numbers of samples, randomly selected from subarea 3 (Fig. 1).

Size-class (mm)		May 1980 No. of samples				June 1981 No. of samples			
		5	10	15	20	5	10	15	20
90–94	$\bar{x}$	17.8	16.2	14.8	13.3	9.7	10.4	9.2	8.5
	C.V.	0.08	0.10	0.09	0.09	0.24	0.18	0.18	0.17
95–99	$\bar{x}$	31.0	29.9	27.1	26.1	23.5	24.7	24.9	23.5
	C.V.	0.09	0.07	0.06	0.06	0.12	0.07	0.08	0.07
100–104	$\bar{x}$	26.7	25.6	26.3	27.3	28.8	28.9	28.1	29.5
	C.V.	0.08	0.05	0.04	0.04	0.07	0.05	0.05	0.04
105–109	$\bar{x}$	14.5	17.4	18.9	19.5	20.9	19.0	19.9	19.7
	C.V.	0.12	0.13	0.09	0.07	0.09	0.10	0.09	0.07
110–114	$\bar{x}$	5.3	5.7	6.6	7.3	9.3	9.2	10.0	10.6
	C.V.	0.22	0.11	0.09	0.07	0.20	0.10	0.12	0.10
115–119	$\bar{x}$	2.7	2.8	3.1	3.2	4.1	4.4	4.4	4.7
	C.V.	0.27	0.20	0.13	0.10	0.25	0.13	0.10	0.11
120–124	$\bar{x}$	1.3	1.6	2.1	2.2	1.7	1.9	2.2	2.3
	C.V.	0.52	0.24	0.18	0.14	0.37	0.20	0.14	0.16
125–129	$\bar{x}$	0.4	0.4	0.6	0.8	1.6	1.2	1.2	1.1
	C.V.	0.45	0.40	0.30	0.22	0.42	0.32	0.26	0.22
130+	$\bar{x}$	0.4	0.4	0.4	0.3	0.2	0.1	0.2	0.2
	C.V.	1.01	0.55	0.39	0.37	0.89	0.95	0.39	0.34

1968; Watson 1969; Watson and Simpson 1969), and in July 1975 (Stasko 1975). In this last study, 20 samples of 200 crabs were taken. The results indicated a general reduction in the relative abundance of the larger crabs in the catches of 1975, compared to those of the late 1960s.

The effort levels of sampling in this snow crab fishery are comparable to the minimum level suggested by ICNAF (Anon. 1974). The recommendation was that one sample of 200 individuals be measured for every 1000 t landed in a quarter of a year. The sample size was generally above 200 individuals except in 1978 and 1979 when sampling effort was reduced throughout the year. Although, on the average of a fishing season, more than one sample for every 1000 t landed was taken, the sampling effort was often lacking, particularly in the fall. This is because the summer students, who are responsible for most of the sampling, are not available at that time, and regular staff is usually tied up with other duties. In every year, the work was done by only one sampling team and the results of 1980 are indicative of the maximum number of samples that can be collected in one month.

The ICNAF working group on minimum and desirable levels of sampling also tentatively stated that a C.V. of 10% would be satisfactory for data used in the analytical assessments of stocks (Anon. 1974). This would probably be achieved for the most important size-classes (95–120 mm) with approximately 20 samples.

The 90–94-mm size-class is partially recruited. Variable culling practices by fishermen at sea explain the relatively higher variability of their percent frequencies in the size distributions.

Besides its potential usefulness in assessing the value of analytical models, these data serve other short-term goals. For instance, it helps to evaluate the size selectivity of the fishing fleet and its accordance with the size regulation, which cannot be strictly enforced in practice. In the past few years, it has also indicated that the catches were based mainly on one molt class, which was probably composed of not many more year-classes, indicating that the fishery was heavily dependent on new recruits. Finally, the results of the sampling can be useful to the industry, for the interpretation of their production trends. Smaller crabs are processed less efficiently and are not as attractive for the claws and legs market.

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The Commercial Catch Sampling Program in the Northeastern United States

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A review of the commercial finfish and shellfish biological sampling program for the northwest Atlantic is presented. A historical overview of the program is discussed briefly, and a description of the program in terms of manpower, problems encountered in sampling, and the general systems and techniques used is given, with specific sampling requirements for some selected species. A 4 yr review (1977–80) of biological sampling is presented. Results indicate that sampling for some species may be adequate, based on the ICNAF standard of one sample per 1000 t per ICNAF division, gear type, and calendar quarter. However, even for those species in which overall sampling appears adequate, deficiencies probably exist on a gear, stock-area basis.

BURNS, T. S., R. SCHULTZ, AND B. E. BROWN. 1983. The commercial catch sampling program in the northeastern United States, p. 82–95. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/ L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Le présent rapport examine le programme d'échantillonnage biologique des États-Unis pour les pêcheries commerciales de poissons, de mollusques et de crustacés dans l'Atlantique nord-ouest. On y élabore brièvement la genèse du programme, et sa description en termes d'effectifs, de problèmes rencontrés au cours de l'échantillonnage, et de techniques et systèmes généraux, est présentée, en plus des exigences précises d'échantillonnage pour quelques espèces choisies. On présente aussi un examen de l'échantillonnage biologique portant sur quatre ans (de 1977 à 1980). Les résultats montrent que l'échantillonnage de certaines espèces peut être adéquat d'après la norme de la CIPANO d'un échantillon par 1000 t par division de la CIPANO, par trimestre et pour chaque type d'engin. Toutefois, même pour les espèces dont l'échantillonnage global semble suffisant, des lacunes existent probablement en ce qu'il a trait à l'échantillonnage des prises par certains engins dans certaines régions.

Introduction

PURPOSE OF SAMPLING REGARDING ASSESSMENTS

Biological assessments of any fisheries resource require continuous time series of certain basic information. The same types of data are needed regardless of the species assessed. Basic types of data considered necessary for a minimal biological assessment are: (1) landings, (2) fishing effort, and (3) biological samples (length frequencies, age, and sex) taken from commercial landings (nominal catches). Such data are currently being collected to varying degrees for finfish and shellfish from Maine to Virginia using State and Federal data collection systems. Special studies (independent surveys, sea sampling, and special research projects) are also necessary for estimates of population parameters such as juvenile growth rates, size at maturity, and prerecruit indices required in assessments.

In the United States, the responsibility for marine fisheries falls within the Department of Commerce in the National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS). Within NMFS, the responsibility for assessments in the northeast lies with the Northeast Fisheries Center (NEFC) and its Division of Resource Assessments. The Statistics Investigation of the Resource Assessment Division collects the necessary biological data for assessments.

HISTORICAL OVERVIEW OF THE U.S. SAMPLING PROGRAM IN THE NORTHWEST ATLANTIC

The present U.S. sampling program originated from the haddock sampling program of the 1930s. Sampling areas were defined based on the fishing areas for haddock (Rounsefell 1948), and samples were collected from major ports. This initial sampling program was gradually expanded in the 1940s and 1950s to include other species such as redfish, yellowtail flounder, and silver hake (see Table A1 for a listing of common and scientific names). During this period, port samplers were assigned to the major ports of landing. Sampling activities to obtain biological data such as length frequencies, age structures, sex, fecundity, and fishing effort by area were directed by the biologist with lead responsibility for the species in question, e.g. redfish. When the program was expanded in the 1960s to include more ports, species, and areas, it became necessary to modify the species approach. As a

TABLE A1. A list of common and scientific names of fish and shellfish presented in this paper.

Common name	Scientific name	Common name	Scientific name
Alewife	*Alosa pseudoharengus*	Ocean quahog	*Artica islandica*
American lobster	*Homarus americanus*	Pollock	*Pollachius virens*
American plaice (dab)	*Hippoglossoides platessoides*	Red crab	*Geryon quinquedens*
American shad	*Alosa sapidissima*	Red hake	*Urophycis chuss*
Atlantic cod	*Gadus morhua*	Redfish	*Sebastes marinus*
Atlantic herring	*Clupea harengus*	Rock crab	*Cancer irroratus*
Atlantic mackerel	*Scomber scombrus*	Sculpin uncl.	*Cottidae uncl.*
Atlantic menhaden	*Brevoortia tyrannus*	Scup (porgy)	*Stenotomus chrysops*
Atlantic wolffish	*Anarhichas lupus*	Sea scallop	*Placopecten magelanicus*
Barndoor skate	*Raja laevis*	Searobin uncl.	*Triglidae uncl.*
Black sea bass (sea bass)	*Centropristis striata*	Short-finned squid	*Illex illecebrosus*
Blueback herring	*Alosa aestivalis*	Silver hake (whiting)	*Merluccius bilinearis*
Bluefish	*Pomatomus saltatrix*	Skate uncl.	*Raja sp.*
Butterfish	*Peprilus triacanthus*	Spiny dogfish	*Squalus acanthias*
Conchs	*Busycon, strombus sp.*	Striped bass	*Morone saxatilis*
Cunner	*Tautogolabrus adspersus*	Summer flounder (fluke)	*Paralichthys dentatus*
Cusk	*Brosme brosme*	Surf clam	*Spisula solidissima*
Fourspot flounder	*Paralichthys oblongus*	Tautog	*Tautoga onitis*
Goosefish	*Lophius americanus*	Tilefish	*Lopholatilus chamaeleonticeps*
Gulf Stream flounder	*Citharichthys arctifrons*	Weakfish	*Cynoscion regalis*
Haddock	*Melanogrammus aeglefinus*	White hake	*Urophycis tenuis*
Jonah crab	*Cancer borealis*	Windowpane	*Scophthalmus aquosus*
Little skate	*Raja erinacea*	Winter flounder (blackback, lemon sole)	*Pseudopleuronectes americanus*
Long-finned squid	*Loligo pealei*	Winter skate	*Raja ocellata*
Northern kingfish (king whiting)	*Menticirrhus saxatilis*	Witch flounder (grey sole)	*Glyptocephalus cynoglossus*
Northern puffer	*Sphoeroides maculatus*	Yellowtail founder	*Limanda ferruginea*
Northern shrimp	*Pandalus borealis*		
Ocean pout	*Macrozoarces americanus*		

result, the port agents responsible for collecting statistical data and port samplers (responsible for sampling) were combined to form "port pools." Under the port pool system, which is currently in effect, the port agent is responsible for the collection of landings data, biological samples, fishing effort, and area fished information for all species landed in the port. Figure 1 shows the present statistical areas for sampling and port sampling locations in the northeast region.

Biological sampling efforts in recent years have been augmented under contract sampling by state agencies (Maine, Rhode Island, and Massachusetts), educational institutions (Southern Maine Vocational Technical Institute and Hampton Institute), and cooperative agreements with state agencies (Maine and Massachusetts). In some cases, state agencies take responsibility for collecting statistics, thus releasing NEFC employees for sampling efforts.

General Sampling Considerations

PORT VARIABILITY AND VARIETY OF LANDINGS WITHIN PORTS

In the northeast region, the National Marine Fisheries Service has 19 port pool offices (Fig. 1) located in 10 states from Maine to Virginia covering 21 major ports or port areas. The relative importance of ports in terms of total tonnage landed dictates office location. With such a wide geographic range covered by the program, there are substantial port differences. Ports can be broadly classified into a few major categories as follows: auction, nonauction, multiday trip, day trip, and geographically restricted or dispersed ports or port areas. Table 1 presents the major port and port areas in the northeast region covered by our census of landings and sampling program, and broadly defines the type of port. All of the ports with the exception of Boston and New Bedford are nonauction, and fish are handled by brokers or are purchased directly by dealers or buyers. In the auction ports, vessel operators hail the catch on an auction board and dealers competitively bid on the fish. Biological sampling is more readily accomplished in the auction ports. Since the captains are localized at the auction, more information may be collected in a short period giving the port agent adequate time for sampling. In nonauction ports such as Gloucester and Portland, vessels off-load at numerous dealers around the port, and the port agent has to make daily rounds to the various dealers to obtain catch area information. By the time the rounds have been completed and all vessels contacted, the fish may have already been unloaded and shipped or processed.

Sampling is even more difficult in ports or port areas that are geographically dispersed. Maine, with its long coastline and numerous small ports, limits sampling opportunity by geography alone. Sometimes the agent finds a vessel unloading a species of interest; if the captain consents, the dealer cooperates, and sufficient time for sampling is available, a sample can be taken.

Sampling in ports with a high percentage of day trip

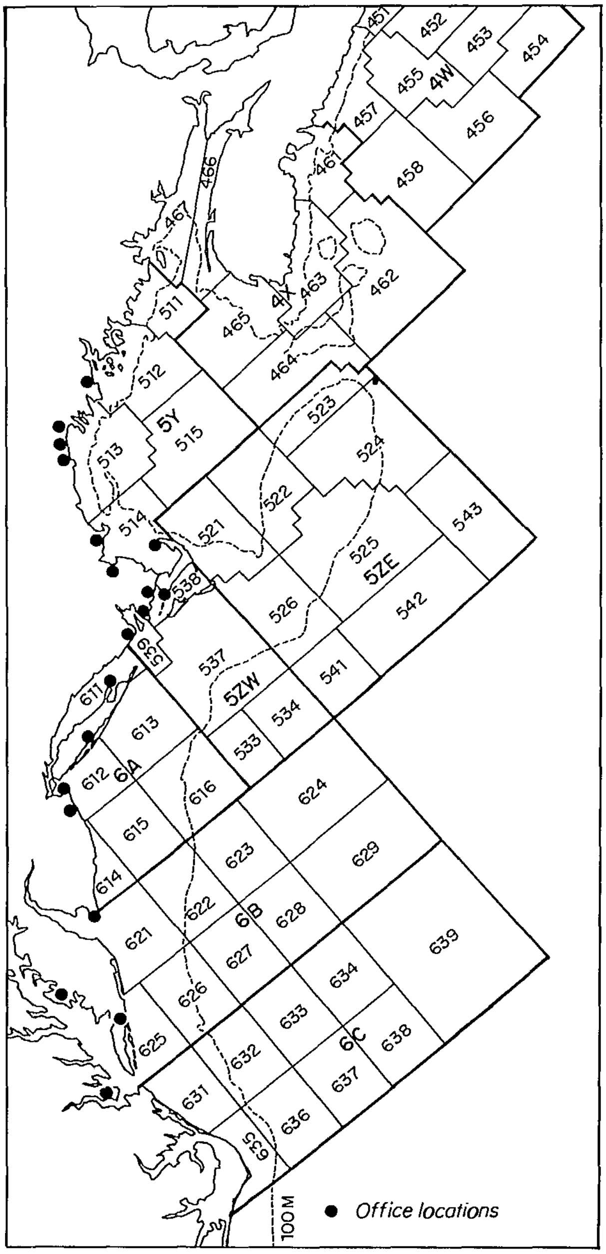


FIG. 1. Fisheries statistical areas (451–639), ICNAF areas (4W-6C), and northeast regional office locations.

vessels also poses problems. Besides the obstacles previously discussed, catches of day trip vessels are usually small making it difficult to obtain a sample before the fish are loaded on a truck and shipped. Also the vessels usually land in the late afternoon or evening and working hours must be flexible enough to cover these situations.

Species composition — There are nearly 100 species of fish and shellfish landed commercially in the area of coverage (Fig. 1). Thus, a priority list was developed in 1975 (Table 2) to assist the port sampler in deciding which species to sample. The order of importance given in this list was superseded when Atlantic cod, haddock, yellowtail flounder, Atlantic herring, squid, Atlantic mackerel, and butterfish came under management and took top priority. Other than those species mentioned above the list still remains useful.

As opportunities for sampling vary due to seasonality and other factors, assessment biologists must depend on samplers to order priorities carefully. It is hoped that by careful monitoring of landings and sampling progress, inadequacy of sampling can be determined before it is too late to correct.

TYPES OF GEAR

About 40 different types of gear are used for capturing fish in the northeast region. The most important gears include: otter trawl, long line, gill net, purse seine, scallop dredge, clam dredge, stop seine, pound net, lobster pots, and weirs. Table 3 presents the major gear types and the fraction of the landings taken by a particular gear for sampled species in 1980. Results show that otter trawlers land the largest portion of the commercial catch for most finfish (except Atlantic herring, Atlantic mackerel, bluefish, weakfish, and tilefish). Consequently, sampling is concentrated in the otter trawl fishery. However, in recent years, the Atlantic cod and pollock fishery has shifted towards gill nets. The average fraction of gillnet landings over all areas for cod and pollock is 0.16 and 0.33, respectively. As gillnet landings occur primarily in the Gulf of Maine, the percentage contribution is higher if only that area is considered. Such changes in gear used can cause assessment problems unless port agents alter sampling procedures to reflect the gear shift. Therefore, it is important that a fishery be monitored closely with respect to gears employed so that adjustments in sampling can be implemented on a timely basis.

MARKET CATEGORIES AND CULLING

Many species of fish are separated (culled) into size groups or market categories at sea or as the fish are unloaded at the dock. Culling is generally a result of economic considerations as price differences exist for different size groups of fish.

During periods of scarcity the number of culls or market categories (size groups) increases because of supply and demand and changing market conditions. Conversely, during periods of abundance for a given species, the number of categories may decline. Figure 2 shows the standard landings forms with species and market category designations used for recording purposes. In some cases the dealers have additional market categories not included on the form. For example, a dealer may include a market category of regular winter flounder, which is intermediate between large and small. If this occurs, the port agent must make a judgment on whether to add the regular category into the large or small

TABLE 1. Ports and major port areas, with the number of trips, interviews or logs collected for the northeast region of the United States, 1980.

Port or area	State	Multiday trip vessels[c] Trips	Multiday trip vessels[c] Interviews or logs	Day trip vessels[d] Trips	Day trip vessels[d] Interviews or logs	Types of port[e]		Office
Eastport[a]	ME	—	—	—	—	nonauction	dispersed	yes
Rockland	ME	506	396	534	47	nonauction	restricted	yes
Port Clyde Area	ME	7	4	349	10	nonauction	dispersed	no
Boothbay Harbor[a]	ME	—	—	—	—	nonauction	dispersed	yes
Portland	ME	863	315	3720	134	nonauction	restricted	yes
York	ME	0	0	3173	2	nonauction	dispersed	no
Gloucester	MA	2043	1348	9688	1290	nonauction	restricted	yes
Boston	MA	894	641	0	0	auction	restricted	yes
Plymouth and Cape	MA	481	251	2573	131	nonauction	dispersed	no
Provincetown	MA	697	306	3642	304	nonauction	restricted	yes
Chatham	MA	0	0	3413	0	nonauction	restricted	no
New Bedford	MA	3444	3235	0	0	auction	restricted	yes
Newport	RI	2070	984	724	0	nonauction	restricted	yes
Pt. Judith	RI	1456	495	3733	774	nonauction	restricted	yes
Greenport	NY	370	157	1853	258	nonauction	dispersed	yes
Patchogue[b]	NY	—	—	—	—	nonauction	dispersed	yes
Pt. Pleasant	NJ	284	74	1631	300	nonauction	restricted	yes
Cape May	NJ	1175	240	5099	342	nonauction	restricted	yes
Ocean City	MD	209	97	3273	264	nonauction	dispersed	yes
Chincoteague	VA	172	68	1583	87	nonauction	dispersed	yes
Hampton	VA	2068	614	0	0	nonauction	dispersed	yes

[a]Eastport and Boothbay Harbor are areas where NMFS employs only contract personnel primarily for herring sampling.
[b]Trips and interviews for Patchogue are included under Greenport.
[c]Multiday trip — vessels that fish more than 1 d.
[d]Day trip — vessels that fish during the day and return to port at night.
[e]Type of port — nonauction: fish sold to dealers or brokers; auction: fish sold by bidding process; restricted: port activities geographically confined to port; dispersed: port activities cover a wide geographic area.

market category for winter flounder. The decision is usually based on price, when samples are available. Alternatively, it may be decided that there is a need to add a new market category. Market categories may shift according to market conditions. For example, when haddock were scarce, snapper haddock were upgraded and called scrod. This shifting of categories can also occur on a seasonal basis within a port. Large summer flounder could be upgraded to jumbo on a seasonal basis depending on abundance. Another problem involves between port variability in market categories, that is, large winter flounder in one port may be classified as regular in another port.

If culling is done ashore, every effort is made to obtain samples prior to unloading; otherwise it is necessary to sample each market category in order to obtain representative length frequencies and age data. An alternative approach would be to sample the catch at sea, which would then include discards as well. NMFS has conducted sea sampling on occasion, but budget and staffing restrictions have generally precluded large-scale activities.

DEALER LIMITATIONS

Nearly all biological sampling is accomplished at the discretion of the dealers. Without their cooperation it would be virtually impossible to sample. Therefore, it is essential that port samplers maintain a good working relationship with the dealers and integrate their sampling into the unloading and processing lines without hindering operations.

Occasionally, due to unloading practices, processing or dealer requests, it becomes necessary to sample fish frames (skeletons) after processing. This works well for flat fish and fairly well for groundfish despite the problem of skeletal sag which can be overcome to some extent by lifting the sag out of the frame when measuring.

Another limitation placed on port samplers involves the boxing of fish. Many dealers pack the fish in boxes and transfer them to a truck for immediate shipment. Under these circumstances, sampling operations may restrict shipment and irritate the dealer. Attempts to sample fish from large trips have been made to allow more time between unloading and shipping.

Many times fish are shipped to market in the round (live weight) which prohibits extraction of otoliths or sexing the fish. If the fish have been gutted and gilled, the dealers generally do not object to otoliths being removed through the gill chamber rather than the top of the head.

A common method of landing fish on Long Island, NY, is consignment shipping in which a trucker or handler merely acts as a point of transfer. Fish are packed in boxes aboard the fishing vessel, transferred through the shipper to a truck and shipped, with the shipper taking a handling fee for each box. In such situations, biological sampling is impossible without purchasing a box.

TABLE 2. Sampling priorities and species responsibilities by port or port area for the northeast region.

Species	Eastport	Rockland	Portland	Gloucester	Boston	Provincetown	Cape area	New Bedford	Newport	Pt. Judith	Long Island	Pt. Pleasant	Cape May	E. Shore	Hampton
Atlantic cod		5	6	8	7	8		7			8	6			
Haddock				9	2			8							
Pollock				10	3										
Redfish		1	1	3	4										
Silver hake		6	2	2						8		5	5		
Yellowtail flounder						2		1	1	6	2				
American plaice								4	3						
Witch flounder			7					5	4						
Winter flounder							3	6	5						
Summer flounder						5	6			7	4	3		2	4
Scup						6	7			9	5			3	5
Butterfish						7	8			10	6			4	6
Atlantic herring	1		4	1		3	2			4					10
Atlantic mackerel	2	3		6		4	5			5	9				
Black sea bass												7	3		
Striped bass															11
Bluefish											2	1	3		
Tilefish												8	6		
Blueback herring															9
Weakfish															8
Squid				5	6	1	9		6	3	7	4	4	5	7
American lobster, crabs					5		1	9	2	2	1	2	2		1
Northern shrimp	3	2	3	4											
Sea scallops								2							2
Surf clams, Ocean quahogs											10	1	1	1	3
Industrial								3		1	3				

NOTE: These priorities are intended as a guide to aid in decision making when confronted with a choice. If a species is not referred to as a priority item for a particular port, it does not mean it should be ignored. Complete coverage of all fisheries is needed. Priorities may have to be shifted when there are seasonal changes in fisheries. When this occurs each field station will be expected to adjust accordingly. Species priorities are ranked from 1 (high) to 11 (low).

LANDING AND UNLOADING TECHNIQUES

Further variations in sampling procedures are required because unloading practices differ by port and by dealers within ports. For some ports, fish are placed in baskets and then dumped onto a chute which enters the processing plant directly. In this case the port agent scoops every fifth fish independent of size from the chute until sufficient fish are taken to complete the sample. (By selecting every fifth fish some random distribution is assured.)

In some ports, unsorted or sorted fish are dumped from the unloading basket into carts, barrels, or large boxes (500–1000 lb). Fish are then randomly selected from three or more containers until the required sample is collected.

In processing plants where fish are dumped into bins or floor piles for later processing, agents are instructed to use a scoop-shovel to collect fish from three or more points in the pile or bins, until sufficient fish are obtained for the sample.

The most common unloading procedure involves transfer from the vessel to shore in small containers or boxes (50–125 lb) or sorting from a chute. Since it is usually impossible to sample before culling, each market category has to be sampled. All fish in one box (market category) are sampled unless the number of fish is not sufficient to complete a sample. Then, two or more boxes of fish are entirely measured until sufficient numbers have been taken to complete the sample. Because of the size of some culls (large cod), 10 to 15 boxes may have to be measured.

At times, sampling of the fish is necessary at the sorting table or cutting line. In this case every fifth fish is again selected until the required number of fish has been measured to complete the sample.

NOAA FORM 88-30 (1-73) U. S. DEPARTMENT OF COMMERCE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION — FORM APPROVED: O.M.B.NO. 41-R2596

PURCHASES FROM FISHING VESSELS (Northeast)

DEALER					DATE
NAME OF VESSEL					VESSEL NUMBER
PORT CODE	COUNTY CODE	DATE SAILED	DATE LANDED	GEAR	GROUNDS
DAYS ABSENT	DAYS FISHED	TRIPS	LOG/INTERVIEW		DEPTH
PRORATE	FISHING ZONE	A	B	C	D

SPECIES AND GRADE		CODE	POUNDS LANDED	PRICE PER POUND	SUBTOTAL DOLLARS	CENTS
COD	Large	0811				
	Market	0813				
	Scrod	0814				
CUSK		0960				
HADDOCK	Large	1470				
	Scrod	1475				
HAKE	Red	1520				
	White	1530				
OCEAN PERCH	(Red fish)	2400				
POLLOCK		2691				
WHITING	Round	5090				
	Dressed	5093				
WOLFISH (Catfish)		5120				
GREY SOLE	Large	1221				
	Small	1222				
LEMON SOLE		1201				
YELLOWTAIL	Large	1231				
	Small	1232				
BLACKBACK	Large	1202				
	Small	1203				
DAB	Large	1241				
	Small	1242				
FLUKE	Large	1210				
	Medium	1212				
	Small	1214				
BLUEFISH	Gutted	0232				
BUTTERFISH	Large	0510				
	Medium	0515				
	Small	0516				
HERRING, SEA		1685				
MACKEREL		2120				
SCUP	Large	3290				
	Medium	3292				
	Small	3293				
SEA BASS	Large	3351				
	Small	3355				
STRIPED BASS		4180				
TAUTOG		4380				
TILEFISH		4470				
SHRIMP		7360				
LOBSTER	Large	7274				
	Select	7273				
SCALLOPS, SEA		8009				
SQUID		8030				
OTHER FOR FOOD		5760				
OTHER FOR REDUCTION		5290				
		TOTAL				

NOTE: Individual reports are confidential and only summary data are released.

NOAA FORM 88-29 (1-73) U. S. DEPARTMENT OF COMMERCE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION — FORM APPROVED: O.M.B. NO. R41-2596

PURCHASES FROM FISHING VESSELS CHESAPEAKE STATES

DEALER					DATE
NAME OF VESSEL					VESSEL NUMBER
PORT CODE	COUNTY CODE	DATE SAILED	DATE LANDED	GEAR	GROUNDS
DAYS ABSENT	DAYS FISHED	TRIPS	LOG/INTERVIEW		DEPTH
PRORATE	FISHING ZONE	A	B	C	D

SPECIES AND GRADE		CODE	NUMBER OF POUNDS PURCHASED	PRICE PER POUND	SUBTOTAL DOLLARS	CENTS
BLUEFISH	Round	0231				
	Gutted	0232				
BUTTERFISH	Large	0510				
	Medium	0515				
	Small	0516				
BLACKBACKS		1200				
FLUKE	Jumbo	1218				
	Large	1210				
	Medium	1212				
	Small	1214				
KING WHITING	(King fish)	1970				
LING	(Red hake)	1520				
MACKEREL	(Boston)	2120				
PORGY	Large	3290				
	Medium	3292				
	Small	3293				
SEA BASS	Large	3351				
	Medium	3353				
	Small	3355				
STRIPED BASS	Large	4180				
	Small	4180				
WEAKFISH		3446				
WHITING	(Round)	5090				
CONCHS		7750				
LOBSTERS	Large	7274				
	Select	7273				
	Small	7272				
SEA SCALLOPS		8009				
SQUID		8030				
		TOTAL				

NOTE: Individual reports are confidential and only summary data are released.

FIG. 2. Standard forms for recording landings, values, and effort in the northeast region.

Sampling Targets

ICNAF

In the early 1970s, ICNAF adopted minimum standards for sampling. For each country a minimum of 200 lengths was required per 1000 metric tons or fraction thereof per ICNAF division, gear, and calendar quarter (ICNAF Redbook 1974). On the other hand, our requirements asked for a maximum of five samples per month per species per market category and sampling area. However, this required daily monitoring, which was performed by one port sampler located in Boston. All agents called in daily landings and when a species was sampled at or near the maximum level, samplers were directed to concentrate on another species. This worked well for major species but did not succeed in allocating samples when the maximum was not needed.

Monitoring is extremely important in this region because of priorities for sampling so many species. At present, sampling is monitored through weekly field reports to area supervisors and by a biologist responsible for coordinating sampling activities.

TABLE 3. Fractions of landings by major gear types for sampled species in the northeast region, 1980.

Species	Line trawl	Handine	Otter trawl	Gill net	Purse seine	Scallop dredge	Pound net	Stop seine	Weir	Clam dredge	Pots	Other	Total
Atlantic herring			0.12		0.42			0.39	0.04			0.03	1.00
Surf clam										1.00		—	1.00
Redfish			0.97									0.03	1.00
Haddock			0.89	0.06								0.05	1.00
Sea scallop			0.01			0.98						0.01	1.00
Atlantic cod	0.02		0.78	0.16								0.04	1.00
Yellowtail flounder			0.94			0.04						0.02	1.00
Pollock	0.02		0.57	0.33								0.08	1.00
Summer flounder			0.94			0.02	0.03					0.01	1.00
Ocean quahog										1.00		—	1.00
Winter flounder			0.96			0.01						0.03	1.00
Silver hake			0.98	0.01								0.01	1.00
Industrial			0.99		0.01							—	1.00
American plaice			0.91	0.01								0.08	1.00
Long-finned squid			0.81				0.14					0.05	1.00
Butterfish			0.97				0.02					0.01	1.00
American lobster			0.18								0.81	0.01	1.00
Atlantic mackerel		0.02	0.40	0.08	0.29		0.10					0.11	1.00
Witch flounder			0.91									0.09	1.00
Scup		0.04	0.72				0.22					0.02	1.00
Tilefish	0.97		0.03									—	1.00
Jonah crab											1.00	—	1.00
Bluefish		0.07	0.20	0.24			0.37					0.12	1.00
Red hake			0.97								0.01	0.02	1.00
Black sea bass		0.01	0.68				0.02				0.26	0.03	1.00
Weakfish		0.02	0.36	0.16	0.02		0.29					0.15	1.00

NOTE: Data include the coastal states from Maine to Virginia inclusive.

GENERAL SPECIES REQUIREMENTS

As a general rule of thumb each sample contains 100 lengths and 25 scale or otolith samples (at least one for each centimetre interval as represented in the length frequency). Specific requirements are shown in Table 4.

In addition to the above requirements, each species has particular stock and sampling area requirements. These correspond to management areas made up of a statistical area or groups of statistical areas (Fig. 1). For a detailed review of species requirements, sampling procedures and sampling areas in the northeast refer to *Manual for sampling, interviewing, and coding in the northeast region* (R. L. Schultz, unpublished data). This manual is distributed to all agents and is of a loose-leaf nature to allow for changes.

REQUIREMENTS FOR SELECTED SPECIES

Atlantic cod, haddock, and pollock sampling — Atlantic cod, haddock, and pollock are treated as a group because the designated sampling areas are the same, as are collection procedures for biological samples. The basic biological sample calls for measuring 100 fish (to the nearest centimetre) per market category for a fishing trip within a designated sampling area (Fig. 3) and taking 10–20 age structures per sample with at least one otolith per centimetre interval. After one otolith per centimetre interval is collected, port agents then randomly select fish for additional otoliths until the maximum number for the sample is reached. In addition to the length frequencies, age structures, and sample weight, information is taken on the fishing trip (called an interview) including data on hail weight, fishing effort, and area fished (Fig. 4).

A typical groundfish trip may include all three species of fish and the port agents must decide which species and/or market categories to sample. Usually Atlantic cod and haddock are separated by market category at sea, precluding sampling by species. If Atlantic cod were selected and four market categories landed, sampling protocol calls for one sample (50–100 lengths, 10–20 otoliths and weight) per market category. In this case, four samples would be required. However, given the time constraints, it usually is not possible to sample all four market categories and the agent now has to decide which market categories to sample. Generally this decision is based on past sampling for the species and the port agent will try to fill in for market categories that were missed the previous time Atlantic cod was sampled.

Sea scallop sampling — To obtain scallop samples, port agents ask cooperating scallop vessel operators to randomly save the top shells from scallops from the last two of the trip. Special boxes marked "NMFS Scallop Samples" are provided to the vessel operator for collecting the shells, and at the end of the trip these boxes of shells are

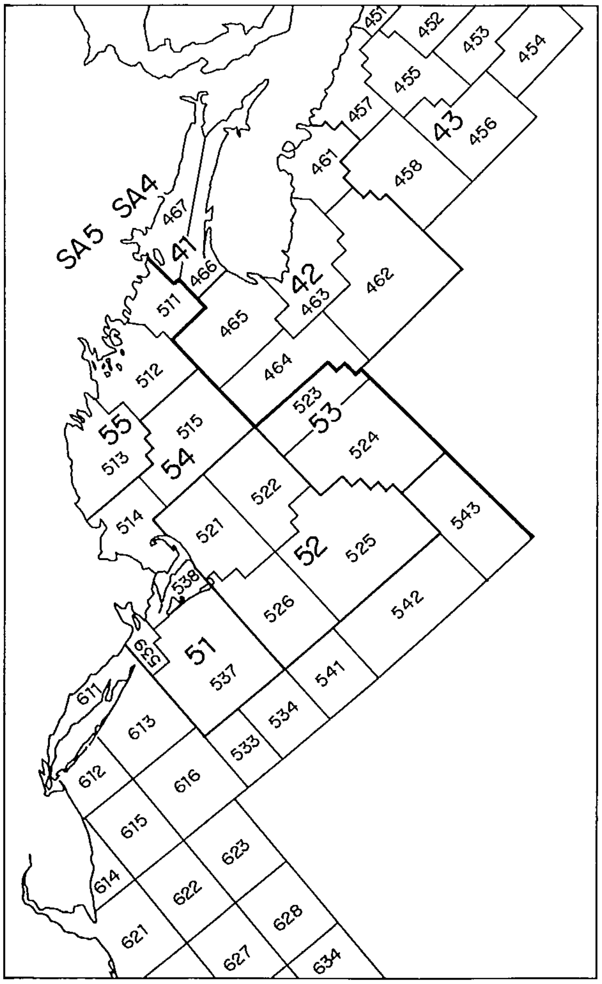


FIG. 3. Atlantic cod, haddock, and pollock sampling areas (41–43, 51–55).

picked up by the port agent and measured. A special measuring board graduated in 5-mm intervals with mechanical counters is used to measure 200 top shells of randomly selected shells from the box. A sample of shells for aging is also taken: three shells per 5-mm interval greater than or equal to 115 mm and two shells per 5-mm interval less than or equal to 114 mm. Additional information (interview) on the area fished, date, depths, and port, etc, is reported on a special scallop length-frequency form (Fig. 5).

The system of placing boxes on board fishing vessels for collecting shells works quite well at present, but could have its drawbacks when scallops come under management. The vessel captain may refuse to save shells entirely or fishermen could select shells that would bias the sample, particularly if a minimum shell size were imposed. Obviously, no shells below the minimum size would be included in the sample.

Surf clam/ocean quahog sampling — Surf clam samples are taken whenever an interview from a surf clam vessel is obtained. The interview involves asking the captain or mate a standard set of questions to obtain information on areas fished and fishing effort, etc. After the interview, the port agent samples the surf clam or ocean quahog landings. A sample consists of measuring 30 clams or quahogs to the nearest millimetre. These bivalves are normally landed in cages containing 32 bushels per cage. The port agent randomly selects five of the cages and selects six clams to measure from each cage. Under a contract study with the University of Maryland Eastern Shore commercial age samples are taken by NMFS from the port of Ocean City, MD. This study is to evaluate the feasibility of routine determination of the commercial age composition. At present, no commercial age samples are taken for ocean quahogs. However, an NMFS research project using mark and recapture techniques is ongoing to

TABLE 4. Sampling requirements (numbers of length measurements, scales, otoliths, or shells) per sample by species for the northeast region.

Species	Length measurement	Scales	Otoliths	Shells
Alewife	100	—	20	—
American plaice	100	25	—	—
Black sea bass	100	25 or	25	—
Blueback herring	100	—	25	—
Bluefish	100	—	25	—
Butterfish	100	—	25	—
Atlantic cod:				
scrod	50	—	10	—
market	100	—	20	—
large	100	—	20	—
mixed	100	—	20	—
Cusk	100	—	20	—
Haddock:				
scrod	50	15 or	15	—
large	100	20 or	20	—
Short-finned squid	50	—	—	—
American lobster, crabs	100 sexed	—	—	—
Long-finned squid	50	—	—	—
Atlantic mackerel	100	—	freeze 30 fish	—
Ocean quahogs	30	—	—	—
Pollock	100	—	20	—
Redfish	100 sexed	—	10 males	—
			10 females	—
Scup	100	25 or	25	—
Atlantic herring (adult)	100	—	freeze 30 fish	—
Sea scallops	200	—	—	2-3/5-mm interval
American shad	100	25 or	25	—
Northern shrimp	50	—	—	—
Silver hake	100 sexed	—	10 males	—
			10 females	
Weakfish	100	25	—	—
Striped bass	100	25	—	—
Summer flounder	100	25	--	—
Surf clams	30	—	—	—[a]
Northern puffer	50	—	10	—
Tilefish	100	25	—	—
White hake	100	25 or	25	—
Yellowtail flounder	100 sexed	25 males	—	—
		25 females		
Winter flounder	100	25	—	—
Witch flounder	100	25	—	—
Industrial	1–3 bushels	—	—	—

[a]One to two bushels of surf clams per month are taken for aging studies.

INTERVIEW		CODE	COLUMN
Vessel	JoJo	123456-S	
Vessel			
Vessel			
Date landed	10/1		
Year	1981		*1–2*
Area	525		*3–6*
Quarter	---		*7*
Month	OCTOBER		*8–9*
Species / Cat	Y'Tail (UNC)		*10-13*
Gear	TRAWL		*14-16*
Port	NEW BEDFORD		*17-19*
Sample number	---		*20-21*
Depth range	20-30F		*22*
Sampling method	125 # Box		*23*
Sex	SEXED		*25*
Catch locale	407066		
Hail wgt. (1,000#)	2.5		
Mesh size	5.5		
Number of scales	50		
No. of otoliths	---		
Mid-depth	25		*Total →*
Sample wgt. males	40 lbs.		
Sample wgt females	85 lbs.		
Sample wgt total	125 lbs.		

LENGTH SAMPLE

MALES								FEMALES								COLUMN
CARD SEQUENCE																28–29
1		6		1		6		1		6		1	1	6		31–33
2		7		2		7		2		7		2	2	7		34–36
3		8	3	3		8		3		8		3	7	8		37–39
4		9	7	4		9		4		9		4	9	9		40–42
5		0	9	5		0		5		0		5	12	0		43–45
6		1	12	6		1		6		1		6	14	1		46–48
7		2	10	7		2		7		2		7	13	2		49–51
8		3	8	8		3		8		3		8	12	3		52–54
9		4	7	9		4		9		4		9	10	4		55–57
0		5	2	0		5		0		5		0	7	5		58–60
1		6		1		6		1		6		1		6		61–63
2		7		2		7		2		7		2	2	7		64–66
3		8		3		8		3		8		3	1	8		67–69
4		9		4		9		4		9		4		9		70–72
5		0		5		0		5		0		5		0		73–75
			58										90			76–80

CODE SEQUENCE:	01	02	03	04	05	06	07	08	09	10	11	ETC
START L-F COLS. WITH:	1	16	31	46	61	76	91	106	121	136	151	ETC
No males 58		*No. fems* 90				*Grand total* 148						

NOTE: ALWAYS ENTER MALES ON LEFT, FEMALES ON RIGHT

FIG. 4. Completed finfish length-frequency form.

validate the periodicity of ring formation in ocean quahogs.

Atlantic herring sampling — The Atlantic herring biological sampling program probably represents the best sampling coverage for any species in the northeast region. The program has existed since 1960 and provides the longest continuous time series of length frequency, age, and length-weight data available for any species assessed in the region.

The juvenile Atlantic herring sampling program is handled as follows: freezers are maintained at various sardine plants along the coast of Maine and fishery inspectors (State of Maine Department of Agriculture) on duty at these plants under a cooperative agreement with NEFC take a sample of 100 fish from each carrier vessel as fish are unloaded. Sample boxes are provided with space on the cover to record the desired sample information. The samples are later collected by either NEFC staff or State of Maine Department of Marine Resources (DMR) personnel under NMFS contract at approximately 2–4-wk intervals. Processing of these samples is done by DMR under contract and the summarized data sent to NEFC for analysis and archiving. Samples are presently taken on the basis of 15 subareas for 52 statistical weeks by gear.

Adult Atlantic herring samples are taken primarily at the port of Gloucester although other ports may be involved depending on the landing patterns. NEFC statistical agents integrate this sampling with other activities.

Sampling protocol for NMFS requires at least one sample per week by sampling area. A sample consists of 100 fish measured in centimetres for natural total length (from the tip of the snout to the tip of the tail). After the fish have been measured, a subsample of 30 fish is selected for aging and frozen with at least one fish per centimetre interval. An age sample consists of (1) five fish less than 26 cm, (2) 20 fish from 26 to 33 cm, and (3) five fish greater than 34 cm.

SEA SCALLOP LENGTH SAMPLE

YEAR 1974 STATISTICAL AREA 526

DEPTH (FATHOMS) 30 - 45 QUARTER 1

MONTH July SPECIE NO. ____

GEAR 13 PORT 244

SAMPLE NO. ____ UNIT AREA 406856

REMARKS ____

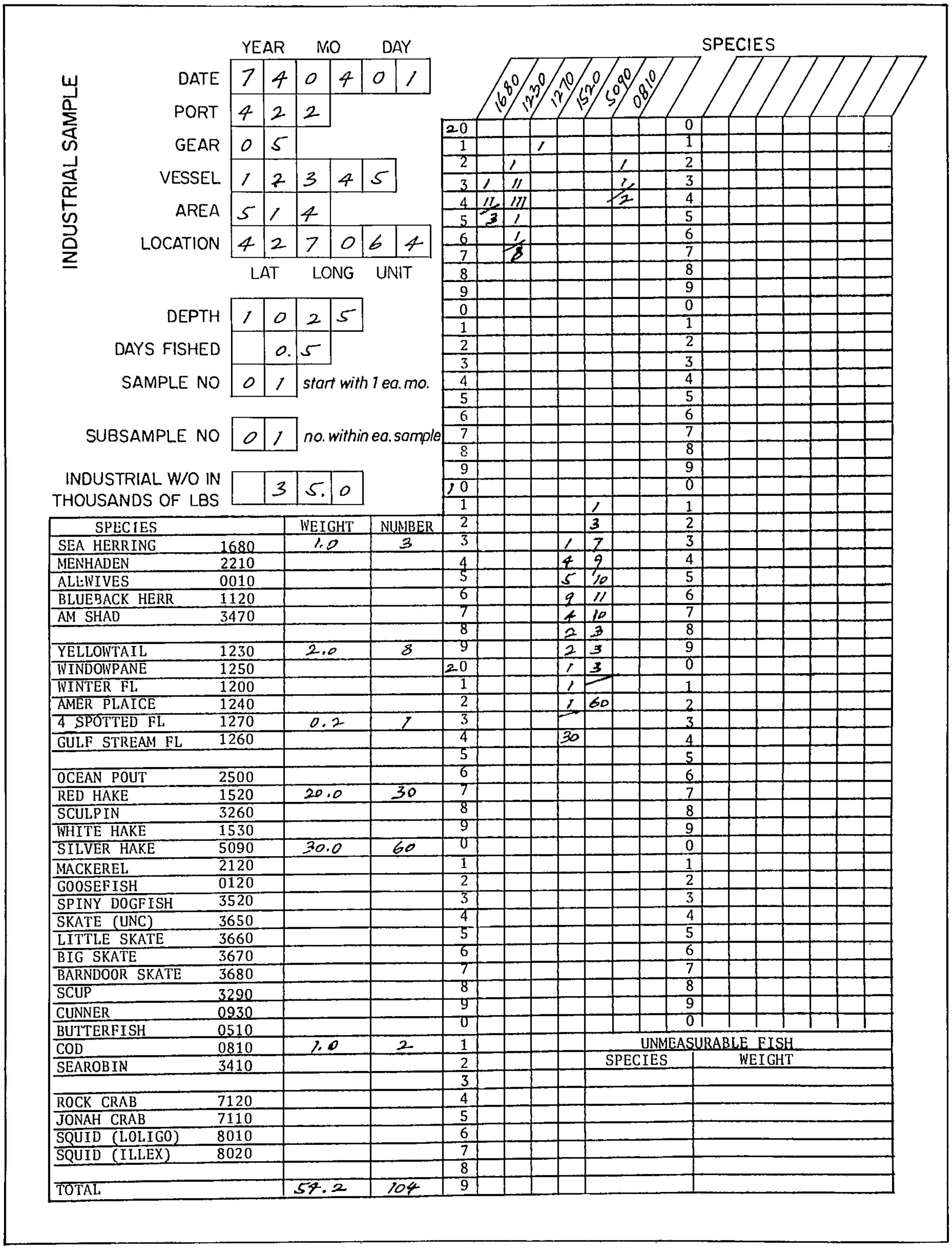
MEASURED BY John Doe

LENGTH MM.	SEQ. NO. 1 FREQ.	FIELD	LENGTH MM.	SEQ. NO. 2 FREQ.
		1	75–79	30
		2	80–84	34
		3	85–89	25
		4	90–94	18
		5	95–99	22
		6	100–104	13
30–34		7	105–109	4
35–39		8	110–114	1
40–44		9	115–119	
45–49	3	10	120–124	
50–54	5	11	125–129	
55–59	7	12	130–134	
60–64	9	13	135–139	
65–69	12	14	140–144	
70–74	15	15	145–149	
TOTALS	51			149

FIG. 5. Completed sea scallop length-frequency form.

In addition, the State of Massachusetts Division of Marine Fisheries samples adult Atlantic herring landings as part of its management responsibilities for managing the waters 3 mi from the coast, and an informal agreement exists for archiving these data at NEFC. In exchange, NEFC supplies them with summary length and landings data.

Industrial sampling — Industrial sampling procedures for mixed species depend on methods of unloading. Typically, the common method for unloading is to flood the fish hold, pump the fish out onto a conveyor and then dump them directly into a truck. The point of sampling takes place on the conveyor where the port agent periodically scoops fish from the conveyor until two or more



INDUSTRIAL SAMPLE

	YEAR		MO		DAY	
DATE	7	4	0	4	0	1
PORT	4	2	2			
GEAR	0	5				
VESSEL	1	2	3	4	5	
AREA	5	1	4			
LOCATION	4	2	7	0	6	4
	LAT		LONG		UNIT	

DEPTH	1	0	2	5	
DAYS FISHED		0.	5		
SAMPLE NO	0	1	start with 1 ea. mo.		
SUBSAMPLE NO	0	1	no. within ea. sample		
INDUSTRIAL W/O IN THOUSANDS OF LBS		3	5.	0	

SPECIES		WEIGHT	NUMBER
SEA HERRING	1680	1.0	3
MENHADEN	2210		
ALEWIVES	0010		
BLUEBACK HERR	1120		
AM SHAD	3470		
YELLOWTAIL	1230	2.0	8
WINDOWPANE	1250		
WINTER FL	1200		
AMER PLAICE	1240		
4 SPOTTED FL	1270	0.2	1
GULF STREAM FL	1260		
OCEAN POUT	2500		
RED HAKE	1520	20.0	30
SCULPIN	3260		
WHITE HAKE	1530		
SILVER HAKE	5090	30.0	60
MACKEREL	2120		
GOOSEFISH	0120		
SPINY DOGFISH	3520		
SKATE (UNC)	3650		
LITTLE SKATE	3660		
BIG SKATE	3670		
BARNDOOR SKATE	3680		
SCUP	3290		
CUNNER	0930		
BUTTERFISH	0510		
COD	0810	1.0	2
SEAROBIN	3410		
ROCK CRAB	7120		
JONAH CRAB	7110		
SQUID (LOLIGO)	8010		
SQUID (ILLEX)	8020		
TOTAL		57.2	104

SPECIES

	1680	1230	1270	1520	5090	0810
20						
1			/			
2		/				/
3	/	//				//
4	//	///				/2
5	/3	/				
6		/				
7		8				
10						
1					/	
2					3	
3				/	7	
4				4	9	
5				5	10	
6				9	11	
7				4	10	
8				2	3	
9				2	3	
20				1	3	
1				1		
2				1	60	
3						
4				30		

UNMEASURABLE FISH

SPECIES	WEIGHT

FIG. 6. Completed industrial sample form.

TABLE 5. Commercial length-frequency samples collected and metric tons (live wt) per sample for the northeast region, 1977–80.

	Number of samples				Metric tons per sample			
Species	1977	1978	1979	1980	1977	1978	1979	1980
Atlantic herring	371	500	721	403	137	101	90	207
Surf clams[a]	131	372	192	224	177	47	82	77
Redfish	103	63	147	54	154	256	105	203
Haddock	210	181	119	138	61	99	160	181
Sea scallops[a]	74	104	117	168	150	139	122	75
Atlantic cod	166	122	90	78	207	322	493	688
Yellowtail flounder	90	58	70	97	184	198	229	199
Pollock	48	23	59	27	272	770	263	677
Summer flounder	58	48	47	64	153	176	309	180
Ocean quahogs[a]	6	110	46	68	1402	93	346	223
Winter flounder	89	48	40	71	119	257	305	244
Silver hake	60	44	35	48	366	545	471	366
Industrial	115	50	32	11	74	145	224	353
American plaice	16	17	27	24	444	560	421	565
Long-finned squid	0	11	20	31	856	66	195	124
Butterfish	7	17	15	36	207	216	189	145
American lobster[b]	8	3	15	11	312	901	146	171
Short-finned squid	0	1	9	0	1028	361	177	333
Atlantic mackerel	15	3	7	30	92	535	284	89
Witch flounder	9	12	6	1	277	295	504	3381
Windowpane	8	4	5	0	235	509	317	968
Scup	10	16	5	26	847	583	1749	326
Tilefish	2	1	3	1	1038	3413	1280	3681
Spiny dogfish	0	0	3	0	371	36	631	2785
Jonah crab	1	0	3	5	193	194	46	20
Bluefish	0	0	2	9	3374	3766	2036	518
Red hake	2	0	1	2	1696	4521	8145	2478
Cusk	0	0	1	0	1238	1537	1696	1805
Squid (N.S.)	42	0	0	0	16	590	537	283
Red crab	4	0	0	0	311	1432	1216	2547
Black sea bass	0	0	0	10	2424	2111	1721	97
Weakfish	0	0	0	11	6260	6588	10080	1015
Total	1665	1808	1837	1648				

NOTE: Underlined values represent total landed weight if no samples were taken.
[a]Meat weights are used for sea scallops, ocean quahogs, and surf clams.
[b]Offshore lobster landings only.

bushels of mixed fish have been collected. Two bushels of mixed fish per 50 000 lb (22.7 t) is the basic sample. However, another bushel of fish is collected for each additional 25 000 lb (11.3 t) landed. The selection process extends throughout the unloading operation so that the problem of layering is not a factor.

After the sample is taken each bushel of fish is sorted to species, weighed, and measured (to the nearest centimetre). Results are tabulated on an industrial sample form (Fig. 6) and each bushel is recorded on a separate form. Sampling requirements call for a minimum of 5 samples per month for each sampling area (5Y, 5Ze, 5Zw), and in addition each vessel should be sampled at least once a month.

Industrial landings and samples have declined substantially in recent years (Table 5) and today Pt. Judith is the only major port where mixed industrial fish are landed.

REVIEW OF SAMPLING IN THE NORTHEAST REGION, 1977–80

A review (1977–80) of commercial biological samples collected by port agents or under contract for the northeast region is given in Table 5. Metric tons of landed catch per sample are also presented to provide an index of sampling intensity for the various species. During the period, 32 species were sampled to varying degrees and the total number of samples collected ranged from 1648 during 1980, to 1837 during 1979. Sampling coverage for the managed species, Atlantic herring, surf clams, haddock, yellowtail flounder, long-finned squid, Atlantic, mackerel, and butterfish appears adequate assuming sampling target of about one sample per 200 t. For the remaining managed species, Atlantic cod, ocean quahog, and short-finned squid sampling needs to be improved.

For other species in Table 5, the sampling levels appear to be adequate in some cases and in need of substantial improvement in other cases. This table is intended merely as a general overall view of sampling, and while sampling for some species may appear to be adequate (e.g. haddock), a more detailed evaluation by stock areas and gears would undoubtedly reveal serious deficiencies for some managed and unmanaged species.

Alternative to Port Agent Sampling

Sea Sampling

An additional source of catch information relative to species composition, length distribution, age composition, and discards would consist of observations aboard commercial vessels (sea sampling) during the actual fishing operations. To obtain the more detailed data available on a tow by tow basis, sea sampling programs at a minimal level have long been a part of NEFC assessment effort. This effort reached its peak in the period from 1977 to 1980 when 44 trips were taken. Detailed data collected consisted of (1) catch/effort data, (2) discards, and (3) length-frequency samples of discards and marketable catch. When sampling a mixed catch for species composition or length-frequency distributions, sampling was attempted on a random basis. If the catch sampled was being sorted by market category, a stratified random sample was required. The strata would consist of market categories and a sample of each market category was made. Discard was measured by species on a bushel basis. In the case of large catches where it was not practical to obtain discards on a bushel basis, the captain's estimate of bushels discarded was compared with the sampler's estimate and the sea sampler's judgment was used to estimate the final value.

Resources to conduct a full-scale program on domestic vessels have never been available. In contrast, detailed data and samples are taken aboard foreign vessels through an observer program funded by the foreign vessels (supplemented occasionally by trips by research biologists). The foreign vessel coverage is about 20-25% of the total vessel days.

Summary and Recommendations

Biological sampling of commercial catches is one of the basic elements of any analytical fisheries assessment. Therefore, it is essential to obtain unbiased representative samples. To accomplish this one must be able to accurately monitor landings by stock area, season, and gear in order to adjust sampling to reflect changes in landing patterns. At present we depend on the port sampler's judgment, experience, and a flexible sampling design to make the correct on the spot sampling decisions to accommodate changing fishing patterns and dealer operations. Therefore probably the most important consideration in any sampling program lies in the motivation, education, and training of port samplers.

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Implications of Accuracy of Sampling Information on Management Advice

Incidences de la précision des données d'échantillonnage sur les avis de gestion

Analogies to the Status Quo TACs: Their Nature and Variance

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POPE, J. G. 1983. Analogies to the status quo TACs: their nature and variance, p. 99–113. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Two new methods for estimating status quo Total Allowable Catches (TACs) (leapfrog and ANOVA TACs) are developed. Approximate formulae are presented for estimating the variability induced in these TACs by the variability of input data. The relationship of these methods to standard TAC estimation methods is discussed as is the applicability of the variability formulae.

POPE, J. G. 1983. Analogies to the status quo TACs: their nature and variance, p. 99–113. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

On développe ici deux nouvelles méthodes permettant d'estimer le total des prises admissible (TPA) (le TPA "saute-mouton" et le TPA établi par analyse de variance) qui correspond au status quo. Des formules approximatives sont présentées pour l'estimation de la variabilité inhérente à ces TPA, variabilité qui est une fonction des incertitudes des données utilisées. On compare ces méthodes standard pour l'estimation des TPA, et discute l'applicabilité des formules estimatives de la variabilité.

1. Introduction

The estimation of Total Allowable Catches (TACs) is a major task of fisheries assessment scientists. While how to estimate them is well established, their probable variance has proved something of a mystery. This is because the estimation of TACs is a somewhat recursive, not to say subjective, science which does not lend itself to examination of variances. To try to penetrate this mystery was the original incentive for this paper but to do this required simpler formulations of TACs. Two simpler formulations were developed. These are of some interest in themselves in that they might be used instead of standard methods. The author would argue, however, that it is the insight they give into the TAC estimation that should be of greatest interest. This paper therefore describes these two methods and estimates their variance. It also draws some general conclusions about the TAC estimation process and the sources of its variance.

2. Background

Estimating Total Allowable Catches (TACs) is an important activitity of fisheries assessment scientists. Moreover, it is one that is a major justification for the various expensive data series that they collect. It is reasonable therefore to ask what effect does the variability of the various data series have on the variability of the TAC. If we knew the answer to this it would help us to decide rationally how much to spend on the various data sets.

Unfortunately, answering this question fully is not easy because the standard practice is recursive and subjective. Standard practice usually involves the following eight steps:

1) establish a data set for the fish stock of catch-at-age data ($C(i, j)$) for each year i and each age j, effort data ($f(i)$), recruitment data ($R(i)$), weight-at-age data ($W(j)$), and estimates of natural mortality;

2) using Virtual Population Analysis or cohort analysis, estimate population numbers at age and fishing mortality at age based on the data set and on estimates of fishing mortality or population estimates for the greatest age (g) each year and for each age of the terminal year (t);

3) make minor adjustments to greatest age and terminal year values to obtain a consistent interpretation of fishing mortality at age;

4) use estimates of fishing mortality or population at age to calibrate fishing effort or catch-per-unit-effort data;

5) use estimates calibrated in step 4) to estimate terminal fishing mortality;

6) unless terminal values estimated in step 5) are effectively unchanged, return to step 2);

7) calibrate recruitment estimators using population estimates of each year's new recruits;

8) using estimates of population numbers and recruitment levels obtained above, make forecasts of catch numbers in year $t + 1$ and year $t + 2$ subject to proposed levels of fishing mortality (F).

In general, the proposed level of fishing mortality in year $t + 1$ will be that which gives a preagreed TAC for year $t + 1$. In ICES, the proposed level of fishing mortality in year $t + 2$ is often either the same as acted in year t or some proportion of it. We shall call TACs which are designed to maintain current F levels status quo TACs. The problem with this method of estimating TACs is that the calculation route is complex and it is difficult to see how to investigate the variance of the resulting TAC except perhaps by a Monte Carlo simulation approach such as that shown in Pope and Gray (1983). An alternative is to consider only the variability generated in the forecast made in step 8) above rather than in the whole assessment procedure, step 1)–step 8). This was the approach used by Pope and Garrod (1975) and also by Doubleday (1979).

Another alternative is to simply consider how well or badly past TACs have been set in the light of hindsight (e.g. Macer et al. 1979) or by independent working groups using the same data (Garrod et al. 1977). All of these methods give insights into the problem but a general formula that related the variability of the TAC to the variability of the inputs would be very valuable even if it were only approximately true.

The main problem of developing such a general formula is the recursive and subjective nature of steps 2) through 8). To proceed, therefore, we ideally need a formulation of a TAC that is simpler than current practice but which mirrors its main features.

Two possible formulations are developed in this report. The first, the leapfrog TAC, is very simple but does not mirror current practice. It is shown, however, as a very simple illustration of the nature of the status quo TAC calculation process. The second formulation — the ANOVA TAC — is somewhat more complex but would seem to mirror most of the processes we carry out at present. This method, therefore, relates to the normal TAC assessment in rather the same way that cohort analysis relates to virtual population analysis (VPA). That is, in practice, we would probably choose to use the 'exact' method but the simpler method illustrates what in fact we are doing and enables us to develop formulae for the variances of the results.

3. Leapfrog TACs

The procedure for estimating TACs shown in Section 2 requires that a time series of data is available. Examination of the structure of the separable VPA (Pope and Shepherd 1982) suggests, however, that it should be possible to set a TAC based only on 2 yr assessment data (i.e. catch-at-age data, weight-at-age data, effort data, and recruitment indices).

Suppose we have assessment data for years $t - 1$ and t and wish to set a TAC in year $t + 1$ such that $F(t + 1) = F(t - 1)$. Pope and Shepherd (1982) consider the case where fishing mortality at any age j in any year i may be given as $F(i) \times S(j)$ where $F(i)$ is a year effect and $S(j)$ an age effect. Using their equation (14) we may then write

$$(3.1)\quad \ln[C(t, j + 1)/C(t - 1, j)] = \ln[F(t)/F(t - 1)] + \ln[S(j + 1)/S(j)] - 0.4444\, F(t)\, S(j + 1) - 0.5556\, F(t - 1)\, S(j) - M.$$

where M is natural mortality.

An equivalent formula can be written to relate $C(t + 1, j + 1)$ and $C(t, j)$. For a simple leapfrog TAC we set $F(t + 1) = F(t - 1)$ and thus

$$(3.2)\quad \ln[C(t + 1, j + 1)/C(t, j)] = \ln\,[F(t - 1)/F(t)/F(t)] + \ln[S(j + 1)/S(j)] - 0.4444\, F(t - 1)\, S(j + 1) - 0.5556\, F(t)\, S(j) - M.$$

Hence, subtracting (3.1) from (3.2) leads to

$$(3.3)\quad \ln[C(t + 1, j + 1)/C(t, j)] = \ln[C(t, j + 1)/C(t - 1, j)] + 2\ln[F(t - 1)/F(t)] + [F(t) - F(t - 1)]\{0.4444\, S(j + 1) - 0.5556\, S(j)\}.$$

The last term of the RHS will generally be far smaller than the second term and will be ignored. With obvious manipulations (3.3) may be written as

$$(3.4)\quad C(t + 1, j + 1) = \frac{C(t, j + 1)\, C(t, j)}{C(t - 1, j)} \left(\frac{F(t - 1)}{F(t)}\right)^2.$$

Thus the catch-at-age of all but the youngest age ($j = 1$) caught in year $t + 1$ may be estimated from the past 2 yr catch-at-age data. An analogous formula to (3.4) can be written for $C(t + 1, 1)$ in terms of a recruitment index for prerecruit fish of $R(t)$ and $R(t + 1)$. $R(t)$ of course predicts the size of the year-class which gives $C(t, 1)$.

Briefly,

$$(3.5)\quad C(t, 1)/F(t) = r\, R(t)$$

where r is a constant, and

$$(3.6)\quad C(t + 1, 1)/F(t - 1) = r\, R(t + 1, 1)$$

so

$$(3.7)\quad C(t + 1, 1) = C(t, 1)\, \frac{R(t + 1)}{R(t)}\, \frac{F(t - 1)}{F(t)}.$$

Hence, we may write the Total Allowable Catch (TAC)

$$(3.8)\quad \mathrm{TAC} = \sum_{j=1}^{g} W(j)\, C(t + 1, j),$$

where g is the greatest age in the catch-at-age data, and where the $C(t + 1, j)$ are given by (3.4) and (3.7) and $W(j)$ is the average weight at age j.

Since fishing mortalities enter these equations as ratios, we might replace them by the ratios of fishing effort $f(t - 1)$, $f(t)$ at least for species where a constant catchability is a reasonable assumption. This calculation of the TAC is interesting since it would seem to imply that we may estimate a TAC to give $F(t + 1) = F(t - 1)$ with only 2 yr assessment data and without knowing the actual values of $F(t - 1)$, $F(t)$ or M!

I do not recall seeing this formulation anywhere else although it is so simple I cannot believe it has not been developed somewhere. For convenience, I propose it be called the leapfrog TAC because we jump from $F(t-1)$ to $F(t+1)$. Clearly, it does not mirror standard practice but we may estimate its approximate variance easily using the Taylor expansion approach. That is, we may express the small error in TAC as ΔTAC. ΔTAC is the result of equivalent small errors in $f(t-1)$, $f(t)$, $R(t)$, $R(t+1)$ and the $C(t-1, j)$, $C(t, j)$. As a first approximation to ΔTAC we have, using a Taylor's expansion, that

$$(3.9)\quad \Delta\text{TAC} = \sum_{j=1}^{g} \frac{\partial \text{TAC}}{\partial C(t-1, j)} \Delta C(t-1, j)$$

$$+ \sum_{j=1}^{g} \frac{\partial \text{TAC}}{\partial C(t, j)} \Delta C(t, j)$$

$$+ \frac{\partial \text{TAC}}{\partial F(t-1)} \Delta F(t-1) + \frac{\partial \text{TAC}}{\partial F(t)} \Delta F(t)$$

$$+ \frac{\partial \text{TAC}}{\partial R(t)} \Delta R(t) + \frac{\partial \text{TAC}}{\partial R(t+1)} \Delta R(t+1)$$

$$+ \sum_{j=1}^{g} \frac{\partial \text{TAC}}{\partial W(j)} \Delta W(j).$$

If we square both sides and sum for all possible values (assuming the independence of each data type) we obtain an equation relating the coefficient of variation of the TAC (CV(TAC)) to the coefficients of variation of the data sets. These coefficients of variation could be expressed separately for each $C(i, j)$, $f(i)$, $R(i)$, and $W(j)$ for years $i = t-1$, t and all ages j, but for the sake of simplicity we assume that all $C(i, j)$ have the same coefficient of variation, (CV(C)); as do $f(t-1)$, $f(t)$, (CV(f)); and as do $R(t)$, $R(t+1)$, (CV(R)); and as do all $W(j)$, (CV(W)).

We can then write

$$\text{CV(TAC)}^2 \cong \theta(C)\,\text{CV}(C)^2$$
$$+ \theta(f)\,\text{CV}(f)^2$$
$$+ \theta(R)\,\text{CV}(R)^2$$
$$+ \theta(W)\,\text{CV}(W)^2$$

where writing $C(t+1, j)\ W(j)$ as $Y(j)$

$$(3.11)\quad \theta(C) = \{Y(g)^2 + \sum_{j=1}^{g-1} [(Y(j) + Y(j+1))^2$$
$$+ Y(j+1)^2]\}/\text{TAC}^2$$

$$(3.12)\quad \theta(f) = 2\{Y(1) + 2\sum_{j=2}^{g} Y(j)\}^2/\text{TAC}^2$$

$$(3.13)\quad \theta(R) = 2Y(1)^2/\text{TAC}^2$$

$$(3.14)\quad \theta(W) = \sum_{j=1}^{g} Y(j)^2/\text{TAC}^2.$$

The standard assessment practice described in steps 1)–8) of Section 2 and the leapfrog method described in this section have one feature in common: in both methods the catch-numbers-at-age in the TAC year are taken to be directly proportional to the last available catch-numbers-at-age data for the year-class (those of year t) or to the appropriate recruitment index for the year-class. From equation (3.4) we see that for the leapfrog method the coefficient of proportionality is

$$(3.15)\quad \frac{C(t, j+1)}{C(t-1, j)} \times \left(\frac{F(t-1)}{F(t)}\right)^2.$$

Equivalently, if steps 1)–7) are followed to estimate $F(i)$ and $S(j)$ and a TAC is estimated in year $t+1$ such that

$$F(t+1) = F(t-1)$$

the coefficient of proportionality may be written as

$$(3.16)\quad \frac{F(t-1)}{F(t)} \frac{S(j+1)}{S(j)} \frac{[1 - \exp\{-Z(t-1, j+1)\}]}{[1 - \exp\{-Z(t, j)\}]}$$
$$\times \frac{Z(t, j)}{Z(t-1, j+1)} \exp\{-Z(t, j)\}$$

where $Z(i, j) = F(i) \times S(j) + M$ for all i.

By adapting Gray's (1977) approximation

$$(3.17)\quad \frac{1 - \exp\{-Z(i, j)\}}{Z(i, j)} \cong \exp\{-Z(i, j)/2.25\}$$

this may be rewritten as

$$(3.18)\quad \frac{F(t-1)}{F(t)} \frac{S(j+1)}{S(j)} \exp\{-(0.4444\,F(t-1)\,S(j+1)$$
$$+ 0.5556\,F(t)\,S(j) + M)\}.$$

Comparing (3.18) with (3.15) we observe that following the steps 1)–7) leads us to a coefficient of proportionality which is more complex than the leapfrog method but which is less dependent upon the fishing effort estimates of the last 2 yr. It follows that equation (3.10) is unlikely to estimate the variance of a TAC estimated by the standard assessment practice. In particular the component of variance due to the variance of fishing mortality (effort) (3.12) is likely to be heavily overstated.

To provide a suitable formulation of the variance we clearly need a TAC estimation method that follows the standard assessment practice while maintaining something of the simplicity of the leapfrog method. Such a method is proposed in the next section.

4. ANOVA TACs

The results of the previous section make it clear that the leapfrog TAC cannot be expected to have a similar variance to the standard assessment method and we must therefore look for a closer analogy. The essential feature of the standard method is that catch-at-age data from a number of past years are used to estimate fishing mortality and population sizes by age and year. These estimates are then used to:

1) calibrate the fishing effort data against fishing mortality data so as to be able to predict $F(t)$ from effort data;

2) estimate the age effects on fishing mortality ($S(j)$); and

3) calibrate indices of recruitment so as to be able to predict $R(1, t)$, etc.

The $F(t)$ and $S(j)$ thus estimated are used to calculate the ratio of catch-numbers-at-age in the TAC year to either the catch-numbers-at-age in year t or the recruitment estimates. The advantage of this approach is that the TAC is less dependent on the effort data of any 1 yr than is the case with the leapfrog TAC.

Pope and Shepherd (1982) show that the problem of estimating $F(i)$ and $S(j)$ which are consistent with past years' data may be regarded as the problem of finding values of the $F(i)$ and the $S(j)$ such that a least squares fit is obtained to the matrix of log catch ratios ($D(i, j)$) given by

$$(4.1) \quad D(i, j) = \ln\{C(i+1, j+1)/C(i, j)\}.$$

They also show that such least squares solutions are not unique and that the $D(i, j)$ matrix has a structure that closely approximates to the 2-way analysis of variance (ANOVA model):

$$(4.2) \quad D(i, j) = \alpha(i) + \beta(j) + \mu + \epsilon$$

where $\alpha(i)$ is the year component, $\beta(j)$ is the age component, μ is the overall mean and ϵ is an error term resulting from catch-at-age data sampling errors.

The actual assessment tasks of 2) through 6) shown in Section 2 may be regarded as an attempt to estimate separable fishing mortality estimates which as far as possible are consistent with the catch-at-age data and consistent with fishing effort or catch-per-unit-effort data. As we have noted above, the least squares method indicates that this interpretation will not be unique. By contrast, the ANOVA interpretation of the catch-at-age data is unique. If we could extrapolate this in time to give the year effects $\alpha(t)$ and $\alpha(t + 1)$, then we could use the ANOVA model to predict $D(t, j)$ and $D(t + 1, j)$, the log catch ratio of the forecast years to the previous years. The problem therefore is to relate $\alpha(i)$ to measures of fishing effort.

Pope and Shepherd's (1982) equation (B.1) gives the year total $D(i,\bullet)$ where $\bullet$ indicates summing for all ages as

$$(4.3) \quad D(i,\bullet) = (g-1)\ln[F(i+1)/F(i)] + \ln[S(g)/S(1)] - F(i+1)\,0.4444\sum_{j=1}^{g-1} S(j+1) - F(i)\,0.5556\sum_{j=1}^{g-1} S(j) - (g-1)M$$

They normalize the $S(j)$ by arbitrarily setting $S(x) = 1$ where x is an age between 1 and g; however, for the purpose of the development here Pope's (1979) normalization

$$\sum_{j=1}^{g} S(j) = g$$

will be used, and to further simplify the problem an additional constraint $S(g) = 1$ will be adopted.

The result of this is that

$$(4.4a) \quad g - 1 \leq \sum_{j=1}^{g-1} S(j+1) \leq g$$

and in practice, since $S(1)$ is usually small,

$$(4.4b) \quad \sum_{j=1}^{g-1} S(j+1) \cong g$$

and

$$(4.5) \quad \sum_{j=1}^{g-1} S(j) = g - 1.$$

Since

$$(4.6) \quad D(i,\bullet) = (g-1)(\alpha(i) + \mu)$$

we see that approximately

$$(4.7) \quad \alpha(i) + \mu \cong \ln[F(i+1)/F(i)] - 0.4444\frac{g}{g-1}F(i+1) - 0.5556F(i) + \text{Constant}.$$

In many cases g will be about 8 yr and if we assume $g = 8$ we may simplify (4.7) to give

$$(4.8) \quad \ln[F(i+1)/F(i)] - 0.51F(i+1) - 0.56F(i) + \text{Constant}.$$

If $F(i + 1)$ and $F(i)$ are in the region of 1.0 then a very possible approximation to (4.8) would be

$$(4.9) \quad \frac{1}{2}\ln[F(i+1)/F(i)^3] + \text{Constant}.$$

Figure 1 shows the relationship between equation (4.8) and the approximate form of (4.9) for values of $F(i + 1)$ of 0.3, 0.5, 0.9, 1.4, and 1.7 and values of $F(i)$ set at 50, 100, and 150% of the value of $F(i + 1)$. It is clear that for values of $F(i + 1)$ between 0.5 and 1.7 and with $F(i)$ between 50 and 150% of $F(i + 1)$ of these values that the approximation is closely related to equation (4.8) with a slope of 1.0. Only for the $F(i + 1) = 0.3$ series and for the upper point of the $F(i + 1) = 0.5$ series and the lowest point of the $F(i+ 1) = 1.4$ series and the lowest two points of the $F(i + 1) = 1.7$ series does the approximation depart more than 0.1 from the true function line. For many fish stocks therefore the approximation should prove entirely adequate. For those with lower F values, the alternative approximation $\ln[F(i + 1)/F(i)^2]$ may prove more suitable but since this yields rather similar results for the first order of components of variation of the TAC, the exposition given here will be entirely in terms of the approximation (4.9). Thus, for many stocks, we can hope to relate $\frac{1}{2}\ln[F(i+1)/F(i)^3]$ to $\alpha(i)$. Provided fishing effort (f) predicts fishing mortality (i.e. $F = qf$), we should then expect the $\alpha(i)$'s to correlate closely with

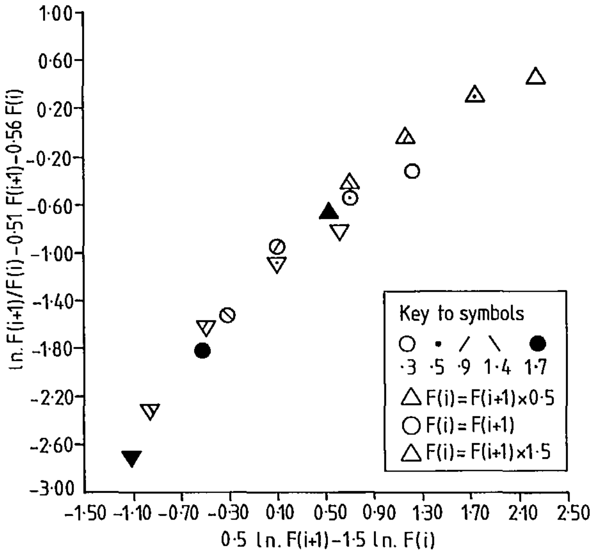

FIG. 1. The relationship between the exact formulae (4.8) for $\alpha(i)$ and the approximation used with ANOVA TACs (4.9) for a range of $F(i)$ and $F(i + 1)$ values.

$\frac{1}{2}\ln[f(i + 1)/f(i)^3]$ with a slope of about 1.0.

Suppose we find a correlation between the $\alpha(i)$'s and the approximate effort function (4.9) of the form

$$\alpha(i) = a + \frac{1}{2}\ln[f(i + 1)/f(i)^3] \tag{4.10}$$

where a is the intercept and where by the definition of $\alpha(i)$ we may write

$$a = -\frac{1}{t - 1}\sum_{i=1}^{t-1}\frac{1}{2}\ln[f(i + 1)/f(i)^3]. \tag{4.11}$$

We may then predict

$$\alpha(t) = \alpha(t + 1) = a - \ln[f(t)] \tag{4.12}$$

where we require that $F(t + 2) = F(t + 1) = F(t)$, e.g. when we wish to estimate a TAC to give unchanged fishing mortality.

With estimates of $\alpha(t)$ and $\alpha(t + 1)$ it is possible to predict $\ln[C(t + 1, j + 1)/C(t, j)]$ and $\ln[C(t + 2, j + 2)/C(t + 1, j + 1)]$ for $j = 1$ to $g - 2$.

Using the catch-at-age data in year y we may therefore predict the catch-at-age in year $t + 1$ for all ages except the youngest as

$$C(t + 1, j + 1) = C(t, j)\exp\{\alpha(t) + \beta(j) + \mu + \sigma_1^2/2\} \tag{4.13}$$

where $\sigma_1^2/2$ is the correction for the transformation from the logarithmic mean to the arithmetic mean and σ_1^2 is estimated as the mean of the squared deviations of $D(i, j)$ from the ANOVA model. A similar equation to (4.13) is then used to relate the catches in year $t + 2$ to those in year $t + 1$. This will be necessary as in many cases TACs are set two years on from the last catch-at-age data, e.g. the 1983 TAC is set in 1982 using 1981 catch-at-age data. This means that the two youngest ages represented in the TAC are not represented in the last year's catch-at-age data and must therefore be estimated by recruitment indices. In practice, the youngest age in the catch-at-age data frequently has a variable proportion of the fully recruited fishing mortality applied to it. This may mean that the third age in the TAC must often also be estimated using recruitment indices. We will designate these indices by $R(i, 1)$, $R(i, 2)$, and $R(i, 3)$, respectively where i refers to the year of the catch they predict. In normal working group practice they would be calibrated using regressions of past years' data with VPA population estimated in past years. This method is not open to us here because we would like to estimate our TAC independent of mortality estimates. We may, however, calibrate each R by using either a regression of $C(i, j)/f(i)$ on $R(i, j)$ or finding the average value of either $C(i, j)/(f(i)\,R(i, j)$ or its natural logarithm. We will call this calibration coefficient $r(j)$. For convenience we will use the latter approach and set

$$\bar{r}(j) = \{\prod_{i=1}^{t-1} C(i, j)/(f(i)\,R(i, j))\}^{1/t-1}\exp\sigma_2^2/2 \tag{4.14}$$

where $\sigma_2^2/2$ is the correction from the geometric to the arithmetic mean and is estimated from the perceived variance of $\ln[C(i, j)/f(i)\,R(i, j)]$.

We may now write the TAC as

$$\text{TAC} = \sum_{j=1}^{g} C(t + 2, j)\,W(j) \tag{4.15}$$

where for $j = 1$ to 3

$$C(t + 2, j) = f(t)\,R(t + 2, j)\,\bar{r}(j) \tag{4.16}$$

and for $j = 4$ to g

$$C(t + 2, j) = C(t, j - 2)\exp(2\alpha(t) + \beta(j - 1) + \beta(j - 2) + 2\mu + \sigma_1^2). \tag{4.17}$$

We may then make some attempt to estimate variance using the Taylor's expansion method. As usual with this method it is convenient to express variability as the square of the coefficients of variation. These are assumed for simplicity to be the same for each of the four chief estimator sets of catches-at-age [CV(C)], fishing effort [CV(f)], recruitment indices [CV(R)], and weights-at-age [CV(W)]. It is, however, instructive to partition the variation into two components. The first component designated by θ is due to the most recent year's estimators. The second designated by Φ is due to past years' data used to calibrate current measures.

We may thus write

$$\begin{aligned}\text{CV(TAC)}^2 = {} & (\theta(C) + \Phi(C))(\text{CV}(C))^2 \\ & + (\theta(f) + \Phi(f))(\text{CV}(f))^2 \\ & + (\theta(R) + \Phi(R))(\text{CV}(R))^2 \\ & + (\theta(W) + \Phi(W))(\text{CV}(W))^2\end{aligned} \tag{4.18}$$

Details of the calculation of the θ's and Φ's are shown in the mathematical appendix.

Where

(4.19) $Y(j) = W(j)\, C(t + 2, j)$

and

(4.20) $\delta(j) = 0$ for $j \leq 3$

(4.21) $\delta(j) = 1.0$ for $j > 3$

the formulae for the θ's and Φ's are

(4.22) $$\theta(C) = \sum_{j=4}^{g} [Y(j) + (Y(j-1)\,\delta(j-1) + Y(j-2)\,\delta(j-2))/(t+1)]^2/\mathrm{TAC}^2$$

(4.23) $$\theta(f) = \{\sum_{j=1}^{3} Y(j) - (2 + \frac{1}{t-1})\sum_{j=4}^{g} Y(j)\}^2/\mathrm{TAC}^2$$

(4.24) $$\theta(R) = \sum_{j=1}^{3} (Y(j)/\mathrm{TAC})^2$$

(4.25) $$\theta(W) = \sum_{j=1}^{g} (Y(j)/\mathrm{TAC})^2$$

(4.26) $$\Phi(C) = \{Y(1)^2(t-1) + [Y(3) - Y(4) - Y(5)]^2 + [Y(2) - Y(4)]^2 + \sum_{j=4}^{g} [Y(j-2) - Y(j)]^2(t-2) + \sum_{j=6}^{g} [Y(j) + Y(j-1)]^2\}/((t-1)\mathrm{TAC})^2$$

(4.27) $$\Phi(f) = \{[\sum_{j=1}^{3} Y(j) - 2\sum_{j=4}^{g} Y(j)]^2\,(t-2) + [\sum_{j=1}^{3} Y(j) - 3\sum_{j=4}^{g} Y(j)]^2\}/((t-1)\mathrm{TAC})^2$$

(4.28) $$\Phi(R) = \sum_{j=1}^{3} Y(j)^2/((t-1)\,\mathrm{TAC}^2)$$

(4.29) $$\Phi(W) = 0.$$

As with the leapfrog TAC the relative sizes of these components of variation will obviously depend on the relative sizes of the $Y(j)$ which will vary from year to year. It is thus only possible to say what the coefficient of variation of the TAC will be in a particular set of circumstances.

The components of variation are thus best discussed in the context of the example in the next section.

5. Examples of the Methods and Their Variance

To prepare examples of the leapfrog TAC and the ANOVA TAC the data presented by the ICES North Sea Roundfish Working Group of 1979 (Anon. 1979) for North Sea cod were used. Their catch-at-age data for the years 1969–78 together with the recruitment indices for these years form the basis of the examples.

In order that conventional methods of forecasting could be made to compare with the leapfrog and ANOVA TACs, the catch-at-age data for ages 2–11 were interpreted using separable VPA (Pope and Shepherd 1982) for the combinations of F_{78}, S_{11} and M shown in the text table.

	F_{78}	S_{11}	M
Run I	0.9	1	0.1
Run II	0.8	1	0.2
Run III	0.7	1	0.3

The resulting series of $F(i)$'s correlated extremely closely as shown in the text table.

Correlation matrix of $F(i)$'s

	Run I	Run II	Run III
Run I	1.000	0.999	0.997
Run II	0.999	1.000	0.999
Run III	0.997	0.999	1.000

It is clear therefore that a measure of international fishing effort which correlated reasonably with one of these series would correlate reasonably with the other two and that therefore fishing effort data would not in this case enable us to choose between the various levels of natural mortality adopted. A similar result was reported by Pope (1979).

Unfortunately, the effort data for this stock do not give a very close relationship with the fishing mortalities and so were not used in the examples. Instead the actual annual fishing mortalities for the years generated by run II were used as though they were fishing effort. Using this measure of fishing effort:

1) illustrated that for the ANOVA TAC the regression of $\alpha(i) + \mu$ on $\frac{1}{2}\ln(F(i+1)/F(i)^3)$ would have a high correlation (0.990) with effort data which is proportional to fishing mortality;

2) illustrated that for both the leapfrog TAC and the ANOVA TAC the predicted catch-at-age and the actual weight would be similar to those calculated by conventional methods given good data.

The results from runs I to III and the recruitment data were then used to form the basis of a predicted 1979 TAC such that $F(1979) = F(1977)$ for each M level. The catch-at-age predicted from each of these forecasts and the catch weight in 1979 were estimated as were the equivalent leapfrog TAC results. These are shown in Table 1 which indicates the closeness of the results from the different M's and the similarity of these to the leapfrog TAC result. The calculations involved in estimating the leapfrog TAC are shown in Appendix B. These results do not therefore contradict the conclusion, based on the formulation of the leapfrog TAC, that status quo TACs are not altered by the natural mortality level used.

The values of the components of variation (calculated from the $M = 0.2$ run) are

TABLE 1. Comparison of the results of a leapfrog TAC with normal forecasts for North Sea cod, 1979, assuming $F_{79} = F_{77}$

	Catch at age in 1979			
		Forecast		
Age	Leapfrog	$M = 0.1$	$M = 0.2$	$M = 0.3$
1	16 167	7 328	7 481	7 590
2	42 721	46 018	46 098	45 635
3	35 693	48 138	47 455	46 584
4	4 058	4 242	4 205	4 168
5	3 646	2 788	2 752	2 715
6	922	793	777	759
7	379	298	293	287
8	106	97	95	91
9	112	155	152	150
10	30	36	36	35
11	14	9	9	9
12	2	7	6	6
TAC (1 000 t)	169	187	185	183

(5.1) $$\mathrm{CV(TAC)}^2 = 1.35\ \mathrm{CV}(C)^2 + 7.66\ \mathrm{CV}(f)^2 + 0.001\ \mathrm{CV}(R)^2 + 0.33\ \mathrm{CV}(W)^2.$$

Thus if the coefficient of variation of each of the inputs was 10%, then the coefficient of variation of the TAC would be 30.6%. This of course would be largely a result of the variability of fishing effort. Clearly, it would be unwise to use a leapfrog TAC unless no other method was available and we had reasonable confidence in the fishing effort measure.

It seems unlikely that this coefficient of variation is applicable to status quo TACs calculated in the conventional fashion since it is much higher than those that result from the simulations shown in Pope and Gray (1983).

TABLE 2. Comparison of an ANOVA TAC with normal forecasts for the North Sea cod in 1980 assuming $F_{80} = F_{78}$.

	Catch at age in 1 000's in 1980			
		Forecast		
Age	ANOVA	$M = 0.1$	$M = 0.2$	$M = 0.3$
1	12 645	10 205	13 436	13 705
2	26 005	25 531	25 633	25 697
3	19 720	15 848	16 032	15 971
4	16 603	15 430	15 333	15 211
5	1 707	1 696	1 695	1 698
6	1 194	1 154	1 153	1 150
7	383	341	337	332
8	128	118	117	116
9	65	54	52	51
10	54	52	51	51
11	15	15	15	15
12	5	7	6	6
TAC (1 000 t)	159	145	146	146

The results of runs I-III and the recruitment data were also used to predict a 1980 TAC such that $F(1980) = F(1979) = F(1978)$ for each M level. The catch-at-age predicted from each of these forecasts and the catch weight in 1980 were estimated as were the equivalent ANOVA TAC results. These are shown in Table 2 which indicates the closeness of the results from the different M's and the similarity of these to the ANOVA TAC. The computations involved in estimating the ANOVA TAC are shown in Appendix B. Again the conclusion that status quo TACs are little affected by the value of M used seems to be upheld. The values of the components of variation calculated from the $M = 0.2$ run are shown in the text table.

Components of variation for the ANOVA TAC for North Sea cod, 1980.

$\theta(C) = 0.19$	$\Phi(C) = 0.02$
$\theta(f) = 0.60$	$\Phi(f) = 0.07$
$\theta(R) = 0.08$	$\Phi(R) = 0.01$
$\theta(W) = 0.25$	$\Phi(W) = 0.00$

The coefficient of variation of the TAC is thus given by

(5.2) $$\mathrm{CV(TAC)}^2 = 0.21\ \mathrm{CV}(C)^2 + 0.67\ \mathrm{CV}(f)^2 + 0.09\ \mathrm{CV}(R)^2 + 0.25\ \mathrm{CV}(W)^2.$$

Thus if the coefficient of variation of each of the inputs was 10%, then the coefficient of variation of the TAC would be 11%.

It is instructive to compare this result with a simulation of the 1980 TAC using the method explained in Pope and Gray (1983). Table 3 shows comparisons of the results obtained from equation (5.2) and from the simulations for a number of different coefficients of variation of the catch-at-age data, fishing effort data, and recruitment data. In this example catch-weight-at-age data are considered to have zero variance in these comparisons since it is not allowed for in the Pope and Gray method. The results are very similar for the cases where only catch-at-age data and recruitment vary but the ANOVA results are more than 50% larger than the simulated results when effort data are the sole source of variation.

A multiple regression of the simulated results with $\mathrm{CV(TAC)}^2$ as the dependent variable and with $\mathrm{CV}(C)^2$, $\mathrm{CV}(f)^2$ and $\mathrm{CV}(R)^2$ as the independent variables gave a best fit (where the line is forced through the origin) of

(5.3) $$\mathrm{CV(TAC)}^2 = 0.34\ \mathrm{CV}(C)^2 + 0.30\ \mathrm{CV}(f)^2 + 0.07\ \mathrm{CV}(R)^2.$$

Comparing this with equation (5.2) indicates the close agreement of those formulae on the effect of variation in catch-at-age data and recruitment data but suggests that in this case the effect of variation in fishing effort might be overestimated by the ANOVA TAC calculation. Tentatively this discrepancy may be associated with the approximation adopted to obtain (4.9) and hence equation (4.23). This approximation may result in the coefficient of variation of fishing mortality being substituted for 100× the

TABLE 3. Comparison of coefficients of variation of a status quo TAC for North Sea cod in 1980 calculated from equation (5.2) (ANOVA) and simulated using the method of Pope and Gray (1983) (P & G).

		Coefficients of variation of:							
		Recruitment data							
		0		15		30		60	
Effort data	Catch-at-age data	ANOVA	P & G	ANOVA	P & G	ANOVA	P & G	ANOVA	P & G
0	0	0	0	4	4	9	8	18	16
	10	5	4	6	6	10	10	19	16
	20	9	9	10	10	13	12	20	18
	40	18	19	19	19	20	21	26	25
15	0	12	11	13	11	15	15	22	19
	10	13	12	14	12	16	14	22	20
	20	15	14	16	15	18	17	24	22
	40	22	23	23	23	24	25	28	29
30	0	25	16	25	22	26	21	30	25
	10	25	21	25	21	27	23	31	26
	20	26	23	27	23	28	24	32	28
	40	31	31	31	32	32	33	36	35
60	0	49	31	49	32	50	32	52	35
	10	49	32	50	32	50	33	53	36
	20	50	34	50	35	51	35	53	38
	40	52	42	53	42	53	43	55	45

standard deviation of fishing mortality for 4+. Equation (4.23) might perhaps be more correctly written as

$$(5.4) \quad \theta(f) = \{\sum_{j=1}^{3} Y(j) - F(2 + \frac{1}{t-1}) \sum_{j=4}^{g} Y(j)\}^2/\mathrm{TAC}^2.$$

Certainly this change gives a value of $\theta(f) = 0.35$ in the example and hence a revised form of equation (5.2) of

$$(5.5) \quad \mathrm{CV(TAC)}^2 = 0.21\ \mathrm{CV}(C)^2 + 0.35\ \mathrm{CV}(f)^2 + 0.09\ \mathrm{CV}(R)^2 + 0.25\ \mathrm{CV}(W)^2.$$

This compares very well with equation (5.3) with $\mathrm{CV}(C) = 40\%$, $\mathrm{CV}(f) = 60\%$ and $\mathrm{CV}(R) = 60\%$; equation (5.3) gives $\mathrm{CV(TAC)} = 44\%$ which is almost exactly the figure given by simulation.

Thus equation (5.4) might be used in preference to equation (4.23) when calculating the variability of a status quo TAC calculated in the standard fashion. Equation (4.23) should, however, be regarded as the estimate of the variability of the ANOVA TAC which is presumably therefore more variable in some circumstances than the standard method. This might be viewed as the price paid for not using an estimate of natural mortality when the ANOVA TAC is calculated.

6. Discussion and Conclusions

The two new status quo TAC formulations explained in sections 3 and 4 of this report indicate that such TACs may be computed without a knowledge of M. This conclusion also seems to be supported by the numerical results of Section 5. This would suggest that status quo TACs are not particularly sensitive to the value of M used. However, unless we know M it is difficult to know whether we should maintain the status quo or increase or decrease the level of fishing for optimum yield. Nevertheless, status quo TACs are robust short-term measures that might be combined with robust indicators of optimum yield (possibly Schaefer curves) to provide a sensible basis for fisheries management as suggested in Pope (1979).

The chief virtue of both the leapfrog and the ANOVA methods is their simple structure which enables us to calculate the variability introduced into the TACs calculated by variable input data. This indicates that the leapfrog method is very sensitive to variability in fishing effort data and should only be used if sufficient data for other methods are unavailable. The variability of the ANOVA TAC is, however, far less sensitive to the variability of fishing effort. Indeed, the formulation suggests that, when the contribution of the recruiting ages to the TAC is twice the contribution of the older ages, the effect of variability in effort data may be largely canceled out in the resulting TAC. Another interesting feature of the ANOVA TAC formulation is that variability in the most recent years' data is far more important than variability in the past year's data used to calibrate it. In fact, these effects tend to be about $1.0/(t - 1)$ smaller where t is the number of years data available.

The steps involved in estimating an ANOVA TAC closely parallel the steps used to estimate a status quo TAC in the standard fashion. The example of Section 5 also suggests that the ANOVA TAC is a reasonably close analogy to the standard method. It would therefore seem worthwhile to use the equations (4.18)–(4.29) to study the relationship between input data variability and TAC variability as a first step in optimizing the sampling of input data.

The actual values of the components of variation in equations (5.1), (5.2), (5.3), and (5.5) obviously depend heavily on the age structure of the catch in the TAC year. Equations (4.18)–(4.29) indicate that large incoming year-classes will emphasize the variation in R and diminish the importance of the variation in f. Conversely, f will be most important for low mortality stocks where most of a TAC is taken from nonrecruiting ages. This would be the case where a recruitment failure has occurred indicating that in these circumstances estimates of status quo TACs become more variable. A special case of this would arise if all the TAC was taken from age 4. This same situation would also give the worst case situation for catch-at-age and weight-at-age data.

If we had 10 yr of data this worst case would give

(6.1) $$\mathrm{CV(TAC)}^2 = 1.05\ \mathrm{CV}(C)^2 + 4.96\ \mathrm{CV}(f)^2 + 1.00\ \mathrm{CV}(W)^2.$$

If in these rather unlikely circumstances we wished the coefficient of variation of the TAC to be 10% we could achieve this by sampling C, f, and W with coefficients of variation of 3.8% for each data set. It is quite unlikely, however, that a 3.8% coefficient of variation for fishing effort data could be attained since its variation may be more due to the natural variation of the catchability coefficient than the sampling variability of fishing effort. This factor may therefore determine how accurately it is worth sampling catch-at-age or weight-at-age data. The worst case situation for $\theta(R) + \Phi(R)$ is when all the TAC comes from one recruiting age. In this case $\theta(R) + \Phi(R) = 1.0 + 1.0/(t - 1)$. If all the catch came from age 2 or 3 and we had 10 yr of data we would have

(6.2) $$\mathrm{CV(TAC)}^2 = 0.11\ \mathrm{CV}(C) + 1.11\ \mathrm{CV}(f)^2 + 1.11\ \mathrm{CV}(R)^2 + 1.0\ \mathrm{CV}(W)^2.$$

We might therefore judge that coefficients of variation of from 3 to 5% would be desirable for each of these data sets so that in almost any circumstances we would have a TAC with a 10% coefficient of variation or better. In practice, such a level of precision is unlikely to be achieved.

An alternative to concentrating on worst case levels of coefficient of variation of TAC is to require only that the average TAC has a coefficient of variation of 10%. This would require much less precise input data series. Probably a sensible way to decide on the appropriate precision for input series would be to use equations (4.18) through (4.29) and (5.4) to estimate the components of variation for the stock configurations shown in past years.

Table 4 shows the values each θ and Φ would have taken supposing the past years' North Sea cod catch-at-age data to have been realizations of ANOVA TACs. On average then this suggests a coefficient of variation of

(6.3) $$\mathrm{CV(TAC)}^2 = 0.08\ \mathrm{CV}(C)^2 + 0.20\ \mathrm{CV}(f)^2 + 0.22\ \mathrm{CV}(R)^2 + 0.25\ \mathrm{CV}(W)^2$$

if equation (4.23) is used for $\theta(f)$. If equation (5.4) is used for $\theta(f)$

(6.4) $$\mathrm{CV(TAC)}^2 = 0.08\ \mathrm{CV}(C)^2 + 0.11\ \mathrm{CV}(f)^2 + 0.22\ \mathrm{CV}(R)^2 + 0.25\ \mathrm{CV}(W)^2.$$

Coefficients of variation of 10% in all the input data would thus lead to an average coefficient of variation of <9% in the TAC in either case. Perhaps more importantly since the sum of the θ and Φ are less than 1.0 in nearly every year, a coefficient of variation of 10% on all input data would have resulted in coefficients of variation of the TACs of <10% in all of the years except perhaps 1969 and 1970; the worst case being 1969 when the coefficient of variation of the TAC would have been 11%.

The above results suggest that provided we can accept that the variation of the ANOVA TAC is a reasonable

TABLE 4. Values of the θ and Φ for each input data set calculated from the catch-at-age data of North Sea cod (1969–78) assuming these to be ANOVA TAC estimates based on 10-yr data.

Year	$\theta(C)$	$\theta(f)^a$	$\theta(f)^b$	$\theta(R)$	$\theta(W)$	$\Phi(C)$	$\Phi(f)$	$\Phi(R)$	$\Phi(W)$	Total[a]	Total[b]
1969	0.13	0.66	0.07	0.10	0.21	0.01	0.08	0.01	0.00	1.21	0.61
1970	0.13	0.69	0.14	0.06	0.16	0.01	0.08	0.01	0.00	1.14	0.58
1971	0.03	0.00	0.06	0.25	0.27	0.02	0.00	0.03	0.00	0.60	0.66
1972	0.01	0.09	0.16	0.33	0.34	0.03	0.01	0.04	0.00	0.84	0.91
1973	0.06	0.01	0.01	0.22	0.27	0.02	0.00	0.02	0.00	0.62	0.62
1974	0.07	0.15	0.04	0.14	0.20	0.01	0.02	0.02	0.00	0.60	0.49
1975	0.07	0.09	0.02	0.13	0.19	0.01	0.01	0.01	0.00	0.51	0.44
1976	0.04	0.00	0.02	0.26	0.29	0.02	0.00	0.03	0.00	0.63	0.65
1977	0.02	0.09	0.20	0.20	0.21	0.02	0.01	0.02	0.00	0.56	0.68
1978	0.02	0.07	0.14	0.35	0.37	0.03	0.01	0.04	0.00	0.89	0.96
Average	0.06	0.18	0.09	0.20	0.25	0.02	0.02	0.02	0.00	0.76	0.66

[a]Using equation (4.23).
[b]Using equation (5.4).

analogy of the variation of a conventionally forecast status quo TAC, we are able to make some suggestions as to suitable coefficients of variation for the stock assessment data to be collected for this purpose.

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Mathematical Appendix A

Derivation of Equations (4.18)–(4.29)

From equations (4.13) and (4.16) we may write

$$\text{(A1)} \quad \text{TAC} = \sum_{j=1}^{3} W(j)\, f(t)\, R(t+2, j)\, \bar{r}(j) + \sum_{j=4}^{g} W(j)\, C(t, j-2) \exp\{2\alpha(t) + \beta(j-1) + \beta(j-2) + 2\mu + \sigma_1^2\}.$$

Further, using equations (4.11) and (4.12), and recalling that

$$(t-1)(\beta(j) + \mu) = \sum_{i=1}^{t-1} n[C(i+1, j+1)/C(i, j)]$$

we may write

$$\text{(A2)} \quad \exp\{2\alpha(t) + \beta(j-1) + \beta(j-2) + 2\mu + \sigma_1^2\} = [\exp \sigma_1^2] \left\{\frac{f(1)}{f(t)} \prod_{i=1}^{t-1} f(i)^2\right\}^{1/(t-1)} f(t)^{-2} \left\{\frac{C(t, j-1)}{C(1, j-1)} \prod_{i=1}^{t-1} \left[\frac{C(i+1, j)}{C(i, j-2)}\right]\right\}^{1/(t-1)}.$$

Substituting this and equation (4.14) in equation (A1) allows the TAC to be written as a function of the input variable set $C(i,j)$, $f(i)$, $R(i,j)$, $W(j)$ and the two variances σ_1^2 and σ_2^2.

We may therefore follow the approach used in Section 3 of developing a first approximation to ΔTAC, in terms of small errors in the input variables, using the first order terms of a Taylor expansion. This may then be squared and summed for all possible values (assuming the independence of each data type) to obtain an approximate equation relating the coefficient of variation of the TAC to the coefficients of variation of the input variable set. Designating members of the input variable set as $x(k)$ the approximate equation is thus

$$\text{(A3)} \quad \text{CV(TAC)}^2 = \sum_{\text{all } k} \left\{\frac{\partial \text{TAC}}{\partial x(k)} \frac{x(k)}{\text{TAC}}\right\}^2 \text{CV}(x(k))^2.$$

Developing this for each $x(k)$ would lead to a very extensive equation. To simplify matters, therefore, we will consider only the case where the various types of input variable have each a common coefficient of variation. Thus for all i and j

$$\text{(A4)} \quad \text{CV}(C(i,j)) = \text{CV}(C)$$

$$\text{(A5)} \quad \text{CV}(f(i)) = \text{CV}(f)$$

$$\text{(A6)} \quad \text{CV}(R(i,j)) = \text{CV}(R)$$

$$\text{(A7)} \quad \text{CV}(W(j)) = \text{CV}(W).$$

Since the current levels of input variables (the $C(t,j)$, $f(t)$, $R(t+2, j)$, and $W(j)$) enter equations (A1) and (A2) in a different way to those of the earlier years it is worth splitting the variability of the TAC into components due to the current levels of the input values (designated by $\theta(C)$, $\theta(f)$, $\theta(R)$, and $\theta(W)$) and to those due to past values (designated by $\Phi(C)$, $\Phi(f)$, $\Phi(R)$, and $\Phi(W)$).

We may now develop the equations for each θ and Φ in turn.

$$\text{(A8)} \quad \theta(C) = \sum_{j=1}^{g} \left\{\frac{\partial \text{TAC}}{\partial C(t, j)} \frac{C(t, j)}{\text{TAC}}\right\}^2$$

and hence from equations (A1) and (A2) we may write

setting $\delta(j) = 0$ for $j \leq 3$

and $\delta(j) = 1$ for $j > 3$

$$\text{(A9)} \quad \theta(C) = \sum_{j=4}^{g} \left[Y(j) + \frac{(Y(j-1)\,\delta(j-1) + Y(j-2)\,\delta(j-2))}{t-1}\right]^2 / \text{TAC}^2$$

$$\theta(f) = \left\{\frac{\partial \text{TAC}}{\partial f(t)} \frac{f(t)}{\text{TAC}}\right\}^2$$

and hence from equations (A1) and (A2)

$$\text{(A10)} \quad \theta(f) = \left\{\sum_{j=1}^{3} Y(j) - \left(2 + \frac{1}{t-1}\right) \sum_{j=4}^{g} Y(j)\right\}^2 / \text{TAC}^2$$

$$\text{(A11)} \quad \theta(R) = \sum_{j=1}^{3} \{\frac{\partial \text{TAC}}{\partial R(t+2, j)} \frac{R(t+2, j)}{\text{TAC}}\}^2.$$

Hence from equation (A1)

$$\text{(A12)} \quad \theta(R) = \sum_{j=1}^{3} (Y(j)/\text{TAC})^2.$$

$$\text{(A13)} \quad \theta(W) = \sum_{j=1}^{g} \{\frac{\partial \text{TAC}}{\partial W(j)} \frac{W(j)}{\text{TAC}}\}^2.$$

Hence from equation (A1)

$$\text{(A14)} \quad \theta(W) = \sum_{j=1}^{g} \{Y(j)/\text{TAC}\}^2$$

$$\text{(A15)} \quad \Phi(C) = \sum_{i=1}^{t-1} \sum_{j=1}^{g} \{\frac{\partial \text{TAC}}{\partial C(i, j)} \frac{C(i, j)}{\text{TAC}}\}^2.$$

Hence from equations (A1) and (A2) and after some rearrangement

$$\text{(A16)} \quad \Phi(C) = \{Y(1)^2 (t-1) + [Y(3) - Y(4) - Y(5)]^2 + [Y(2) - Y(4)]^2 + \sum_{j=4}^{g} [Y(j-2) - Y(j)]^2 (t-2) + \sum_{j=6}^{g} [Y(j) + Y(j-1)]^2\}/\text{TAC}^2 (t-1)^2$$

$$\text{(A17)} \quad \Phi(f) = \sum_{i=1}^{t-1} \{\frac{\partial \text{TAC}}{\partial f(i)} \frac{f(i)}{\text{TAC}}\}^2.$$

Hence from equations (A1) and (A2)

$$\text{(A18)} \quad \Phi(f) = \{\sum_{j=1}^{3} Y(j) - 2\sum_{j=4}^{g} Y(j)\}^2 \frac{t-2}{(t-1)^2 \text{TAC}^2} + \{\sum_{i=1}^{3} Y(j) - 3\sum_{j=4}^{g} Y(j)\}^2 \times \frac{1}{(t-1)^2\,\text{TAC}^2}$$

$$\text{(A19)} \quad \Phi(R) = \sum_{i=1}^{t-1} \sum_{j=1}^{3} \{\frac{\partial \text{TAC}}{\partial R(i, j)} \frac{R(i, j)}{\text{TAC}}\}^2.$$

Hence from equations (A1) and (4.14)

$$\text{(A20)} \quad \Phi(R) = \sum_{j=1}^{3} Y(j)^2/(t-1)\,\text{TAC}^2.$$

Since the terms for W are only concerned with the current year

$$\text{(A21)} \quad \Phi(W) = 0.$$

Apart from the components due to the input variables, components are also due to the σ_1^2 and σ_2^2. These, however, result in second order terms and since, for this simple exposition, such terms have otherwise been ignored, it seems inappropriate to include them.

Appendix B

Examples of the Calculation of Leapfrog and ANOVA TACs

Data Inputs

The data used to calculate the leapfrog and ANOVA TACs shown in Tables B1 and B2 were as follows. Catch-at-age, weight-at-age data and recruitment indices for the 1968–76 year-class (from the International Young Herring Survey) were as given for North Sea cod in Anon. (1979). Lower estimates were adopted for the recruitment indices of the 1977–79 year-classes equivalent to those used for the standard method runs on Table B2. The fishing effort data were also the same as were used for the standard runs. As a result the TACs estimated are somewhat lower than those given in Anon. (1979) and are only intended for illustrative purposes and not as an alternative assessment of North Sea cod.

Construction of the Leapfrog TAC

The construction of the leapfrog TAC is shown in Table B1. The data used are fishing effort for 1977 and 1978, recruitment indices for 1-yr-old fish in 1978 and 1979, and catch-at-age data for 1977 and 1978. The calculations are very simple. Column A shows the product of

$$C(1978, j+1)\ C(1978, j)/C(1977, j).$$

Column B shows the product of

$$\text{Column A} \times \{f(1977)/f(1978)\}^2.$$

This is the value of $C(1979, j+1)$ given by equation (3.4). Column C shows the product of

$$C(1978,1)\ R(1979)\ f(1977)/R(1978)\ f(1978)$$

which is the value of $C(1979,1)$ given by equation (3.7).

The catch-at-age estimates for 1979 are set out under Results. These multiplied by the weight-at-age data and summed give the estimate of the leapfrog TAC of 169 311 t.

Construction of the ANOVA TAC

The construction of the ANOVA TAC is shown in Tables B2–B5. Table B2 shows the log catch ratio matrix for North Sea cod based on catch-at-age data from ages 2 to 10 for 1969–78. The grand total was estimated and divided by the number of cells to give an estimate of μ. Age totals were estimated. These were divided by 9 (the number of cells on which they were based) and μ subtracted to give estimates of the $\beta(j)$. Year totals were estimated and divided by 9 to estimate the $\alpha(i) + \mu$ terms. A linear regression of these terms on $0.5 \ln f(i+1) - 1.5 \ln f(i)$ was then performed. This was highly significant and gave a prediction of $\alpha(1978) + \mu = -1.05$. A two-way ANOVA was then performed on the log catch ratio data to estimate the residual mean square which was used to estimate $\sigma_1^2 = 0.11$.

TABLE B1. Calculation of a leapfrog TAC for North Sea cod, 1979.

Data			Calculations A	Calculations B	Calculations C	Results $C(79,j)$ ('000)	Results $W(j)$ (kg)	Results $Y(j)$ (t)
i	77	78						
$f(i)$	0.6774	0.8000						
$R(i+1)$	9.9	4.9						
$C(i, j)$	('000)	('000)						
j = 1	109 448	38 575	59 584	42 721	16 167	16 167	0.50	8 084
2	51 760	169 055	49 782	35 693		42 721	0.91	38 876
3	22 560	15 242	5 660	4 058		35 693	2.02	72 100
4	4 170	8 378	5 085	3 646		4 058	3.83	15 542
5	1 748	2 531	1 286	922		3 646	5.76	21 001
6	595	888	528	379		922	7.65	7 053
7	811	354	148	106		379	9.13	3 460
8	273	338	156	112		106	10.39	1 101
9	96	126	42	30		112	11.26	1 261
10	23	32	19	14		30	12.02	361
11	8	14	32	23		14	12.51	175
12	53	18				23	12.92	297

Leapfrog TAC = 169 311 t

A = $C(1978, j+1)\, C(1978, j)/C(1977, j)$ } equation (3.4)

B = $A\, (f(1977)/f(1978))^2$ } equation (3.4)

C = $C(1978,1)\, R(1979)\, f(1977)/(R(1978)\, f(1978))$ — equation (3.7)

The results from Table B2 were then used in Table B3 with the 1978 catch-at-age data to estimate catch-at-age in 1979 for age 3 and older and catch-at-age in 1980 for age 4 and older. These were estimated by multiplying the catch-at-age j in 1978 by $\exp(E(j))$ to give the catch-at-age $j+1$ in 1979. This was then multiplied by $\exp(E(j+1))$ to give the catch-at-age $j+2$ in 1980. $E(j)$ being taken as the value of

$$\alpha(1978) + \beta(j) + \mu + \sigma_1^2/2$$

estimated in Table B2.

To estimate the catch of 1-, 2-, and 3-yr-old fish in 1980, the calculation shown in Table B4 was performed. The value of

$$\ln\{C(i, 1)/[f(i) \times R(i, 1)]\}$$

$$\ln\{C(i, 2)/[f(i) \times R(i, 2)]\}$$

$$\ln\{C(i, 3)/[f(i) \times R(i, 3)]\}$$

was computed for each year from 1969 to 1978. The mean and variance of these were then computed for each age and the exponential of the mean + ½ variance was multiplied by the fishing effort and the appropriate recruitment index for 1980. It was noted that the Young Herring Surveys gave a poor estimation of the 3-yr-olds.

The results of all these calculations are set out in Table B5, which shows the catch-at-age data for 1980, the weight-at-age and the resulting ANOVA TAC for 1980.

TABLE B2. Calculation of an ANOVA TAC for North Sea cod, 1980. Part 1: $\ln\{C(i+1,j+1)/C(i,j)\}$ matrix and the derivation of $\alpha(1978)$, μ, $\beta(j)$ and σ_1^2.

	$\ln\{C(i+1, j+1)/C(i, j)\}$												
	j									Col. A	Col. B = *A*/9	Col. C	Col. D
i	2	3	4	5	6	7	8	9	10	Totals	$\alpha(i) + \mu$	0.5 $\ln(f(i+1))$ $-1.5\ln(f(i))$	$f(i)$
1969	−0.34	−0.95	−0.78	−0.97	−0.99	−1.20	−0.54	−0.22	−0.16	− 6.16	−0.68	0.67	0.55
1970	−0.64	−1.01	−0.70	−1.05	−0.95	−0.99	−0.13	−0.99	−0.94	− 7.41	−0.82	0.49	0.63
1971	−1.23	−1.05	−0.91	−0.77	−0.50	−0.33	−0.15	−0.58	−1.41	− 6.92	−0.77	0.51	0.66
1972	−1.31	−1.20	−0.97	−0.84	−1.04	−1.09	−1.00	−2.11	−0.47	−10.04	−1.12	0.17	0.79
1973	−0.95	−1.24	−1.10	−0.67	−0.79	−0.97	−0.45	−1.12	−0.16	− 7.46	−0.83	0.45	0.69
1974	−1.11	−1.06	−0.86	−0.97	−0.95	−1.19	−0.76	−1.46	−0.81	− 9.17	−1.02	0.24	0.80
1975	−1.04	−1.00	−1.06	−1.04	−0.82	−0.70	−0.98	−1.18	−1.64	− 9.47	−1.05	0.20	0.82
1976	−1.46	−1.53	−1.31	−0.87	−1.02	−0.98	−0.67	−0.85	−1.91	−10.60	−1.18	0.10	0.82
1977	−1.22	−0.99	−0.50	−0.68	−0.52	−0.88	−0.77	−1.10	−0.49	− 7.15	−0.79	0.47	0.68
												(0.22)	0.80
t = 1978													
Totals	−9.32	−10.05	−8.19	−7.86	−7.59	−8.33	−5.44	−9.62	−7.98	−74.38		0.80	
$\beta(j)$ = Totals/9.0 − μ	−0.12	− 0.20	+0.01	+0.04	+0.07	−0.01	+0.31	−0.15	+0.03	$\mu = -74.38/81 = -0.92$			

Linear regression of *B* on *C* gives
$R = 0.99$, df = 7, $P < 0.001$
$\alpha(i) + \mu = -1.25 + 0.90\{0.5 \ln f(i+1) - 1.5 \ln f(i)\}$
$\alpha(1978) + \mu = -1.25 + 0.90 \times 0.22 = -1.05$

ANOVA

Cause	df	Sum sq.	Mean sq.	*F* ratio	*P*
Years	8	2.20	0.28	2.53	<0.05
Ages	8	1.65	0.21	1.90	<0.10
Residual	64	6.97	0.11		
Total	80	10.82			

$\sigma_1^2 = 0.11$

TABLE B3. Calculation of an ANOVA TAC for North Sea cod, 1980. Part 2: estimation of $C(1980,4)$ to $C(1980,12)$.

j	$E(j)$[a]	$C(1978, j)$ ('000)	exp[$E(j)$]	$C(1979, j+1)$ ('000)	exp[$E(j+1)$]	$C(1980, j+2)$ ('000)	$j+2$
2	−1.12	169 055	0.326	55 159	0.301	16 603	4
3	−1.20	15 242	0.301	4 588	0.372	1 707	5
4	−0.99	8 378	0.372	3 117	0.383	1 194	6
5	−0.96	2 531	0.383	969	0.395	383	7
6	−0.93	888	0.395	351	0.364	128	8
7	−1.01	354	0.364	129	0.502	65	9
8	−0.69	338	0.502	170	0.317	54	10
9	−1.15	126	0.317	40	0.379	15	11
10	−0.97	32	0.379	12	(0.379)	5	12

[a] $E(j) = \alpha(1978) + \beta(j) + \mu + \sigma_1{}^2/2$.

Table B4. Calculation of an ANOVA TAC for North Sea cod, 1980. Part 3: estimation of C(1980, 1) to C(1980, 3).

i	$C(i, 1)$ ('000)	$f(i)$	$R(i, 1)$	$\ln\{C/(f \times R)\}$	$C(i, 2)$ ('000)	$f(i)$	$R(i, 2)$	$\ln\{C/(f \times R)\}$	$C(i, 3)$ ('000)	$f(i)$	$R(i, 3)$	$\ln\{C/(f \times R)\}$
1969	5 109	0.55	6.3	7.30	23 009	0.55	5.5	8.94	31 590	0.55	30.5	7.54
1970	47 304	0.63	59.9	7.13	27 373	0.63	6.3	8.84	16 392	0.63	5.5	8.46
1971	61 347	0.66	89.4	6.95	149 128	0.66	59.9	8.24	14 385	0.66	6.3	8.15
1972	6 317	0.79	2.8	7.96	195 922	0.79	89.4	7.93	43 709	0.79	59.9	6.83
1973	33 809	0.69	31.5	7.35	30 551	0.69	2.8	9.67	52 648	0.69	89.4	6.75
1974	15 715	0.80	11.2	7.47	53 537	0.80	31.5	7.66	11 799	0.80	2.8	8.57
1975	35 086	0.82	54.5	6.67	54 771	0.82	11.2	8.69	17 597	0.82	31.5	6.52
1976	7 165	0.82	6.1	7.27	97 453	0.82	54.5	7.69	19 330	0.82	11.2	7.65
1977	109 448	0.68	44.2	8.20	51 760	0.68	6.1	9.43	22 560	0.68	54.5	6.41
1978	38 575	0.80	9.9	8.49	169 055	0.80	44.2	8.47	15 242	0.80	6.1	8.05
1979		0.80	4.9			0.80	9.9			0.80	44.2	
1980		0.80	7.6			0.80	4.9			0.80	9.9	

$\bar{x}_1 = 7.48$
$\sigma^2 = 0.32$
$C(1980, 1) = 7.6 \times 0.8 \exp(7.48 + 0.32/2)$
$= 12\,645$

$\bar{x}_2 = 8.56$
$\sigma^2 = 0.48$
$C(1980, 2) = 4.9 \times 0.8 \exp(8.56 + 0.48/2)$
$= 26\,006$

$\bar{x}_3 = 7.49$
$\sigma^2 = 0.66$
$C(1980, 3) = 9.9 \times 0.8 \exp(7.49 + 0.66/2)$
$= 19\,720$

Table B5. Calculation of ANOVA TAC for North Sea cod, 1980. Part 4: estimation of catch weight.

j	$C(1980, j)$ ('000)	$W(j)$ (kg)	$Y(j)$ (t)
1	12 645	0.50	6 323
2	26 006	0.91	23 665
3	19 720	2.02	39 834
4	16 603	3.83	63 589
5	1 707	5.76	9 832
6	1 194	7.65	9 134
7	383	9.13	3 497
8	128	10.39	1 330
9	65	11.26	732
10	54	12.02	649
11	15	12.51	188
12	5	12.92	65

TAC = 158 838 t

Effects of Systematic, Analytical, and Sampling Errors on Catch Estimates: A Sensitivity Analysis

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An algorithm that emulates certain aspects of the assessment for fish stocks of the northwest Atlantic is presented. Simulations are used to gain insight on the effects of various systematic, analytical, and sampling errors on catch estimates. This analysis suggests that, for a species like cod, catch projections are very sensitive to the independent index of stock size used for "tuning" sequential population analysis. Uncertainties of mean weight at age also appear as an important source of error in catch projections. A routine assessment of the relative impact of precision and accuracy of a given parameter on catch projections would permit the identification of critical elements of the sampling programs for a given fishery and lead to the design of efficient sampling programs.

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Un algorithme simulant certains aspects de l'évaluation des stocks de poissons sur la Côte Est du Canada est présenté et est utilisé afin de démontrer les effets de certaines erreurs systématiques, analytiques et d'échantillonnage sur l'estimation des prises. Cette analyse suggère que, pour une espèce comme la morue, le calcul des prises prévues est influencé largement par l'indice indépendant de la taille du stock qui est utilisé pour « ajuster » l'analyse séquentielle des populations. Le poids estimé moyen pour un âge donné apparaît également comme une source importante d'erreurs dans le calcul des prises. Pour une pêche donnée, l'auteur suggère qu'une évaluation routinière de l'impact relatif de la précision et de l'exactitude d'un paramètre donné sur le calcul des prises devrait permettre d'identifier les facteurs critiques des programmes d'échantillonnage et mener au développement de programmes d'échantillonnage plus efficaces.

Introduction

Many of the groundfish and pelagic stocks of the northwest Atlantic are currently managed through the application of a total allowable catch (TAC) calculated from a fishing mortality rate called $F_{0.1}$. The estimation of TACs generally involves a sequential population analysis (SPA) to reconstruct historical population levels and a projection model that uses the most recent information on growth and partial recruitment coefficients for estimating the catch at $F_{0.1}$ in future year(s).

Estimates obtained from sequential population analyses for recent years are particularly sensitive to the uncertainties of the initial F-values. Inaccurate "starting values" may generate spurious trends in stock size estimates. For this reason, one or more independent measures of stock size are often used to "tune" a sequential population analysis. It is the purpose of this paper to analyze the sensitivity of catch estimates obtained from projection when an independent measure of stock size is used to tune the sequential population analysis. Figure 1 outlines the different steps of an assessment for many groundfish and pelagic stocks in the northwest Atlantic.

The "Tuning Phase" of Sequential Population Analysis (SPA)

Typically, the determination of starting F's for sequential population analysis (e.g. cohort analysis or virtual population analysis) involves an iterative process which attempts to optimize a given criteria. For example, by assuming an arbitrary constant value for the instantaneous rate of natural mortality for all ages in all years, a cohort analysis is performed by using estimates of age-specific fishing mortalities in the last year, which are derived from estimates of partial recruitment in previous years and an arbitrary value for the fully recruited F in the most recent year. Input F's for the oldest age group in each year are also fixed arbitrarily. Then one or more criteria are used to "adjust" or "fine tune," in an iterative manner, the initial estimates so that the output of the cohort analysis "matches" some series of observations. This search for the "best" solution is often done either haphazardly or systematically (more or less), through the analysis of a series of cohort analyses (or "cohort runs") covering a wide range of values for input parameters. The objective function (i.e. the function to be optimized) is generally unspecified, the search being

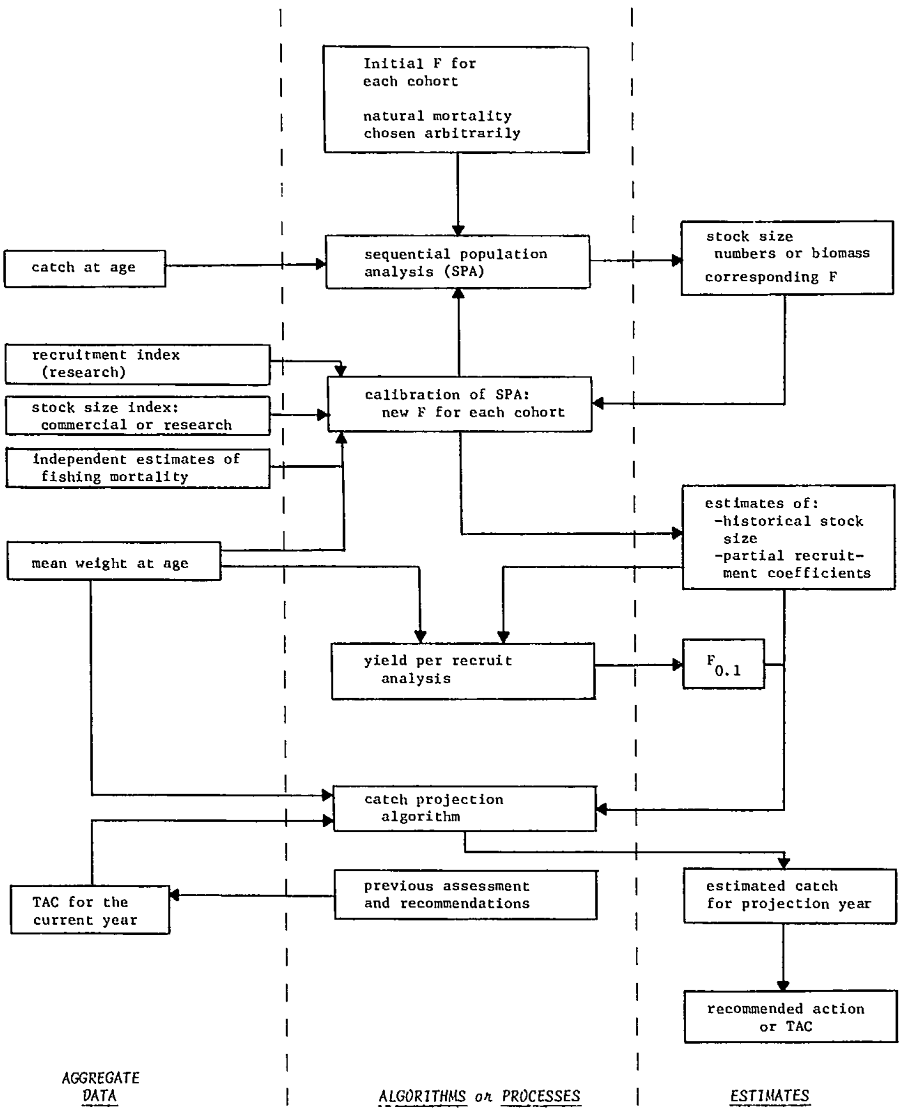

FIG. 1. Diagram showing how sequential population analysis, yield per recruit analysis, and the projection algorithm are used for estimating catch in the projection year(s). Such an assessment process is currently used for estimating total allowable catch (TAC) for many groundfish and pelagic stocks in the northwest Atlantic.

monitored by the analysis of graphical output. Sometimes correlations are used as an index of "best fit"; sometimes the purpose of this iterative scheme is to bring the final stock size calculated from SPA as close as possible to a regression line relating the results of a sequential population analysis and an independent index of stock size. Figure 2 summarizes some of the variables commonly used in this "tuning" process.

When independent measures of stock size are used to tune a sequential population analysis, the computation of terminal F-values clearly appears as an "estimation problem." Unless some constraints are applied, this estimation process will be poorly designed, since there are generally more unknowns than the number of observations. As a means of improving the design of this estimation process, it is generally accepted that the number of unknowns be kept to a minimum by making additional assumptions regarding the definition of terminal F-values for the oldest age group in each year and the definition of partial recruitment coefficients for the final year of the analysis. Failure to do this may give spurious results. For example, high correlations may not be indicative of a predictive capability if unknowns are as numerous as the observations: they are, instead, the direct result of a geometric manipulation of data. In this case, perfect correlations can be obtained; in practice, correlations that are lower than unity (say 0.85–0.99) have been reported in most assessments, mainly because the assignment of initial values is limited to a

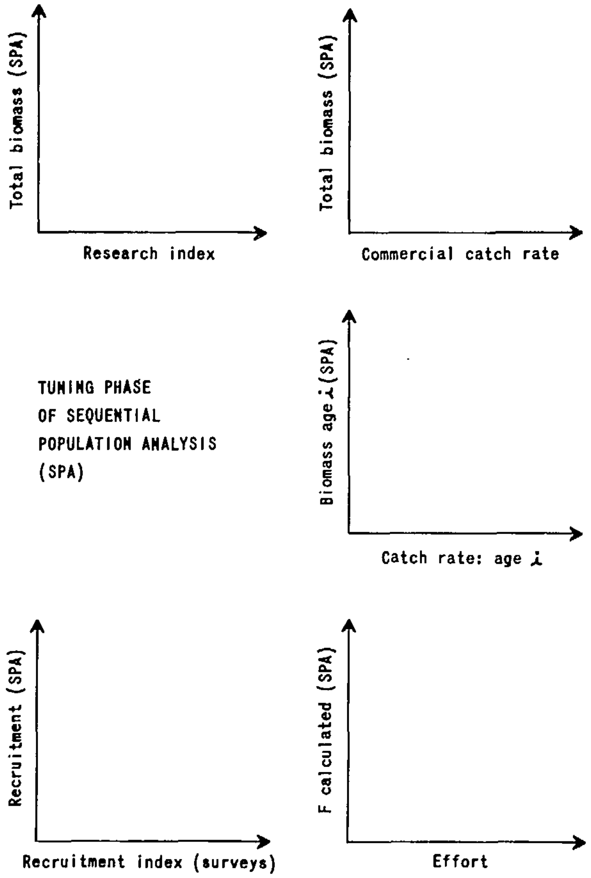

FIG. 2. Commercial catch rates, recruitment indices, and stock size estimates obtained from research surveys are commonly used for 'tuning' sequential population analyses. The relationship between effort and fishing mortalities calculated from sequential population analysis is used less frequently by the Canadian Atlantic Fisheries Scientific Advisory Committee.

domain of "biologically acceptable" values.

The objective function is often, in practice, multidimensional; in other words, more than one measure of stock size are used simultaneously to tune the sequential population analysis. The current optimization scheme does not guarantee that the solution found is optimal. In addition, results presented in Doubleday (1981) suggest that the "tuning phase" of sequential population analysis constitutes an inefficient estimation and that efficient estimates could be designed by considering sequential estimates of year-classes.

An Algorithm for the Tuning Phase

Notwithstanding the problems mentioned above, the tuning phase of sequential population analyses currently plays an important role in the stock assessment process (see O'Boyle 1981). Because each step of the tuning phase is under direct control of the "user," the impact of systematic, analytical, and sampling errors remains, too often, unclear. To obtain a clearer understanding of how such errors are propagated, it is thus necessary to eliminate subjective steps, to identify clearly the criteria to be optimized and to indicate a priori which assumptions will be made. In this section, an algorithm that mimics at least some of the processes of the tuning phase is outlined. Casting the form of certain relationships and objectively defining the purpose of the optimization process will lead to an assessment of the effect of various error types on catch estimates.

NOTATION

Year t_0 is the first year represented in the catch matrix and year t_f, the last. Age b is the youngest age represented in the catch matrix and age m, the oldest. Consequently, $C_{i,t}$ ($i = b, ..., m$; $t = t_0 ... t_f$) identifies each element of the catch matrix. Age-specific estimates of stock size and fishing mortality rates obtained from cohort analysis (Pope 1972) are identified by $N_{i,t}$ and $F_{i,t}$, respectively. Finally, $W_{i,t}$ identifies the mean weight of age group i in year t; similarly, $B_{i,t}$ identifies the stock biomass. For this study, the natural mortality rate, say M, is assumed to be constant for all ages in all years.

STAGE 1

The first stage of the tuning phase serves to estimate $F_{m,t}$ ($t = t_0, ... t_f - 1$), the fishing mortality rates for the oldest age group in each year, and $\bar{r}_i$ ($i = b, ..., m$), the partial recruitment coefficients (Fig. 3A). The $F_{m,t}$ are assigned the value of the overall rate of fishing mortality for ages $k, ..., m - 1$, as computed from the results of a first cohort analysis (k is an arbitrary constant).[1] These F-values serve to initiate a new cohort analysis. This process is repeated in an iterative manner until convergence, a procedure which is often called "stabilization of cohort analysis." Average partial recruitment coefficients, $\bar{r}_i$, for the period ($t_f - v - 1$, $t_f - 1$) are then calculated from the result of the "stabilized" cohort analysis (v is a given constant). The calculation of $\bar{r}_i$ involves the application of a smoothing procedure on the fishing mortality rates $F_{i,t}$. Fishing mortalities are thus smoothed using the running medians of 3 and repeating until convergence; then mesa[2] are "split" and the process is repeated until convergence (McNeil 1977). The stabilization process and the estimation of partial recruitment coefficients are repeated in an iterative manner while the fishing mortality rate for fully recruited ages, say $F_{\bullet,t_f}$, is held constant. In general, few iterations are necessary for estimating $\bar{r}_i$.

[1] $F_{m,t} = \ln(\sum N_{i,t} / \sum N_{i+1,t+1}) - M$, where the summations are from $i = k, ..., m - 1$.

[2] A mesa is a flat two-point local maximum or minimum (McNeil 1977).

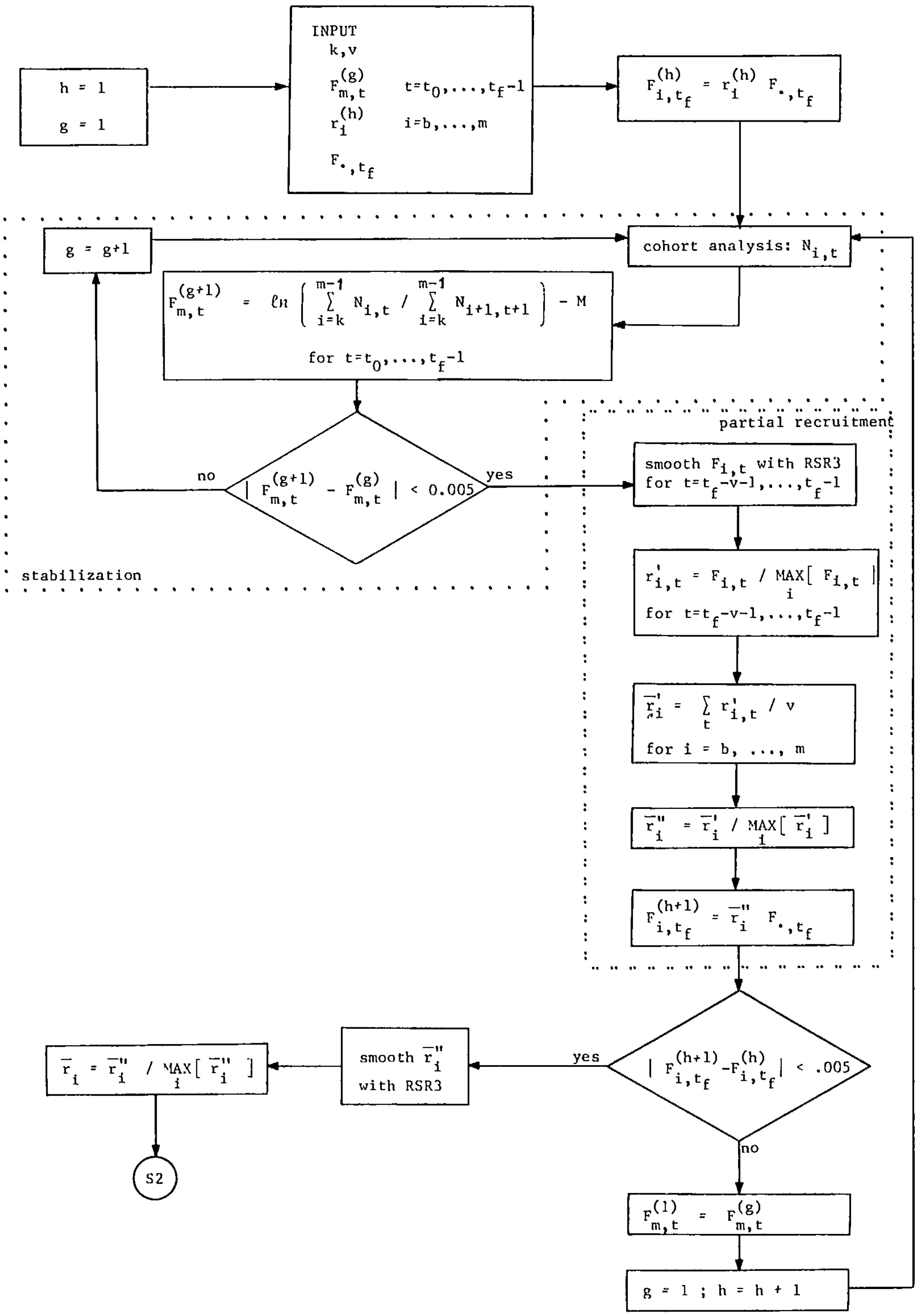

FIG. 3A. Diagram illustrating stage 1 of the tuning phase for sequential population analysis. Stage 1 includes two processes: stabilization of sequential population analysis and estimation of partial recruitment coefficients.

Stage 2

For this stage, the fishing mortality rate for fully recruited ages, $F_{0,\ t_f}$, is allowed to vary while the fishing mortality rates for the oldest age group in each year ($F_{m,t}$, $t = t_0, \ldots, t_f - 1$) and the partial recruitment coefficients ($\bar{r}_i$, $i = b, \ldots, m$) take a constant value, i.e. the quantity resulting from stage 1. Then a given index of stock size (in number or biomass units), say CPUE_t ($t = t_0, \ldots, t_f$), is used to calibrate the cohort analysis (Fig. 3B): this process is, in fact, often referred to as "calibration." The calibration constant defined here, say β, assumes that CPUE_t and the $B_{\bullet,t}$ calculated from cohort analysis are directly proportional. Then we proceed in an iterative manner and calculate the $F^{(s)}_{\bullet,t_f}$ which corresponds to consecutive estimates of the "calibrated" biomass, $B^{(s)}_{\bullet}$. Since

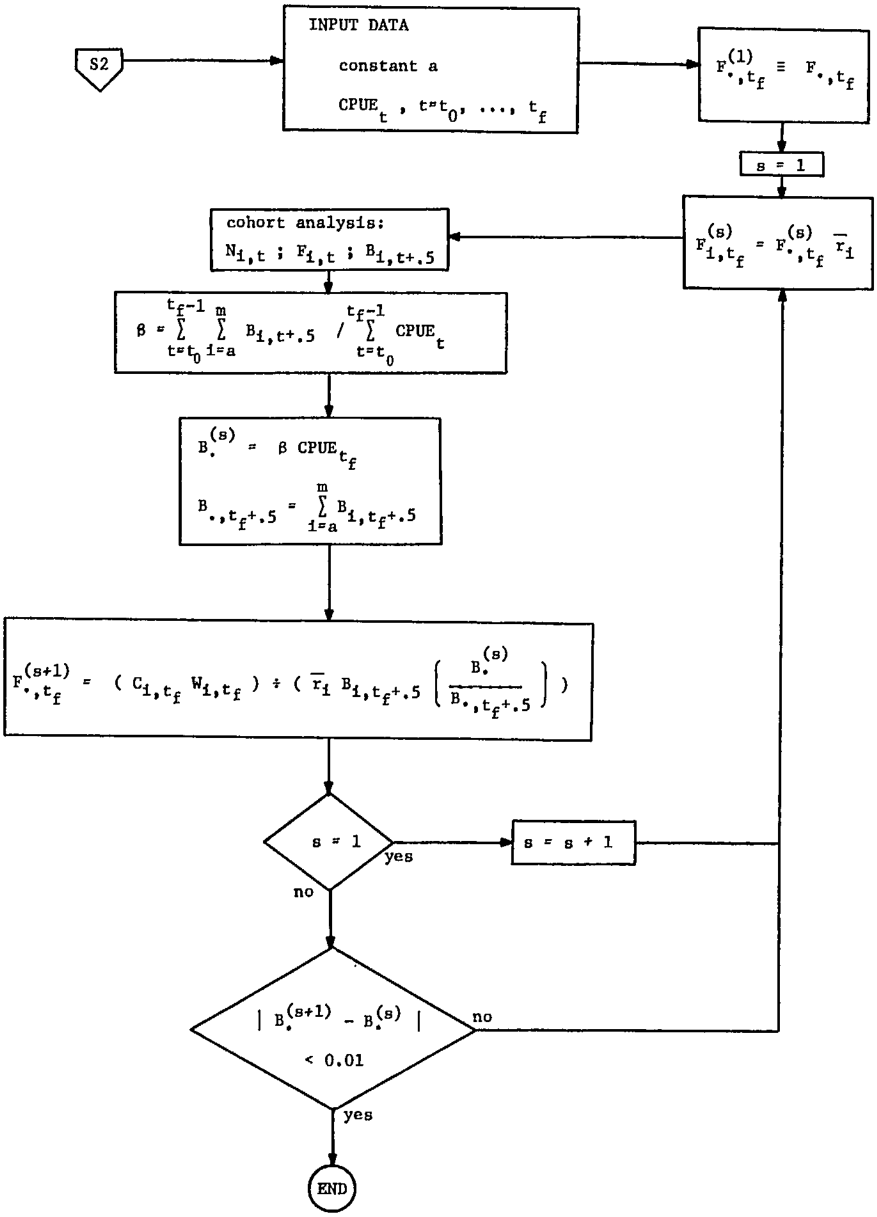

FIG. 3B. Diagram illustrating stage 2 of the tuning phase for sequential population analysis. Stage 2, often referred to as "calibration," serves to calibrate the results of a sequential population analysis from an independent measure of stock size (CPUE_t here).

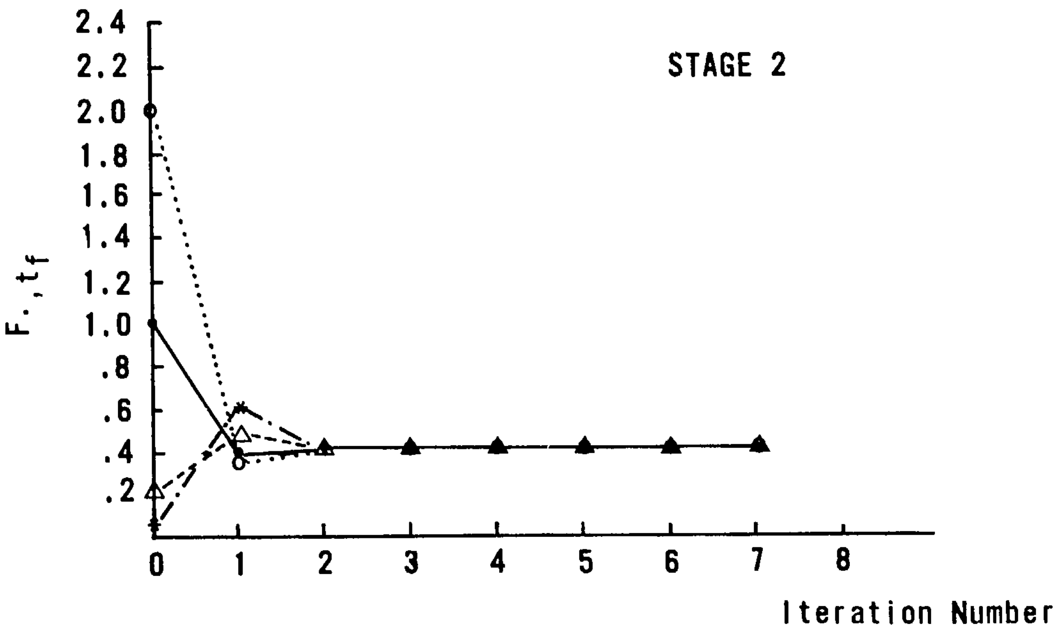

FIG. 4. Graph showing the convergence of the tuning phase for different starting values, $F_{\bullet,t_f}$.

the calibration constant is analogous to the slope of a regression line passing through origin, this iterative process is effectively forcing the stock size estimated for year t_f to lie on the regression line. In all cases tested, less than three iterations were necessary for estimating $B^{(s)}_{\bullet}$ and $F_{\bullet,t_f}$ as illustrated in Fig. 4.

Examples

As a means of illustrating this procedure, the algorithm developed in the preceding section was used for tuning sequential population analyses for cod in divisions 4VsW and 4TVn. As mentioned above, the current criteria for tuning sequential population analyses is sometimes reduced to the visual inspection of graphical output: in such cases, the objective function and the termination rule are not formulated explicitly. A reasonably good agreement between our results and previous assessments would suggest that: (1) putting the last point on the estimated regression line; and (2) estimating partial recruitment from historical average, either played an important role in the tuning process or constitute viable alternatives for the tuning of cohort analysis for a given stock. On the other hand, poor agreement would suggest that other rules and criteria were preferred for the tuning phase.

For cod in 4VsW, the stock size (age 5 and older) estimated for 1980 is 98 257 × 10^3 with the self-tuning cohort analysis and 103 184 × 10^3 in the assessment of Maguire (1981). Close agreement between these estimates, as well as between estimates of fully recruited F, $F_{0.1}$ and the 1982 catch biomass suggests that our algorithm emulates relatively well the optimization process used to tune the cohort analysis for this stock (Table 1). For example, both

TABLE 1. The results of the 1981 assessment of cod in 4VsW (Maguire 1981) are compared with the results of a cohort analysis tuned with the algorithm presented herein and the catch projected at $F_{0.1}$ for 1982.

Variable	Maguire (1981)	Self-tuning and projecting	Difference (%)
Numbers at age for 1980, ages 2–12	—	—	10.1
1980 stock size for age 5 and older (numbers)	103 184 × 10^3	98 257 × 10^3	4.9
1980 fully recruited F	0.225	0.234	3.9
$F_{0.1}$	0.234	0.264	12.0
1982 catch projections at $F_{0.1}$ (t)	53 700	54 238	1.0

processes used the regression of biomass of age 5 and older estimated from sequential population analysis against the catch rate of tonnage class 5. However, Maguire (1981) does not use an historical average for estimating partial recruitment coefficients in the final year but derives these from the total instantaneous mortality rates (Z) calculated from the R.V. population estimates and from the Canadian otter trawl catch per unit of effort at age. The 1975–79 average partial recruitment coefficients calculated from stage 1 are relatively close to Maguire's estimates, as illustrated in Fig. 5.

For cod in 4TVn, there is reasonable agreement between the stock size (age 5 and older) estimates of Sinclair and Maguire (1981) and the estimates computed from our self-tuning cohort analysis (Table 2). There are major disparities, however, in the 1980 estimates of fully recruited

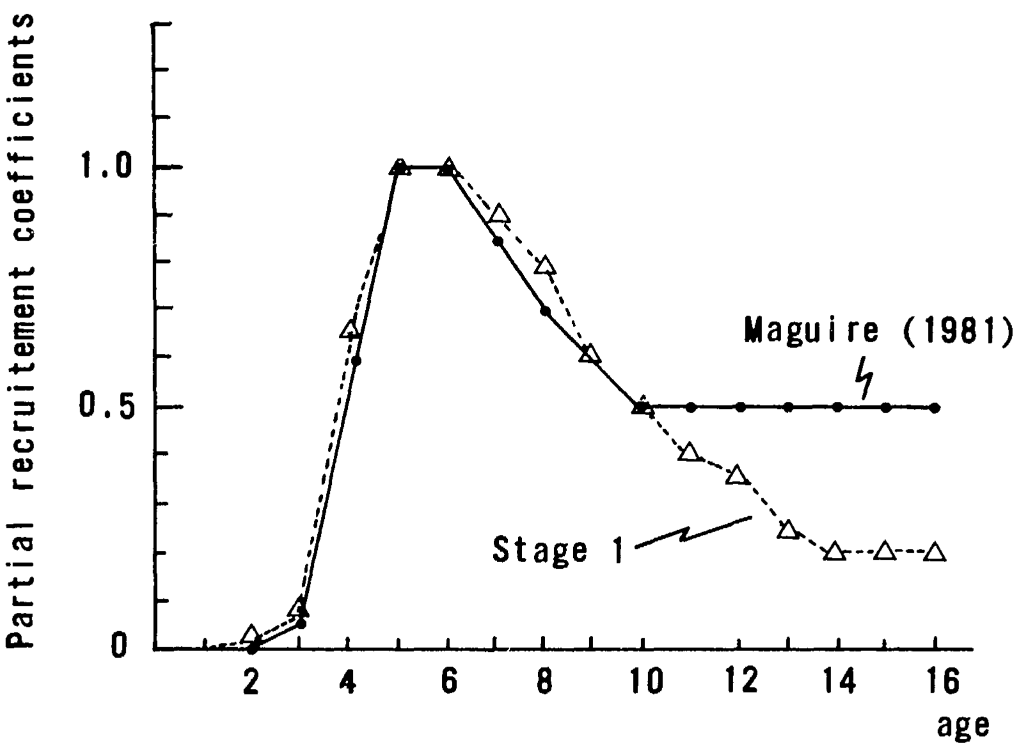

FIG. 5. Comparison of partial recruitment coefficients estimated by Maguire (1981) and those estimated in stage 1 of the tuning phase.

TABLE 2. The results of the 1981 assessment for cod in 4TVn (Sinclair and Maguire 1981) are compared with the results of a cohort analysis tuned with the algorithm presented herein and the catch projected at $F_{0.1}$ for 1982.

Variable	Sinclair and Maguire (1981)	Self-tuning and projecting	Difference (%)
Numbers at age for 1980, ages 3–15	—	—	23.0
1980 stock size for age 5 and older	230 307 $\times 10^3$	204 126 $\times 10^3$	11.4
1980 fully recruited F	0.28	0.41	45.7
1982 catch projections at $F_{0.1}$ (t)	64 628	42 482	34.3

F, as well as for estimates of stock size and partial recruitment coefficients for ages 3 and 4. Because age 3 and 4 fish will be fully recruited in 1982, an error in the 1980 estimate of partial recruitment coefficients for these ages could result in a substantial error in the projected catch for 1982. In their assessment, Sinclair and Maguire (1981) adjusted the coefficient of partial recruitment at age 3 by using the research index for ages 1, 2, and 3. The substitution of the results of stage 1 by Sinclair and Maguire's estimate of partial recruitment coefficients gives a projected catch of 57 000 t for 1982 (Sinclair and Maguire obtain 65 000 t). The disparity still exists since Sinclair and Maguire did not force the regression through the origin and did not put the 1980 point on the regression line when tuning the cohort analysis.

It is clear that the self-tuning cohort analysis developed in the preceding section constitutes a simplification of a rather complex process. The multidimensional aspect of the tuning phase is also neglected but it could be argued that a close examination of previous assessments reveals that a single index of stock size is often given more weight than other indices in the tuning phase. Other indices are then correlated a posteriori with the results of the "tuned" cohort analysis. The proposed algorithm, however, presents distinct advantages. For example, because the algorithm is explicitly formulated, it becomes possible to assess the effect of different error sources on the estimated quantities. The subjectivity of previous methods precluded any assessment of such effects.

Simulated Population

As a means of assessing the performance of our algorithm for tuning cohort analyses, an age-structured population was simulated and fished at $F = 0.385$ for a period of 9 yr, then at $F = 0.288$ for an additional 7 yr and at $F_{0.1}$ for the final year. The time period is assumed to be 1968–84 and the age range, 3–15. Recruitment at age 3 for 1968–84 was calculated as

$$N_{3,t} = \mu + \epsilon \sigma$$

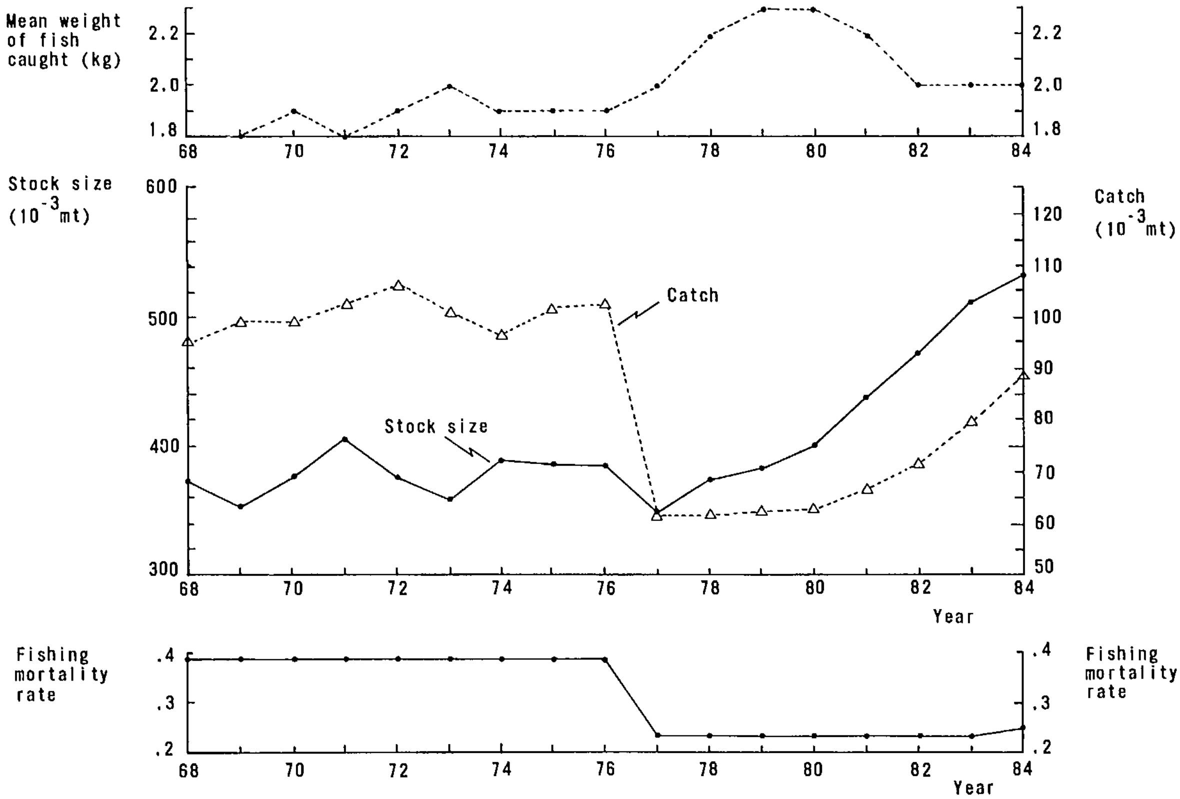

FIG. 6. Catch, stock size, and mean weight obtained by applying a pattern of fishing mortality rates which is similar to the historical pattern observed on certain groundfish stocks of the northwest Atlantic. The results of the simulation are used as a means to assess the performance of our algorithm for tuning cohort analysis and for catch projections.

where

$\mu = 100 \times 10^6$;
$\sigma = 30 \times 10^6$; and
$\epsilon \sim N(0, 1)$.

From these, and from an assumed age distribution in 1968, we simulated a population by using the projection algorithm described in Rivard (1980). A constant natural mortality rate of 0.2/yr was used for all ages, along with the following partial recruitment coefficients and mean weights:

Age	Partial recruitment	Mean weight (kg)
3	0.2	0.80
4	0.7	1.15
5	1.0	1.60
6	1.0	2.21
7	0.9	3.08
8	0.8	4.31
9	0.7	5.26
10	0.6	6.92
11	0.55	7.56
12	0.5	8.00
13	0.5	8.75
14	0.5	10.00
15	0.5	11.50

These partial recruitment coefficients and mean weights at age imply a $F_{0.1}$ value of 0.236 and an F_{max} value of 0.397. The results of the simulation are summarized in Fig. 6. The catch at $F_{0.1}$ in 1984 is 88 858 t, a quantity that will become an important reference point for the next section. Finally, an index of stock size was derived from the stock biomass for age 5 and over as follows:

$$CPUE_t = \frac{1}{1000} \sum_{i=5}^{15} B_{i,t}, \quad t = 1968, ..., 1982.$$

The catch at age ($C_{i,t}$; $i = 3, ..., 15$; $t = 1968, ..., 1982$) and the index of stock size are used below as input data for tuning the cohort analysis.

Effects of Systematic, Analytical, and Sampling Errors on Catch Estimates

The catch projected by any analytic method is only an estimate; the precision and accuracy of catch projections are functions of the precision and accuracy of input information (Rivard 1981). The input of catch projections includes the initial stock size which, itself, is generally the result of a cohort analysis tuned with independent indices of stock size. How precise is our input data for a given

TABLE 3. Sensitivity of projected catch for 1984 with respect to different sources of error.

Type of error	Projected catch for 1984 (t)	Error (%)
Reference	85 535	
Systematic errors (in data)		
In catch-at-age		
A — the 1982 catch is underreported by 10%; age composition correct	84 892	−0.8
B — total catch for 1982 correct but change in age composition (samples came from a fleet component which avoided smaller fish (ages 3 and 4)	85 981	0.5
C — 40% of catch from age 3 is discarded at sea and not reported: all years	85 312	−0.3
D — 40% of catch from age 3 is discarded at sea and not reported: 1981 and 1982	78 256	−8.5
E — unreported 50% discard at sea for age 3, 25% for age 4: 1982 only	69 816	−18.4
In 1983 TAC		
F — the 1983 catch will exceed the 1983 TAC by 10%:	(84 632)	(1.1)[a]
In stock size index		
G — catch rate index for 1982 is underestimated by 10%	73 568	−14.0
H — catch rate index for 1982 is overestimated by 10%	98 364	15.0
Analytical errors (i.e. analytical model is wrong)		
In recruitment for the projection years		
I — Recruitment for 1983–84 is overestimated by 40%	92 561	8.2
J — Recruitment for 1983 and 1984 is calculated from the 1972–82 average recruitment as obtained from a cohort analysis	81 119	−5.2
In catch-at-age composition		
K — age composition distorded through application of age-length key: all years	92 492	8.1
In Terminal F		
L — average F of 8+ is used as terminal F for oldest age group in each year (parametric value = 12+)	80 765	−5.6 (−9.1)[b]
In stock size index		
M — the catch rate index is influenced by a 5% annual increase in fleet efficiency for the last 5 yr	115 642	35.2
Random errors		
In catch-at-age		
N — 15% relative error at age (10 replicates)	66 914–84 680	−21.8 to −1.0
In mean weight at age		
O — for 1968–82 weight-at-age C.V. = 15%; for 1984, C.V. = 20% (6 replicates)	60 486–101 237	−29.3 to +18.4

TABLE 3. (*Concluded*)

Type of error	Projected catch for 1984 (t)	Error (%)
In stock size index		
P — 15% relative error applied to catch rate index from 1968–82 (6 replicates)	74 900–126 723	−12.4 to +48.2
Multiple errors of various types		
In catch-at-age		
Q — 15% relative error at age and age composition distorted through application of age-length key; (6 replicates)	88 828–105 514	3.8–23.4

[a]Represents error made if parametric value is used in the assessment.
[b]Relative error in relation to the parametric value, 88 858 t.

assessment? Given the uncertainties of some quantities, what is the accuracy of the estimated catch and, subsequently, of the total allowable catches (TACs) derived from this estimate? It is the purpose of this section to study the sensitivity of catch calculations to various types of error. Such an analysis should provide an indication of the relative importance of these errors on catch projections and illustrate the potential benefits of an improved sampling program for estimating the various parameters (e.g. mean weight at age, frequency distribution of catch, etc.). For example, should we concentrate our efforts on measuring discards at sea or improve sampling in port? What is the impact of errors in commercial catch rate on the tuning of sequential population analyses and on catch projections established from the results of such analyses?

An analysis of the effect of systematic, analytical and random error on the catch projections is presented; this analysis is carried out on the population described in Fig. 6, by introducing known errors into the "parametric" or "true" values of certain quantities. Because the parametric values are known, it is possible to measure the effect of a given error on the calculations. The expression "systematic error" will be used to describe errors that can occur from inadequate field sampling (discards at sea, misreporting and underreporting, biases in age composition, etc.). "Analytical errors" are those linked to the use of a given model or algorithm. Finally, "random errors" are those resulting from the application of a given sampling scheme or resulting from stochastic variability. It is important to identify these error types at this stage since the error type will dictate the actions needed to improve the data base.

First a test was made with 'no error' in the 1968–82 catch data and stock size index by using the self-tuning cohort analysis followed by the estimation of $F_{0.1}$ and a 2-yr projection determining the catch at $F_{0.1}$ in 1984. When "no error" is introduced, the assessment procedure yields a projected catch of 89 274 t in 1984 (true value is 88 858 t), for a negligible overestimation (<0.5%). No significant difference was found between the partial recruitment coefficients calculated in this test and their parametric values.

For the sensitivity analysis presented hereafter, we used — except where otherwise indicated — the overall rate of fishing mortality of ages 10 and over as the fishing mortality rate which applies to the oldest age group in each year ($F_{m,t}$, $t = t_0, \ldots, t_f - 1$). The corresponding parametric value would be calculated from ages 12 and over, as partial recruitment coefficients were constant for ages 12–15 in the simulated population. Choosing the range of age groups over which F-values are to be averaged is the first decision that has to be made when tuning the cohort analysis. Using the overall rate of fishing mortality for ages 10 and over leads to a projected catch of 85 535 t in 1984, i.e. to a 4% underestimation of the projected catch. In other words, a bias of the order of 4% is systematically introduced in the following case studies because the range of ages used for calculating $F_{m,t}$ was assumed to include ages 10–15. As the purpose of this sensitivity analysis is to assess the effect of a given error on the calculations, the relative error — expressed in percent — was calculated in Table 3 by using 85 535 t as the reference catch projections for 1984: in other words, this relative error measures only the impact of the error introduced. Figure 7, on the other hand, pictures the projected catch in absolute terms, including the 4% bias.

SYSTEMATIC ERRORS ON CATCH AT AGE

Underreporting the total catch in 1982 by 10% had no significant effect on the catch projected for 1984 (Table 3, case A). Similarly, a change in age composition of the catch in 1982 had no significant effect on the 1984 catch estimate (Table 3, case B): the error structure for this case implies that the samples which served to establish the age composition came from a fleet component which avoided smaller fish (ages 3 and 4). The error structure was assumed to result from a 75% reduction in the partial recruitment coefficient for age 3 and a 30% reduction for age 4. In case B, partial recruitment coefficients for 1982 were well estimated because the 1982 catches for ages 3 and 4 have almost no effect on the 1977–81 average partial recruitment coefficient computed in stage 1 of the tuning phase.

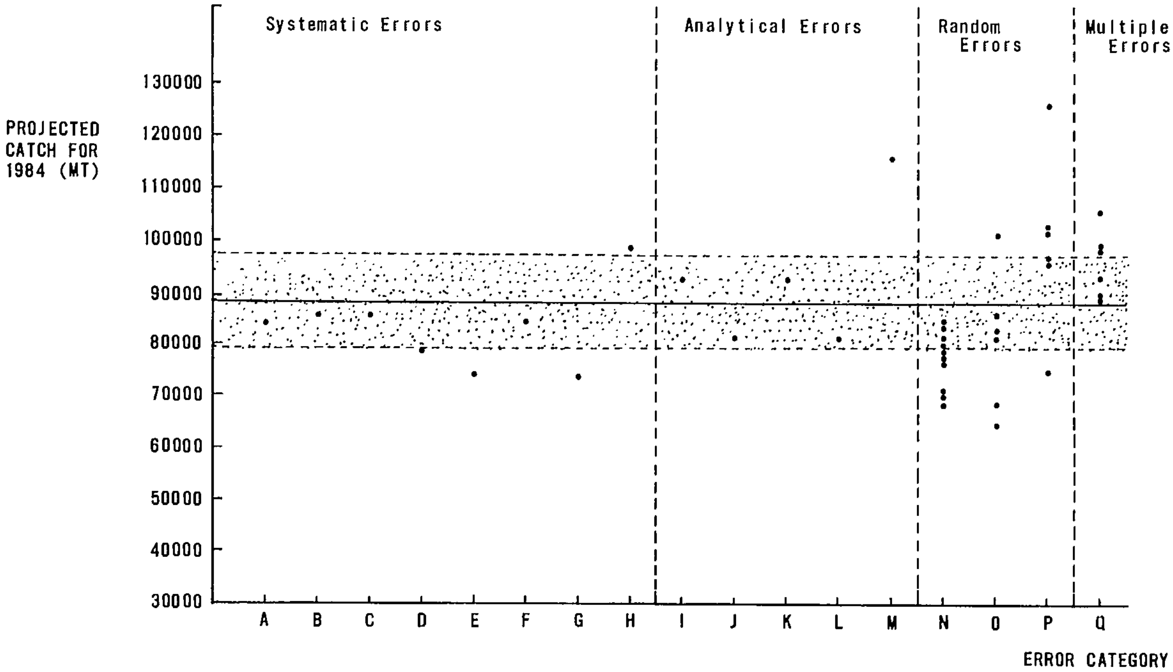

FIG. 7. Response of catch estimates for 1984 to different sources of error. The letters A, B, ..., Q refer to cases of Table 3.

A sustained discarding rate of 40% of small fish (age 3) from 1968 to 1982 had no effect on our catch estimate. However, 'occasional' discarding — for example, when exceptionally high year-classes are recruited to the commercial fishery — may introduce a substantial error in the 2-yr projection, as illustrated by cases D and E (Table 3). In case D, 40% of age 3 fish which are caught in 1981 and 1982 are discarded and their catch is not reported. The reported catches lead to a 9% underestimation in catch projections for 1984. For case E, 50% of age 3 and 25% of age 4 fish which are caught in 1982 are discarded and their catch is not reported. Such an error translates into an even larger underestimation of the 1984 projected catch.

It is also interesting to note that cases A–E result in an underestimation of catch in the projection year. Such errors would thus lead to the recommendation of conservative TACs.

Systematic Errors in Total Allowable Catch

It is common practice in the assessment of many stocks to provide management advice for the upcoming year when the most current data available are from the previous year. Consequently, a 2-yr projection is necessary, in which the catch for the current year is assumed to be equal to the TAC for the current year. When the simulated population in 1983 is calculated from a catch that exceeds the 1983 parametric catch value by 10%, the catch in 1984 at $F_{0.1}$ becomes 84 632 t (Table 3, case F). Consequently, assuming no error in the 1983 catch would result in an overestimation of the catch (85 535 t) for 1983, i.e. an overestimation of 1.1%.

Systematic Errors on Stock Size Index

Cases G and H (Table 3) simulate the response of the tuning-projections assessment algorithm to a 10% under- and overestimation of the independent measure of stock size — a catch rate index, here — for the most recent year. Such an error would result in under- or overestimating the 1984 catch at $F_{0.1}$ by approximately 14%. The 1982 catch rate plays an important role in the tuning phase. An error in this single quantity could lead to the adoption of 'conservative' or 'not so conservative' TACs.

Analytical Errors: Recruitment in the Projection Years

The "projection stage" of an assessment requires an estimate of recruitment for upcoming years. In case I (Table 3), overestimating recruitment in 1983 and 1984 by 40% resulted in an 8.2% overestimate of the catch for 1984.

A common practice in the assessment of stocks is to use an average of recruitment for the past few (up to 10) years for the projection. In case J, the 1972–82 average recruitment (arithmetic mean) led to a minor underestimation of the catch at $F_{0.1}$ for 1984. An average of this type is often used when recent recruitment shows either stability or an upward trend; more conservative estimates of recruitment are generally used when recent recruitment shows evidence of a downward trend (e.g. using the lowest historical recruitment). Thus, errors in the recruitment estimates for the projection years do not appear as a major source of error in this case study.

TABLE 4. Matrix of aging errors.

True age	Average age read as follows												
	3	4	5	6	7	8	9	10	11	12	13	14	15
3	0.91	0.09	—	—	—	—	—	—	—	—	—	—	—
4	—	0.83	0.13	0.04	—	—	—	—	—	—	—	—	—
5	—	0.04	0.71	0.14	0.07	0.04	—	—	—	—	—	—	—
6	—	—	0.07	0.69	0.14	0.07	0.03	—	—	—	—	—	—
7	—	—	0.03	0.11	0.53	0.16	0.11	0.05	0.03	—	—	—	—
8	—	—	—	0.03	0.11	0.53	0.16	0.11	0.05	0.03	—	—	—
9	—	—	—	—	0.03	0.11	0.53	0.16	0.11	0.05	0.03	—	—
10	—	—	—	—	0.02	0.05	0.10	0.51	0.15	0.10	0.05	0.03	—
11	—	—	—	—	—	0.02	0.04	0.09	0.43	0.17	0.13	0.09	0.04
12	—	—	—	—	—	0.02	0.04	0.08	0.12	0.39	0.16	0.12	0.08
13	—	—	—	—	—	0.02	0.04	0.07	0.11	0.15	0.36	0.15	0.11
14	—	—	—	—	—	—	0.02	0.04	0.08	0.12	0.16	0.41	0.16
15	—	—	—	—	—	—	—	0.02	0.05	0.10	0.13	0.20	0.49

ANALYTICAL ERRORS: CATCH COMPOSITION

As a means of simulating the effect of aging error on the estimated catch composition, a new catch matrix was constructed as:

$$\mathbf{C}' = \mathbf{E} \cdot \mathbf{C}$$

where **C** is the 'parametric' catch matrix having elements $C_{i,t}$ ($i = 3, ..., 15$; $t = 1968, ..., 1982$) and **E** is the error matrix represented in Table 4. The use of **C**′ as input data for the tuning-projection algorithm leads to an overestimation of 8.1% for the 1984 catch. If catch composition was estimated by sampling for ages with no application of age-length key, then aging errors of type **E** would bias the age composition as indicated by **C**′ and thus translate into bias in catch projections. However, it is common practice when sampling fish stocks in the northwest Atlantic to estimate the catch composition by applying an age-length key to length samples: the application of age-length keys may itself introduce biases in catch composition (Kimura 1977) and the bias is greater when age-length keys are obtained from a sample with a fixed number of otoliths read at each length. Fournier (1983) also suggests that "bias" in catch composition can be the result of the sampling procedure chosen. Consequently, the error structure and error level introduced by using **C**′ may be assumed to represent a bias introduced when a given sampling scheme is used for estimating catch composition. For example, Labonté (1983) indicates that errors in the order of 7–8% are possible when comparing the age composition derived with two different procedures.

ANALYTICAL ERRORS IN TERMINAL F

In the first stage of the tuning phase for cohort analysis, the $F_{m,t}$ are assigned the value of the overall fishing mortality for ages $k, ..., m-1$. While the parametric value for k in our simulated population is age 12, choosing $k = 8$ for the tuning-projection algorithm leads to a catch estimate of 80 765 t in 1984, and thus underestimates the catch by 5.6%. In most assessments, k is chosen arbitrarily and its choice constitutes a compromise between the highest k which would give satisfactory population estimates from the sequential population analysis, and the lowest k which satisfies the assumption of 'common fishing mortality'. The value of k influences the estimation of partial recruitment coefficients for the oldest age-groups, as illustrated in Fig. 8: while the parametric values of partial recruitment coefficients describe a domed curve, the choice of lower values for k progressively reduces the convexity of the curve and moves the right limb of the curve upward, towards 1. This behavior may explain why asymptotic curves are often obtained when partial recruitment coefficients are estimated from a sequential population analysis.

ANALYTICAL ERRORS IN STOCK SIZE INDEX

The independent measure of stock size, as expressed by a catch rate calculated from the commercial catch and effort data, is often used for tuning the sequential population analysis. The catch rate may be changing, however, because the catchability (q) of the commercial fleet is influenced by technological changes (e.g. introduction of sonar), by changes in fleet composition and by 'learning' factors. As a means of assessing the effect of such changes on catch estimates, we derived a new catch rate time series from:

$$\text{CPUE}'_t = q_t B_{\bullet,t} \qquad t = 1968, ..., 1982$$

where

$$q_t = 1 \times 10^{-3} \text{ for } t = 1968, ..., 1977$$

$$q_{1978} = 1.05 \times 10^{-3} \qquad q_{1980} = 1.16 \times 10^{-3}$$

$$q_{1979} = 1.10 \times 10^{-3} \qquad q_{1981} = 1.22 \times 10^{-3}$$

$$q_{1982} = 1.28 \times 10^{-3}$$

and where $B_{\bullet,t}$ is the simulated stock biomass for age 5 and over. In other words, CPUE'_t is the catch rate resulting from a 5% annual increase in catchability for the 1978–82 period. For the simulated fish population, the

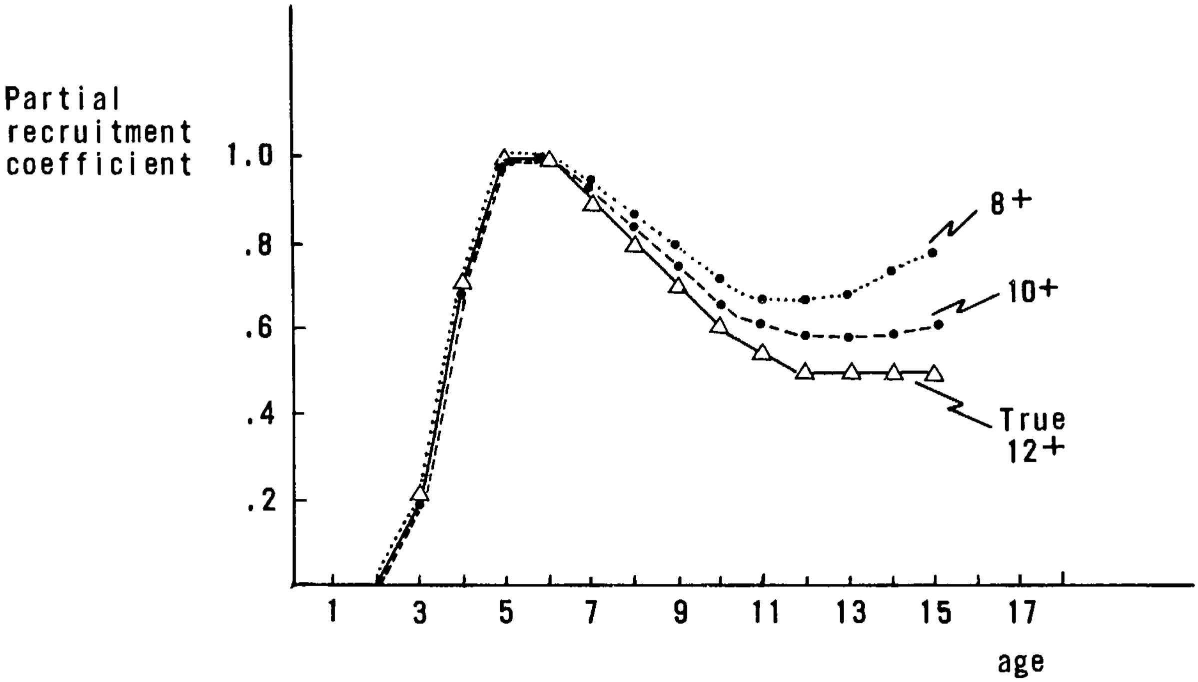

FIG. 8. Influence of k, the first age used in calculating the overall rate of fishing mortality in stage 1 (stabilization) on the estimation of partial recruitment coefficients.

presence of such a trend in catchability would lead to a 35% overestimation in the 1984 catch at $F_{1.0}$ (Table 3, case M). The results of the tuning-projection algorithm are thus very sensitive to the independent index of stock size (commercial catch rates, research survey index) chosen for the assessment of a given stock.

RANDOM ERRORS IN CATCH DATA

As suggested by Smith and Maguire (1983), the variance and covariance structure of catch at age is rather complex as it results from the application of age-length keys to a combination of length-frequency samples. The authors suggest that the length frequencies are the realization of a compound multinomial distribution and indicate that the estimation theory with respect to this complex statistical distribution has not progressed very far in the literature. In absence of a clear definition of the variance–covariance structure of catch at age, ten replicates of the catch matrix were constructed by introducing a 15% relative error in catch at age in the following manner:

$$C'_{i,t} = C_{i,t} + (0.15\ \epsilon\ C_{i,t})$$

where

$$\epsilon \sim N(0,1).$$

The relative error of 15% was assumed constant for all ages. In their assessment of catch estimates for cod in 3Pn-4RS, Gavaris and Gavaris (1983) obtain higher coefficients of variation both for the youngest and oldest age groups but much lower coefficients for intermediate ages; they also mention that cod in 3Pn-4RS are relatively well sampled in comparison to other stocks. Consequently, a 15% relative error in catch at age lies within the expected range of error for current sampling programs. These ten replicates lead to catch estimates ranging from 66 900 to 84 700 t (Table 3, case N): individual estimates are also plotted in Fig. 7 (case N). It is somewhat surprising to see that a randomly distributed error in catch at age leads to catch projections which are systematically below the parametric value. The analysis of intermediate results for the tuning-projection algorithm reveals that the partial recruitment coefficient for age 3 is systematically higher than the parametric value, as illustrated in Fig. 9. In cohort analysis, overestimating initial fishing mortality for a given age results in an underestimation of stock size for that age group. Since fish of age 3 in 1982 will be fully recruited to the fishery in 1984, underestimating the size for that cohort translates into an underestimation of catch in the projection year. Further analysis suggests that 'taking the arithmetic mean' for the calculation of partial recruitment coefficients causes this overestimation of partial recruitment coefficients.

RANDOM ERRORS IN MEAN WEIGHT

In an assessment of the accuracy and precision of catch projections for cod in 4TVn, Rivard (1981) concludes that more than 60% of the variance for catch estimates is due to uncertainties associated with mean weight at age. For this cod stock, the relative error in mean weight varies from

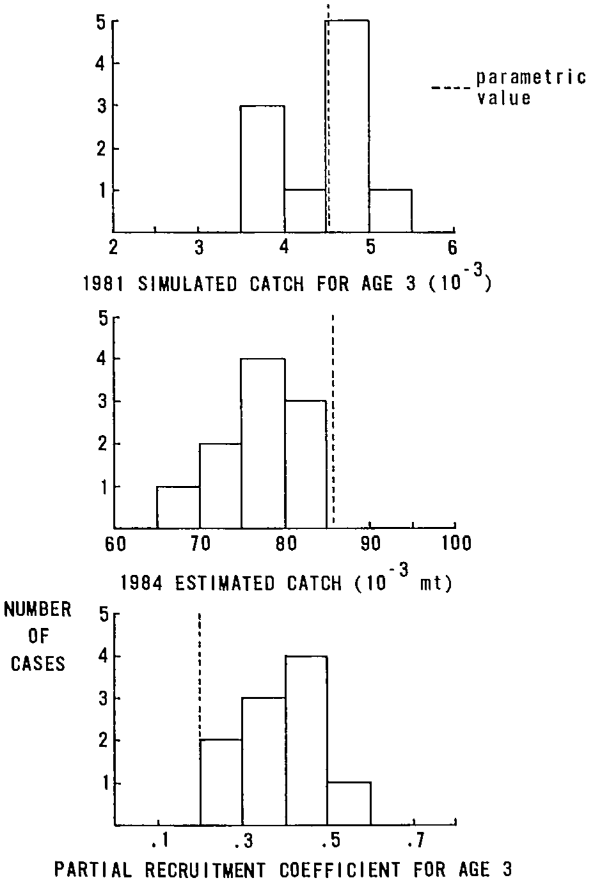

FIG. 9. Effect of random errors in catch data on the estimated catch at $F_{0.1}$ in 1984 and on the estimation of partial recruitment coefficient for age 3.

20% for the youngest age groups to about 45% for the oldest. Error in weight estimates has two components: a stochastic component which arises from the natural variability in weight due to the environment and from the use of current estimates of mean weight for projecting 2 yr ahead, and a sampling component.

Six replicates of the weight matrix were constructed by assuming a 15% relative error: a 20% relative error was used for the weight vector in the projection year. Thus, the new weight data appear as

$$W'_{i,t} = W_{i,t} + \gamma \epsilon W_{i,t}$$

where

γ = 15% for t = 1968, ... 1982
γ = 20% for t = 1984

and

$$\epsilon \sim N(0,1).$$

These replicates lead to catch projections varying from 60 490 to 101 240 t (Table 3, case O). Estimates obtained from each replicate are plotted in Fig. 7. In conclusion, errors in mean weight could seriously influence the precision of catch projections for cod.

RANDOM ERRORS IN STOCK SIZE INDEX

Six replicates of the 1968–82 catch rate series were generated as follows:

$$CPUE'_t = CPUE_t + 0.15 \epsilon CPUE_t$$

where

$$\epsilon \sim N(0,1).$$

When these replicates were used as input data for the tuning-projection algorithm, catch estimates ranged from 74 900 to 126 720 t (Table 3, case P). Individual estimates are also plotted in Fig. 7. Independent indices of stock size thus appear as a major source of error for catch projections. In fact, a 15% relative error in stock size index may be unrealistically low for many stocks. Analytical and systematic errors in the stock size index also have a serious impact on the catch projections (Table 3, cases G, H, and M). It is clear that the tuning phase is strongly dependent upon the independent index of stock size and that trends and uncertainties in the index directly influence the accuracy and precision of catch projections.

MULTIPLE ERRORS

In any given assessment, it is unlikely that a single variable is the sole source of error. The 'error content' of input data can be expected to vary as a function of what is being measured and how well this variable is sampled (coverage, intensity, etc.). As a means of illustrating the effect of simultaneous errors on catch estimates, six replicates of the catch matrix were constructed by introducing a 15% relative error (as in case N) and by applying the error matrix **E** (as in case K) to the resulting catch matrix. The combination of these two error types resulted in overestimating the 1984 catch at $F_{0.1}$ by 3.8–23.4% (Table 3, case Q).

Because two apparently unimportant sources of errors may interact positively and produce substantial errors in catch estimates, or, alternatively, because two important sources of error may yield opposite and mutually canceling errors in catch estimates, it is important to assess simultaneously the impact of input errors in different variables on the results of the tuning-projection algorithm. In other words, an overall measure of uncertainty in catch estimates cannot be obtained by simple addition of errors from different sources.

Summary and Conclusions

An algorithm is presented here to reduce the subjective considerations in tuning cohort analysis and in catch projections. When applied to cod in 4VsW, this algorithm led to catch estimates which were very close to those obtained in a previous assessment for cod in 4VsW. However, this algorithm led to estimates which were substantially lower than the estimates obtained by Sinclair and Maguire (1981) in their assessment of cod in 4TVn. Such disparity exists because 'putting the last point on a zero-intercept regression line' is not the main criteria used for tuning cohort analysis for that stock.

Because all the elements of the tuning-projection process are explicitly formulated, the sensitivity of catch estimates to various error sources can now be assessed. The application of this algorithm to a stock simulated with known parameters led to the conclusion that our formulation of stage 1 of the tuning phase is itself responsible for the occurrence of systematic errors (or bias) in catch estimates. For example, the number of age groups considered for evaluating 'terminal F' in the stabilization stage can displace estimates of partial recruitment coefficients towards unity beyond a certain age. We also observed that using the arithmetic mean of historical estimates leads to an overestimation of partial recruitment coefficients for the youngest age group when normally distributed error is introduced in the catch matrix. Because our algorithm is very close to the process used by CAFSAC subcommittees for certain assessments, special attention should be given for the development of corrective measures or new methods for estimating partial recruitment coefficients.

Our analysis of the response of catch estimates to a wide variety of errors indicates that catch projections are very sensitive to the independent index of stock size that is used for tuning sequential population analysis. When several indices are available, choosing the 'proper' index appears as a very crucial step for any assessment. For instance, using commercial catch rates for tuning sequential population analyses in pelagic fish showing schooling behavior may lead to spurious results if the measure of effort used does not account for temporal changes in fleet efficiency (e.g. introduction of sonar).

Our simulation suggests that catch projections are also very sensitive to sampling and stochastic errors in mean weight at age. This is in agreement with the results of Rivard (1981): for cod in 4TVn, 60% of the variance of catch projections is due to uncertainties associated with estimates of mean weight at age. While errors in mean weight could seriously influence the catch projections for fast growing fish, the error may not be as important for slower growing species.

In the context of this workshop on the sampling of commercial catches, the results presented herein can serve to assess the importance of various components of our sampling programs for achieving a given precision and accuracy in catch projections. The analysis was performed only on one simulated stock having the characteristics of a cod stock of the northwest Atlantic; thus, it would be premature to generalize our conclusions to other species or stocks. For the case studied, our results suggest that the unreported discard at sea of small fish (i.e. fish belonging to the youngest age groups) has relatively low impact on projected catch when the discarding practice has been maintained over a long time period. Relatively large errors can be introduced, however, if a discarding practice suddenly took place in the last year or the last 2 yr that are present in the cohort analysis: in that case, catch is underestimated for the projection year and the total allowable catch (TAC) based upon them would be underestimated. When the discarding of small fish occurs at sea, port sampling is not expected to yield samples which are representative of the removals. While at sea sampling permits a better sampling design and reduces potential bias in the samples collected, it is often not clear how the presence of an observer aboard a given fishing vessel affects the fishing practice and, consequently, the samples taken from that vessel may not be representative of the catch of all vessels in the same category. In their analysis of the problems inherent to each sampling scheme, Zwanenburg and Smith (1983) suggest, in addition, that port sampling programs may not be randomly sampling fish and can be biased by the manner in which the fish are stored in the hold of the vessel. Our results indicate that, for a species like cod, systematic and sampling errors in catch composition can lead to important errors in catch projections. Because the results of sequential population analysis are dependent upon catch composition data, the "quality" of an assessment relies on our ability to obtain an accurate and precise estimation of catch composition through our catch sampling programs. Catch composition estimates are not, as we have seen, the sole source of error but, for a species like cod, errors in catch composition can contribute significantly to the variance and bias of catch projections. We can also formulate a corollary to that statement: because more than one factor influence the ultimate results — i.e. the catch projections — all sampling programs that provide input (e.g. agglomerate data,[3] stock size indices, etc.) to the tuning/projection process must be properly "balanced." In the case studied, for example, there is little value in improving the sampling for catch composition if the variances of the age-specific mean weight estimates remain large.

In general, sensitivity analyses provide indications on the importance of a given error in input data for the calculation of certain quantities. For a given stock, sensitivity analyses should be accompanied with an estimation of variance for input data to provide indications on the corrective measures to be undertaken for improving catch estimates in the projection year. In other words, a given method may be very sensitive to a certain input quantity but still be very 'precise' if this input quantity is itself well estimated. It is thus important to assess, simultaneously, the precision and accuracy of agglomerate data and the sensitivity of catch projections to agglomerate data. Such information can be used to assess the precision and accuracy of catch projections and to evaluate the relative worth of improving the sampling of a given quantity. A routine assessment of the relative impact of precision and accuracy of a given parameter on catch projections should permit the identification of critical elements of the sampling programs for a given fishery and lead to the design of efficient sampling programs.

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[3] Agglomerate data refer here to annual estimates which are the result of various sampling programs and are used as input data for a given assessment: e.g. annual catch at age, mean weight at age, etc.

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Identification of Influential Variables in Yield per Recruit Analyses

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White, G. N., III. 1983. Identification of influential variables in yield per recruit analyses, p. 130–140. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Yield per recruit analysis is used to determine appropriate levels of fishing mortality from growth characteristics of the stock and a partial recruitment pattern. Statistical uncertainties associated with estimates for these input parameters contribute to uncertainty in the results. In general, uncertainties associated with a few input parameters will make the largest contribution to the uncertainties in a result. A sampling program should attempt to minimize the variability of estimates for these influential parameters, although other factors (e.g. costs of improved sampling) must also be considered. The use of approximations in estimating uncertainties is discussed. The concept of the "regret" resulting from statistical errors in a result is introduced to provide a means of determining the suitability of approximate methods. It is shown that some common approximations are particularly questionable when regret is an increasing function of the scale of statistical errors. This stems from the greater weight placed on rare events by such regret functions.

White, G. N., III. 1983. Identification of influential variables in yield per recruit analyses, p. 130–140. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

On se sert de l'analyse du rendement par recrue pour déterminer les taux appropriés de mortalité par pêche à partir des particularités de croissance du stock et d'un régime de recrutement partiel. Les incertitudes statistiques liées aux estimations calculées pour ces paramètres initiaux contribuent à l'incertitude des résultats. De façon générale, les incertitudes liées à seulement quelques paramètres initiaux contribueront pour la plus grande part aux incertitudes d'un résultat. Dans un programme d'échantillonnage, on devrait s'efforcer de minimiser les variations des estimations calculées pour ces paramètres déterminants, bien que d'autres facteurs (par ex. les coûts liés à un meilleur échantillonnage) doivent être également considérés. On traite de l'utilisation d'approximations pour évaluer les incertitudes. On introduit le concept du "regret" découlant des erreurs statistiques observées dans un résultat pour fournir un moyen de déterminer si les méthodes d'approximation sont adéquates. On montre que certaines approximations courantes sont particulièrement discutables lorsque le regret augmente en proportion des erreurs statistiques. Cela découle du fait que ces fonctions liées au regret donnent une plus grande importance aux événements rares.

Introduction

The preparation of biological advice for fisheries management can be divided into three main activities (and academic disciplines)(White 1983):

1) sampling (field biology) — collection of data,

2) analysis (statistics) — estimation of fundamental descriptive parameters, and

3) synthesis (mathematics) — melding of these parameter estimates into a few resultant quantities that describe the resource.

Ideally, each sampling program is designed to allow accuracy requirements for the end product to be met. In stock assessment, these end products include such quantities as a target level of fishing mortality and the projected catches that would result from fishing at this level. To meet this ideal, it is necessary to understand the relationship between the statistical variation associated with a sampling program and the results of a synthesis. As the list of activities suggests, this problem involves a range of disciplines that are only loosely associated in the traditional academic matrix.

This paper will focus on the response of the synthetic phase of stock assessment to parameter estimation errors. This problem is complicated by two features of the models used in syntheses: nonlinearity and dimensionality. Of these, the latter must be our prime concern. This is because, at the level of complexity of the calculations required in stock assessments, modern computers are able to perform arithmetic calculations at a rate that vastly exceeds their ability to accept and transmit data. Thus, nonlinearity is of far less concern than the quantity of data required for a calculation. Furthermore, the collection of fisheries data is costly.

Simplification may be achieved through the use of approximations and by focusing attention on the most critical aspects of a problem. The largest part of this paper is concerned with the effects of some common approximations. A concept of influence will be defined for use in identifying groups of parameters for which improvements in sampling will produce the greatest benefits.

Throughout the paper it will be assumed that the distributions of estimation errors for input parameters are known. This is not, at present, a realistic assumption. Other papers presented at this workshop do, however, offer hope that such information will soon be available. In the absence of data, this must necessarily be a theoretical paper. The danger in a theoretical approach is that the author may stray over the precipice separating that which is possible from theoretical wonderland. It is hoped that the yield per recruit problem will provide a point of reference anchored in the real world to keep the author's feet on solid ground.

The Problem

Fisheries management policies in use today typically require biologists to provide certain results, i.e. the catch corresponding to particular level of fishing mortality, using mathematical models. The actual number that the biologist obtains depends on values assigned to parameters which characterize the biological system and on variables which can be manipulated, called controls. In mathematical terms the relationship between a result y and the input variables (parameters $\mathbf{p} = (p_1, ..., p_k)$ and controls $\mathbf{u} = (u_1, ..., u_l)$ may be written

(1) $y = f(\mathbf{u}, \mathbf{p})$.

The values of the parameters must be estimated from historical sampling data, and are therefore subject to error, while the values of the control variables are considered to be exact.

A transformation model defines the relationship between the results of the synthetic phase of stock assessment and the input parameters (Fig. 1). It may be viewed as a rule, often provided in the form of a computer program, which accepts a list of input parameter and control values and produces a result which, for simplicity, is assumed here to be a single number.

The numbers of parameters and controls in practical problems may be large and the function $f(\mathbf{u}, \mathbf{p})$ difficult to evaluate without the aid of a computer. The yield per recruit problem involves three groups of parameters which are used to characterize (a) growth, (b) partial recruitment, and (c) natural mortality. The control variable is fishing mortality. The actual number of parameters in each group will depend on the way each of the processes is modeled.

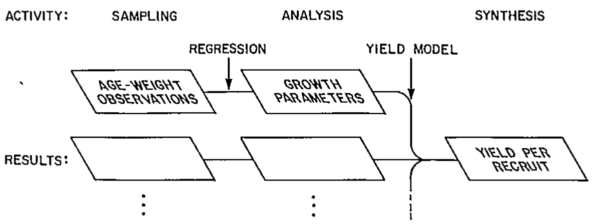

FIG. 1. Diagram of the activities required to obtain estimates of yield per recruit.

Typically, the parameters in a group are estimated together by means of a curve fitting procedure. Because the data involved in obtaining parameter estimates will be different for each group, it is assumed that parameter estimates for the various groups are statistically independent. The fact that, for real problems, the parameters can be grouped in this way makes it possible to focus attention on the group that contributes most to the uncertainty of a result.

The question that concerns us is, roughly speaking, "What is the contribution of sampling variation to uncertainty in the value of a result?" This must be put in more precise terms.

Exact values for input parameters required by (1) are seldom known, so in practice one must calculate an estimate for y:

(2) $\hat{y} = f(\mathbf{u}, \hat{\mathbf{p}})$

where $\hat{\mathbf{p}}$ = estimated value of $\mathbf{p}$.

It is convenient to work with error terms:

(3) $\epsilon = y - \hat{y}$ = result error
$\delta = \mathbf{p} - \hat{\mathbf{p}}$ = parameter estimation error

which are considered to be random variables. Assuming that the statistical procedures used to estimate parameter values are correct, and that no errors were made in transcribing the data, the only way to reduce parameter estimation errors is to improve sampling. Thus an important step towards an answer to the question posed above is to characterize the relationship between δ and ϵ.

In keeping with the intention to focus on synthesis, it will be assumed only that estimates have been obtained for the values of the input parameters and that the estimation error is known. In practice, of course, knowledge of the error distribution will also be imperfect.

It is important to distinguish between effects of sampling and other sources of error. The result y in (1) should be viewed as the value which would be obtained if the "correct" parameter values, $\mathbf{p}$, were used in the model. Even if sampling error were to be eliminated, a result may be very wrong. Without knowledge of the magnitude of sampling error it is, however, difficult to determine the reasons for errors in a result.

The results of a synthesis are often used for prediction, in which case it is impossible to verify their accuracy until some future date. This situation calls for a concept of regret (to be given a precise definition below). The interaction of statistical uncertainty with regret will be seen to play a crucial role in determining the acceptability of approximate answers to our original question.

Measures of Uncertainty

This section presents a brief review of the problem of describing the uncertainty of a random variable. To begin with it is useful to define some concepts (called "vague concepts" by Mosteller and Tukey 1977) which provide a framework into which specific formulae can be inserted at some future time. The random variable (or variables) being discussed may be considered to be a parameter (vector) which has been estimated from sampling data or the random variable obtained as a result from a transformation model.

A random variable may be characterized in terms of its location, scale, and the shape of its distribution. The terms location, scale, and shape are intentionally vague because no single operational definition will be appropriate for all random variables. Thus, depending on the situation, location may be measured by the mean, mode, or median. Scale may, for example, be measured by the standard deviation or the length of a confidence interval. Shape may be described by specifying a family of distributions (e.g. Gaussian, beta, etc.) together with any shape parameters required. Each application requires specific definitions for the concepts of location, scale, and shape as well as estimators for their numerical values.

Suppose that a random variable p has Gaussian shape. The mean and standard deviation are appropriate measures of location and scale. These may be estimated, for example, by obtaining n independent observations. The sample mean provides an estimate $\hat{p}$ of the mean, $\bar{p}$, while the standard deviation σ may be estimated using the sample standard deviation s. Given $\hat{p}$ it is important to be able to answer questions of the form: "What is the length of a $1 - \alpha$ confidence interval about $\hat{p}$?" A naive approach to this question is to use the sample variance s^2 to find $R_{\alpha,G}$ such that

$$(4) \qquad 1 - \alpha = \int_{p - R_{\alpha,G}}^{\hat{p} + R_{\alpha,G}} \frac{1}{\sqrt{2n}\, s} e^{-\frac{(p - \hat{p})^2}{2s^2}} dp.$$

A problem with this method is that it does not account for the uncertainty in the estimate s^2. In practice, one finds that this uncertainty may be quite large. To avoid having to characterize the uncertainty of the estimate s^2, of the uncertainty of the estimate $\hat{p}$ of $\bar{p}$, and so on ad infinitum it is necessary and proper to employ a statistic which does account for the fact that s^2 is, in fact, only an (usually rather crude) estimate. For the problem at hand an appropriate statistic is Student's t, defined by

$$(5) \qquad t(p) = \frac{\hat{p} - p}{\sqrt{s^2/n}}.$$

The distribution of t depends only on n, which is, of course, a definite number measured without error. The role of p in this formula is that of a "dummy" variable, and the $1 - \alpha$ confidence interval may be obtained using readily available tables. The radius $R\alpha,t$ of an interval obtained using (5) will be larger than $R_{\alpha,G}$, particularly if n is very small.

It is tempting to employ $R_{\alpha,G}$ as an approximation for $R\alpha,t$ (unless n is very small). In strict pedagogical terms, the validity of an approximation requires a measure of the difference between the result of an exact calculation and that of an approximate calculation. In defining a suitable measure of the difference between two results it is necessary to consider how these results will be used. Different situations may call for different measures of accuracy, so an approximation that has proven useful in one application may be found wanting in another. This topic will be developed further below after the concept of "regret" has been introduced.

Transformation Models and Approximation

The purpose of this section is to review, primarily for biological readers, some basic concepts which will be used in the sections that follow. These concepts may be understood by anyone who has taken a first course in calculus, although the techniques required to actually apply them to practical problems form the major part of a course in vector calculus.

For a fixed level of the control variable $\mathbf{u}$, a relationship between the error in the result and the parameter error is defined by

$$(6) \qquad \epsilon = g(\delta) = f(\mathbf{u}, \mathbf{p} + \delta) - f(\mathbf{u}, \mathbf{p}).$$

The transformation g captures the essence of our problem, but is of course merely a theoretical construct since the true value of the parameters, p, is unknown. Notice that $g(\mathbf{0}) = 0$. When the number k of parameters is 1, g may be represented by its graph, as in Fig. 2. The line tangent to g at the origin is then

$$(7) \qquad \epsilon_T = g'(0)\delta.$$

Provided δ is small, ϵ_T will be close to ϵ. Thus $g_T(\delta) = g'(0)\delta$ is called a "linear approximation" to $g(\delta)$ at $\delta = 0$.

Now suppose that δ is a random variable. It follows that ϵ is also a random variable and that the distribution of ϵ

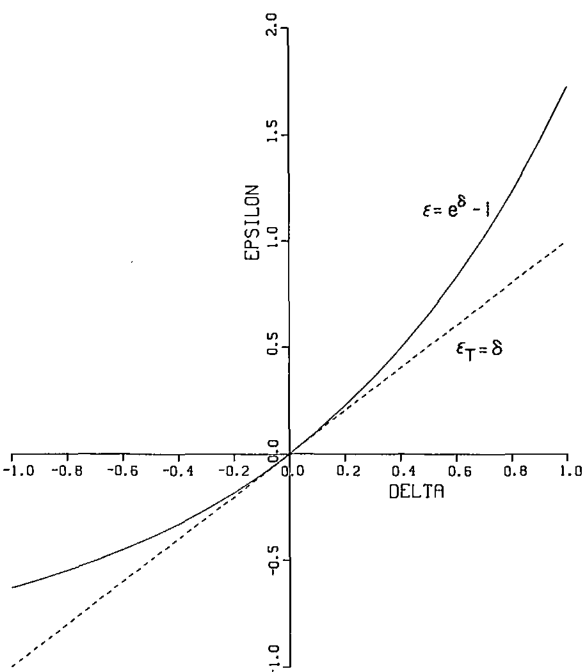

FIG. 2. Graph of a relationship between a parameter error δ and a result error ϵ, for a fixed value of the control variable. Also shown is the line tangent to the curve at the origin.

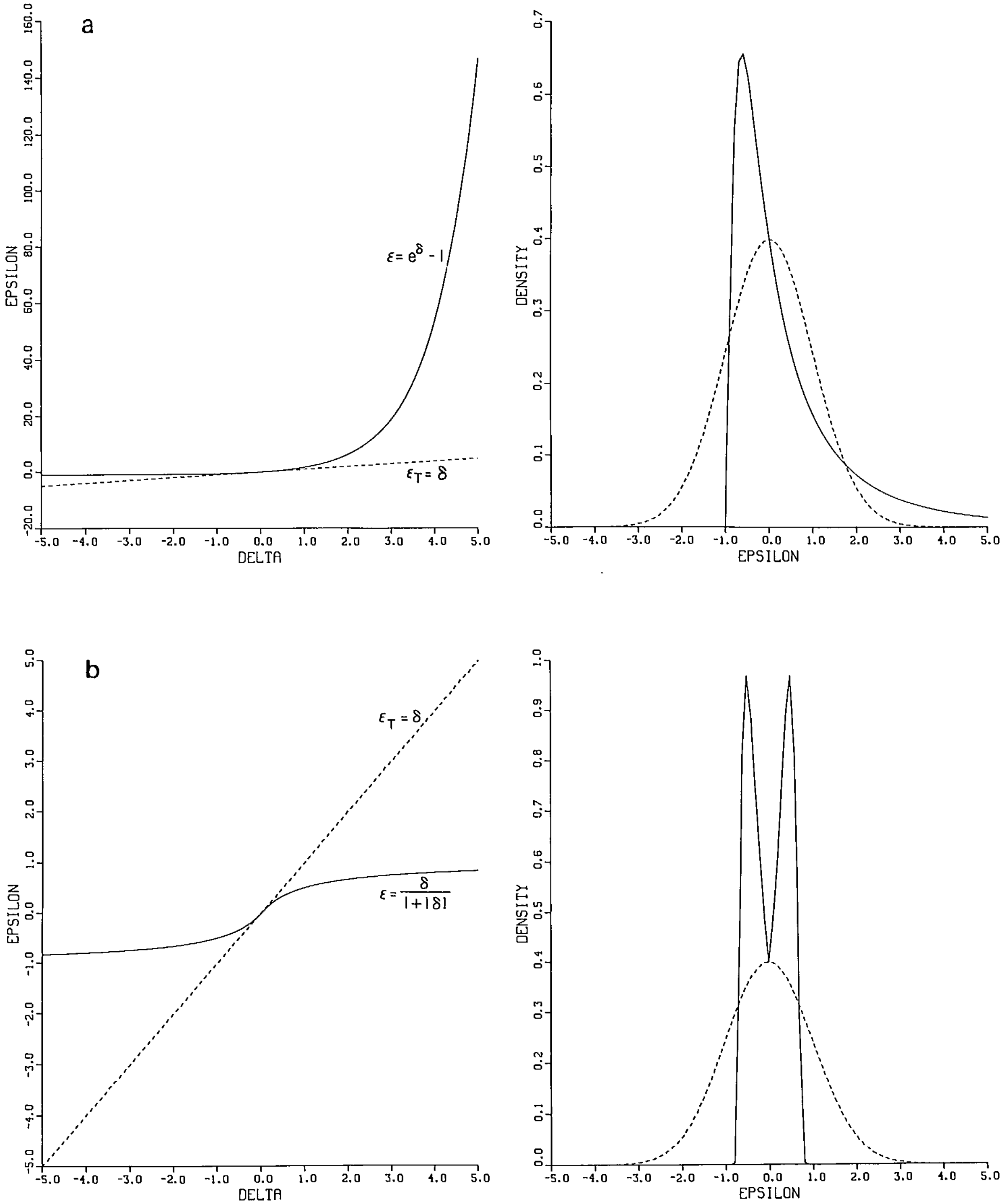

FIG. 3. Distributions of ϵ and ϵ_T produced by assuming that δ is a Gaussian random variable with unit variance. In each case ϵ_T had a distribution identical to that of δ. (a) $\epsilon = e^{\delta} - 1$ (the same relationship plotted in Fig. 2, but at a different scale); (b) $\epsilon = \dfrac{\delta}{1 + |\delta|}$

is determined by that of δ. Unless g and δ satisfy some restrictive, and seldom realistic, assumptions, numerical calculations are necessary to determine the distribution of ϵ. This is especially true for problems involving many parameters.

One case for which numerical calculations are not required is that of a linear transformation. In this case, g may be expressed in the form

$$g(\delta) = \lambda\delta \text{ for } k = 1, \quad \text{or}$$

$$g(\delta) = \sum_{i=1}^{k} \lambda_i \delta_i \text{ for } k > 1.$$

When $k = 1$ and g is linear, $\epsilon = \lambda\delta$ will have the same type of distribution as δ, but the scale will be multiplied by $|\lambda|$. For $k > 1$, one must have additional information. In particular, if δ is Gaussian, then so is ϵ. In the examples that follow it will be necessary (in order to use graphs) to assume $k = 1$. To emphasize that extensions of the one-dimensional results to problems with more dimensions are likely to fail if δ is not Gaussian, it will also be assumed that δ is a Gaussian random variable (with unit variance and mean zero).

Linear approximations, as in (7), may be quite accurate when δ is small. When δ is a Gaussian random variable, however, it can, in principle, take any value between $-\infty$ and $+\infty$. For large deviations from the mean, a linear approximation may introduce, albeit rarely, a large error. The distributions for ϵ and ϵ_T as random variables may, as a result of this effect on large deviations, be quite different (Fig. 3). It is important to observe that the differences in distribution occur in the tails, that is, when δ is large. Thus, as in the case where confidence intervals are approximated using a Gaussian error distribution, a linear approximation may produce only minor changes in the length of a confidence interval for ϵ_T as opposed to ϵ.

The general conclusions of the preceding paragraph remain true for problems where there are many parameters, and new effects are introduced. The following example, for which no linear approximation exists, will serve to illustrate some of the difficulties that may be encountered. Consider the model function

$$(8) \qquad \frac{\delta_1}{|\delta_2|}.$$

This function occurs so frequently that, when δ_1 and δ_2 are independent Gaussian random variables with unit variance, the resulting distribution for ϵ is called the Cauchy distribution. The corresponding density function is

$$(9) \qquad \alpha(x) = \frac{1}{\pi}\frac{1}{1 + x^2}.$$

The mean and variance of this distribution are undefined. Thus sample statistics, which will always be finite, cannot be used to estimate scale and location in the usual way.

With this gruesome example the discussion of transformation is complete. Approximations will be discussed next.

Before the advent of computers, the computational problems in relating sampling uncertainty to its effect on a result made some use of approximations unavoidable. These were applied to the estimation of parameter errors, to the transformation model, or to the distribution of errors associated with a result. The two types of approximation seen most often are: (1) replacement of one distribution by another (usually Gaussian) to simplify calculations; and (2) linear approximation of a nonlinear transformation (often called the "delta" method).

The dangers in approximating one distribution by another have, until recently, gone largely unrecognized. It is now known that many common statistical procedures which assume a particular distribution are highly sensitive to small deviations from this assumption. This has led to the development of robust methods, that is, procedures which are less sensitive to the effects of small changes in distribution (Huber 1981). The implications of this for the problem at hand are, at present, unclear. Certainly one must look carefully at any use of approximations based on replacing one distribution type by another.

The effect of linear approximation is to replace the error distribution of ϵ with that of ϵ_T. Simple examples show that the tails of a distribution may be altered dramatically by such substitutions. In the theory of robustness, two types of changes in distributions are considered: small changes to many observations, and large changes to a few observations. In the next section it will be seen that these types of changes have their counterparts in the concept of regret. Furthermore, for many of the problems encountered in the real world, errors affecting a few observations that lie far from the center of a distribution may be of critical importance.

Regret

The results produced from the synthetic phase of a stock assessment are subject to errors stemming from sampling variation, approximations used during the analysis, unrealistic behavior of the models, and other sources. Ideally all sources of error would be considered in determining the statistical distribution of a result. Often one expresses the uncertainties in a result by means of confidence regions. Suppose, for purposes of illustration, that $I_\alpha = [\hat{y} - R_\alpha, \hat{y} + R_\alpha]$ is a symmetric $1 - \alpha$ confidence interval for an estimate $\hat{y}$ of a scalar result y. This means that, if $1 - \alpha$ confidence intervals were calculated in some number, say N, statistically independent problems, then the chance that the true value, y, in each problem lies in (hits) the associated confidence interval h times will obey a binomial distribution law with parameter $(1 - \alpha)$. In particular,

$$(10) \qquad E[h] = N(1 - \alpha).$$

An approximate confidence interval may, in general, be considered to arise from a small change in α, that is, an approximate $(1 - \alpha)$ confidence interval will be a true $(1 - \alpha')$ confidence interval where α' is "close" to α. It is often argued that, since $E[h]$ is insensitive to small changes in α, precise estimation of the size of a confidence interval is unimportant. Indeed, if N is small, the variation about $E[h]$ will be large enough to mask relatively large errors in the value of α.

This view may be appropriate for situations, such as a game of skeet, in which the score is the number of hits, or theoretical studies in which the size of an error in a result has little practical importance. It may be unacceptable when the results could affect the lives of many people. An extreme example of the latter type of problem is the design of flood control facilities. Such facilities are designed to handle floods whose size lies, for instance, in the 0.99 confidence interval based at zero, that is, a flood that exceeds the capacity of the facility will occur, on the average, only once in every century. The long-term cost of such a facility includes the expenses associated with these extraordinary floods. These are often much greater than if the facility had not been built, but, provided the estimate of their frequency is correct, will be balanced by the rarity of damaging floods.

In the case of flood control planning, there is a very great difference between a 0.97 confidence interval, which would produce an expectation of three large floods each century, and a 0.99 confidence interval. Errors of this magnitude were in fact made in estimating the frequencies of large floods in the United States, leading to a major effort to develop improved estimation procedures by the U.S. Water Resource Council. Increasingly sophisticated statistical procedures based on Stein estimators and robust methods have been employed in attempts to characterize these rare events (Fiering et al. 1978).

Whenever the results of a synthesis enter into planning and decision making, differences between the true value and an estimate of a result are likely to have more serious consequences as the magnitude of the difference increases. Regret, like location and scale, is a vague concept which indicates some measure of the consequences of errors in the estimate of a result. Thus regret may include the interests of future generations as well as immediate consequences of a decision. In principle, then, a measure of regret can help in the problem of determining the ultimate effect of an approximation introduced into a synthetic model.

Realistic measures of regret are difficult to define for most real-world problems, so one must often resort to the use of crude measures. There should be no regret associated with results that have no practical implications beyond the loss of satisfaction associated with being wrong. In this case, a suitable measure of regret might be:

$$\text{(11)} \qquad \text{regret} = \begin{cases} 0 \text{ if } y \text{ lies in the confidence interval} \\ 1 \text{ if not} \end{cases}$$

Thus regret is the same for any error exceeding a fixed size. Such a measure would apply, for example, to the sport of skeet shooting, where any shot which hits the target scores, and even a near miss is unacceptable.

When, as for target shooting, the magnitude of error is important, this should be reflected in the way regret is measured. For example, one might define

$$\text{(12)} \qquad \text{regret} = r\epsilon^2$$

(Fig. 4), where r is a constant and $\epsilon = y - \hat{y}$.

Once a measure of regret has been determined it is possible to evaluate the effect of approximations which affect the distribution (location, scale, or shape) of errors in a result. It is reasonable to make this comparison on the basis of the expected regret.

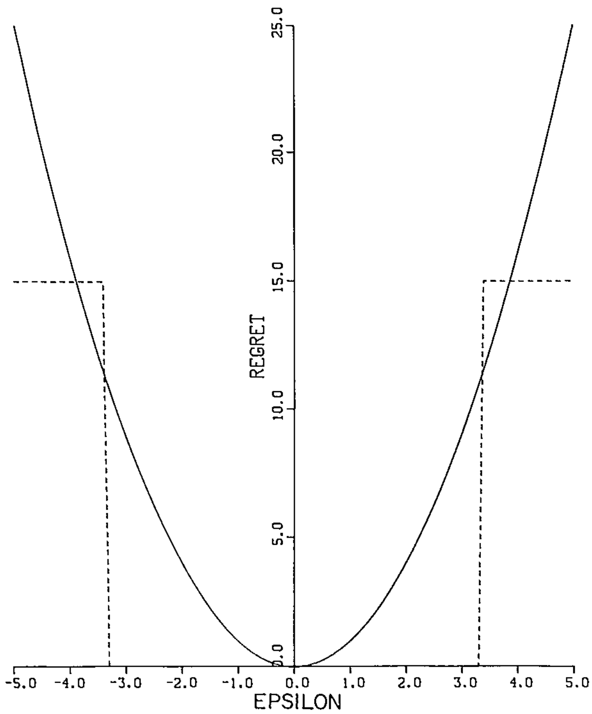

FIG. 4. Two quantitatively different regret functions: solid line — "target shooting," regret = $r\epsilon^2$ dashed line — "skeet shooting," regret = $\begin{cases} 15 & |\epsilon| > 3 \\ 0 & |\epsilon| < 3 \end{cases}$

Suppose, for purposes of illustration, that δ is Gaussian with zero mean and known variance σ^2. The expected regret using (12) is

$$\text{(13)} \qquad E\,[\text{regret}] = r \int_{\infty}^{\infty} \epsilon^2 \frac{1}{\sqrt{2\pi}\,\sigma}\, e^{-\frac{\epsilon^2}{2\sigma^2}}\, dy.$$

The greatest contribution to the expected regret comes from values of ϵ at which the integrand

$$\text{(14)} \qquad I = \epsilon^2 \frac{1}{\sqrt{2\pi}\,\sigma}\, e^{-\frac{\epsilon^2}{2\sigma^2}}$$

is greatest (Fig. 5). These occur when $\epsilon = \pm \sqrt{2}\,\sigma$, or in the vicinity of the endpoints of the 0.85 confidence interval. The expected regret would be quite sensitive to changes in the value of σ or the shape of the tails of the distribution. Similar behavior would be expected whenever regret increases rapidly with the size of ϵ.

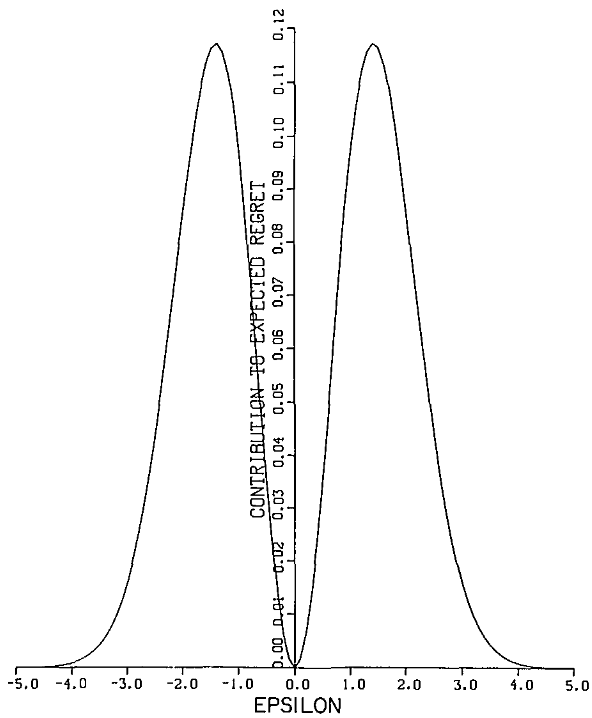

FIG. 5. Contribution of result error ϵ to the expected regret for Gaussian errors and a quadratic regret function.

The shape of the regret function depends on the policies which translate estimates into actions. Insurance schemes are used to reduce the regret caused by large (and thus infrequent) errors at a cost of premiums which one regrets having paid when the error proves to have been small. A "deductable" insurance scheme produces a regret function, like that of skeet shooting, which is the same for any error which crosses a threshold.

Approximations of the type discussed in the previous section would be expected, in general, to have little effect for problems with "skeet shooting" type regret functions. For "target shooting" type regret functions, however, it is necessary to obtain accurate information about the tail regions of the error distribution.

Different uses of a particular type of result may call for different definitions of regret. The results of stock assessments, for example, may be used both to support management actions and as a basis for theoretical studies. The consequences of error in these two situations are quite different and thus require different measures of regret.

The ideas developed in this section stem from the branch of operations research that deals with decisions in the presence of uncertainty. It was found necessary for the purposes of this paper to adapt the theory of situations in which the decision process has been isolated from the process of determining parameter values. The pioneering exposition of the theory of decision under uncertainty is the work of Luce and Raiffa (1957). An excellent introduction for those with little mathematical training is provided by Raiffa (1968), while some more recent developments in the field are discussed by Keeney and Raiffa (1976).

Influence

The preceding sections have laid the foundations for a proper understanding of the concept of influence. Such a concept is necessary because the practical problems with which this paper is concerned are too difficult to tackle in their entirety. Identification of influential variables is a means of focusing attention on those aspects of a problem that are most crucial.

The concept of influence originated with the realization that the shape of regression curves is often controlled by a small number of observations. This has led to a search for useful measures of influence in regression analysis. Thus the concept of influence in regression analysis now encompasses a variety of specific formulae. Most of these are suitable only for use with linear regression models, and the search for influence measures suitable for use with nonlinear regression is continuing (Belsley et al. 1981).

Influence measures used in regression serve to focus attention on a few observations. These are often found to involve atypical values of either the carrier (independent) or response (dependent) variables. For simple problems, that is, curve fitting in the plane, graphical procedures are generally adequate for the detection of influential observations. Thus it is for complex problems involving many variables where measures of influence are invaluable. A well-known example of the importance of influence is provided by Daniel and Wood (1980). By applying a measure of influence to a problem that had been analyzed in numerous published papers, including the first edition of their book, they found a small group of observations that had been recorded incorrectly. When these observations were corrected the result changed dramatically. In this case the change had important economic benefits. It is important to note that influential observations will not, in general, be detected by examining the residuals from a regression.

The purpose of this section is to propose an analogous concept for problems involving transformation models. It will be assumed that the input parameters may be separated into groups that are statistically independent. A measure of influence should pinpoint groups that contribute most to the uncertainty associated with a result. Such groups may have large uncertainties associated with estimates for their parameters, or may include parameters for which a small change in a parameter estimate may produce a large change in a result. Thus a particular measure of influence is *the relative sensitivity of the statistical error in a result to changes in the scale of the estimation error associated with a group of (interdependent) parameters.*

This may be illustrated by the following (oversimplified) example. Let p_1 and p_2 be two independent parameters with Gaussian estimation errors and variances σ_1^2 and σ_2^2, respectively. Assume that

$$y \doteq k_1 p_1 + k_2 p_2 \text{ and } p_1 = p_2 = 0.$$

Thus if $p_1 = p_2 = 0$ it follows that $y = 0$, $\hat{p}_1 = -\delta_1$, $\hat{p}_2 = -\delta_2$, and $\hat{y} = -\epsilon$. Then the equation for estimation error is

$$\epsilon = k_1\delta_1 + k_2\delta_2$$

and ϵ is also Gaussian with variance $\sigma_3^2 = k_1^2\sigma_1^2 + k_2^2\sigma_2^2$ and zero mean. The calculations are simplified if the variance is used as an indication of scale. The influence of the ith parameter is

$$I_i = \frac{k_i^2\delta_i^2}{k_1^2\sigma_1^2 + k_2^2\sigma_2^2}.$$

Thus if $k_1^2\sigma_1^2 > k_2^2\sigma_2^2$ the influence of the first parameter is greater. In practical terms, this implies that, for similar reductions in the estimation errors for the two parameters, the greatest benefit will be obtained by applying the reduction to the first parameter.

Alternately, if one parameter has relatively little influence, reducing its estimation error would have little impact on the scale of uncertainties in the result. A numerical example may be useful. Suppose, in the previous example, that $\sigma_1 = \sigma_2 = 1$ initially, and that $k_1 = 4$, $k_2 = 3$. Then $\sigma_3^2 = 25$ and

$$I_1 = \frac{16}{25} > I_2 = \frac{9}{25}.$$

Eliminating estimation error in the first parameter results in $\sigma_3^2 = 9$, which is only slightly more than half the variance $\sigma_3^2 = 16$ that would be obtained by eliminating all variation in estimates for p_2.

It should be remembered that the definition of influence provided here is only a first effort. Although the idea is, itself, quite simple, difficult issues must be resolved before it can be used. In particular, one must obtain suitable estimates for the scale of variation in both the parameter estimates and the result. It must be kept in mind that a measure of influence can only point out groups of parameters for more careful study. It does not, for example, consider the costs of improvements to sampling programs.

Yield per Recruit

The abstract quality of the preceding sections has been necessary to get to the heart of the problem. This section will supply some bridges over the gap between theory and application, but other gaps will, unfortunately, remain. Before one can hope to use the concept of influence in a yield per recruit problem, it is necessary to have descriptions for the statistical uncertainties associated with the input parameters. These parameters characterize growth, partial recruitment, and natural mortality. For many stocks the current practice is to describe growth in terms of a mean weight and an average partial recruitment for each age group, while natural mortality is set at a constant value. The methods used to arrive at these values are highly subjective and do not provide meaningful estimates of the associated statistical uncertainties. Future progress depends on the development of methods that can provide the required statistical information. A conceptual problem arises here because the only reasonable statistical description of the variation in a parameter may involve the use of a statistic, as in the example in the section of measurement of uncertainty. While such statistics are available for use with commonly employed statistical models, a transformation may alter the distribution to one that is outside the domain of existing theories. Indeed, the study of statistical properties of transformations has, in the past, focused on the problem of changing unusual distributions into those for which a theory has been developed.

It appears, then, that it may not be possible, if one is to employ parametric methods, to avoid the use of approximations to real distributions. There is, however, an alternative. Recent years have seen, in part as a consequence of the easy availability of powerful computers, the development of direct methods for the study of uncertainty (Mosteller and Tukey 1977; Efron 1979). One can, in principle, extend these methods to the problems addressed in this paper. Roughly, the methods are based on constructing a large number of estimates for a parameter. From these it is possible to make inferences directly. It would, in principle, be a simple matter to apply a transformation model to each estimate in turn, and thus obtain an empirical distribution for a result.

A second conceptual difficulty arises because, although the previous sections viewed a result as a scalar quantity, the result of a yield per recruit analysis is a curve of yield per recruit as a function of the control variable, fishing mortality. This curve is used to determine a reference level of fishing mortality from criteria involving the slope of the curve, for instance, the $F_{0.1}$ fishing mortality (Gulland and Boerema 1973).

It is useful to define a measure, $D(y_1,y_2)$ of the "distance" between two yield curves obtained using different parameter estimates. Such a measure should involve both the values of the curves and the slopes. One such measure is

$$D(y_1,y_2) = \left(\int_0^{F^*} (y_1(F) - y_2(F))^2\,dF + \int_0^{F^*} (y_1'(F) - y_2'(F))^2\,dF\right)^{1/2},$$

where F^* is an upper limit for the range of fishing mortalities being considered. The advantage of such a measure over comparisons at a fixed fishing mortality such as $F_{0.1}$ is that $D(y_1,y_2)$ reflects differences in the overall slope of the curve and thus is not tied to a somewhat arbitrary definition of the reference level of F.

A key issue which remains is the need for approximations to the yield per recruit transformation. In the period before digital computers were widely available a great deal of effort was expended in a search for simple ways to conduct this calculation (Beverton and Holt 1957; Ricker 1975). In recent years the most common method has been: (1) obtain partial recruitment at age, $R(a)$; (2) obtain weight at age, $W(a)$; (3) calculate numbers at age, $N(a)$, for a unit recruitment; and (4) obtain yield as the sum:

$$Y(F) = \sum_a F\,R(a)\,W(a)\,N(a).$$

Yield per recruit estimates are commonly employed to determine catch quotas or other regulatory measures. Reference is often made to the F_{max} and $F_{0.1}$ levels of fishing mortality. Numerical calculations of these quantities were used to investigate the range of parameter variation for which linear approximations are useful. For these calculations parametric equations for partial recruitment and growth were used

$$(15) \quad R(a) = 1/(1 + \exp(\alpha(1 - (a/a_{50}))))$$

$$(16) \quad W(a) = W_\infty(1 - \exp(K(a_0 - a)))^3.$$

Existing programs proved unsuitable for these calculations because they frequently failed in the middle of a run. Thus it was necessary to write new programs for this study.

The parameters of these models were estimated using data for the haddock (*Melanogrammus aeglefinus* (L.)) stock in ICNAF Division 4X (O'Boyle 1981) and the cod (*Gadus morhua* (L.)) stock in ICNAF Division 4TVn (Sinclair and Maguire 1981) (Table 1). An estimate of 0.2 was used for the instantaneous rate of natural mortality, M. Numbers-at-age were calculated by the formula

$$N(a + 1) = N(a)\exp(-M - F \times R(a))$$

for ages $a_1, \ldots, a_2$ with $N(a_1) = 1$. The information required to properly describe the statistical errors in the parameter estimates is not yet available. To examine the effects of errors in the estimates of the parameters, the values of $F_{0.1}$ and F_{max} were obtained for a number of values of the parameter M. For each species the response of $F_{0.1}$ was very nearly linear while F_{max} demonstrated a pronounced departure from linearity (Fig. 6). This was also true for changes in the parameters a_0, a_{50}, and K.

These calculations were performed using the CDC APL Version 2 Interpreter on a CDC Cyber 171. The calculation of each value of $F_{0.1}$ or F_{max} required 2–3 s of CPUE time and a negligible terminal connect time. On this system charges are based on "system resource units" (SRU's) which reflect storage requirements as well as CPUE time, and at the time were priced at 7¢ per SRU. Obtaining each value of $F_{0.1}$ or F_{max} required between 1 and 2 SRU's. Computational costs should not be an obstacle to the use of exact calculations. A more serious problem is the cost of developing the necessary software.

TABLE 1. Estimates for the parameters of (15) and (16) used in the numerical calculation.

Parameter	Species: Cod	Haddock
α	14	9
a_{50} (yr)	5	4
W_∞ (kg)	91	6.7
a_0 (yr)	−2.7	−1.2
K	0.034	0.17
Age range	3–15	1–12

It is noteworthy that apparently similar quantities (e.g. $F_{0.1}$ and F_{max}) may exhibit remarkably different degrees of nonlinearity. In the absence of theoretical justification for the use of linear approximation it is important to study each case carefully. Although linear approximation may be useful in certain instances, only by first conducting a nonlinear analysis can one learn where linear approximation is justified.

Discussion

An answer to the question addressed by this paper must await statistical descriptions of the uncertainties associated with estimates for input parameters. Other papers in these proceedings have addressed some of the problems which must be resolved to characterize these uncertainties. It appears that emphasis should be placed on methods which assume neither Gaussian error distributions nor linear response to errors.

The approach described in this paper has implications that transcend the problem of relating uncertainties in a result to those of the input parameters. The concept of regret highlights the links between stock assessments and their effect on a fishery. Investigation of this link may lead to changes in the way stock assessments are conducted. For instance, the expected regret calculated for an asymmetric regret function can be reduced using biased estimators. The different regret functions that apply to research and management objectives would be expected to produce a divergence between estimation procedures used in research and those used for stock assessments. Similarly, the use of influence measures to tailor sampling requirements for management could compromise the suitability of sampling data for research purposes.

The introduction of risk concepts will inevitably focus attention on management tactics and strategies. While it is generally recognized that stochastic influences on a population's dynamics require that management strategies seek less than maximal yields, there has been little analysis of the role that estimation error plays in the success of management initiatives.

Conclusions

There is an important distinction between problems for which regret increases rapidly with the size of an error in a result and problems for which it increases slowly or not at all. In the first instances one must try to characterize large errors accurately, and commonly used methods of approximation cannot be expected to provide valid answers in all cases.

Yield per recruit analysis does fall in the class of problems for which regret is sensitive to the size of errors in

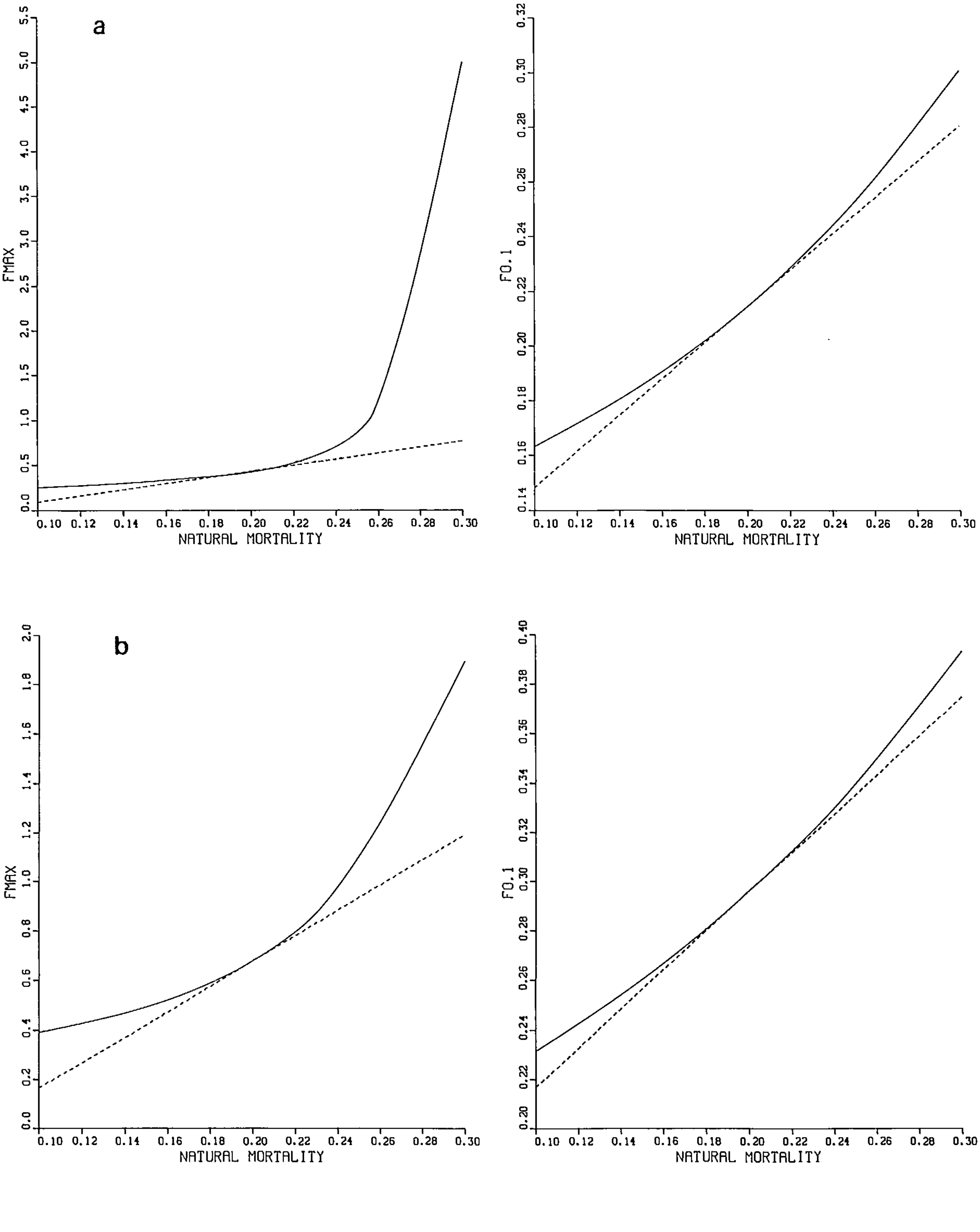

FIG 6. Values of $F_{0.1}$ and F_{max} as a function of the parameter representing natural mortality. See text for details of calculations. (solid line — exact calculation; dashed line — linear approximation) (a) 4TVn cod; (b) 4X haddock.

estimating yields. Fortunately, the calculation of yield per recruit is sufficiently simple that approximate methods are not necessary. Important savings in efforts to improve sampling can, however, be anticipated from use of measures of influence to focus attention on groups of parameters for which improvements in sampling will provide the greatest benefits.

The concepts of influence and regret, although introduced here in response to a specific question, are in fact fundamental to an understanding of the assessment process. Their application will have benefits beyond the questions addressed by this conference.

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Effects of Error in Catch and Effort Data on Tuning Cohort Analysis, with a Postscript on Logistic Production Models

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MOHN, R. K. 1983. Effects of error in catch and effort data on tuning cohort analysis, with a postscript on logistic production models, p. 141–150. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

As cohort analysis is an underdetermined system, it has no unique solution for fishing mortality or population numbers. Therefore, a process known as "tuning" is required to obtain in some sense a best fit. Comparisons of the fishing mortality from the cohort analysis with effort, or biomass from the analysis with catch per unit effort, are the usual bases for tuning. This tuning process is simulated from a modeled two-fleet single species fishery producing both noise-free and 20% contaminated data. The results suggest that fishing mortality versus effort is the preferred basis for comparison. Also, the distance of the last point to the regression line performs better than the correlation coefficient, and both perform much better than the intercept as a measure for tuning.

MOHN, R. K. 1983. Effects of error in catch and effort data on tuning cohort analysis, with a postscript on logistic production models, p. 141–150. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Étant donné que l'analyse par cohortes est un système indéterminé, il n'y a pas de solution unique au calcul de la mortalité due à la pêche ou à l'estimation de l'abondance. Par conséquent, un procédé d'« ajustement » est nécessaire pour obtenir ce que l'on pourrait appeler la meilleure concordance possible. L'ajustement se fait normalement en comparant la mortalité par pêche tirée de l'analyse par cohortes avec l'effort de pêche, ou la biomasse tirée de l'analyse avec la capture par unité d'effort. Ce procédé d'ajustement est appliqué à des données exemptes de bruit et à des données contenant 20% d'erreur relative, établies à partir d'un modèle représentant la pêche d'une seule espèce par deux flottilles. Les résultats indiquent que la meilleure base pour l'ajustement est la comparaison de la mortalité par pêche et de l'effort de pêche. Également, la distance du dernier point à la droite de régression fonctionne mieux que le coefficient de corrélation, et ces deux critères fonctionnent beaucoup mieux que le point d'intersection comme mesure pour l'ajustement.

Introduction

Sequential population analysis (virtual population analysis) (Fry 1949; Gulland 1965) and cohort analysis (Pope 1972) have widespread use in the stock assessment process. In this method of analysis, one tries to determine fishing mortality and population numbers from catch-at-age data over a number of years. This method is underdetermined as it has more unknown quantities than equations. Natural mortality and fishing mortalities for the oldest aged fish in the catch and for the most recent year's catch must be assumed or derived from other sources. Effort data, which often accompany commercial catch data, may be employed either directly or as a catch-per-unit-effort to estimate fishing mortalities to start the population analysis. This process is known as tuning. In light of the multitude of ways with which effort data may be used, it is important to understand the behavior of the tuning process.

Toward this end, a two-fleet fishery is simulated in which all the assumptions of the method are met. The performances of the various tuning methods are then compared for bias and stability.

Methods

INTRODUCTION OF VARIABLES AND NOMENCLATURE

The basis of sequential population analysis is the catch equation which relates the catch, C, to the instantaneous fishing mortality, F, weight-at-age, W_a, and the average population size, $\bar{N}$, over a period of time:

$$(1) \qquad C_{fya} = F_{fya}\bar{N}_{ya}W_{ya}$$

(Throughout this study, catch refers to biomass of catch, not numbers.)

The subscripts refer to the f^{th} fleet, y^{th} period or year, and age a. The average population size can be defined in terms of the instantaneous fishing and natural (M) mortalities acting over the period and the population size entering it.

$$(2) \qquad C_{fya} = F_{fya}N_{ya}\frac{(1 - e^{-M - F_{fya}})}{M + F_{fya}}W_{ya}$$

For simplicity, the natural mortality is assumed to be constant for all ages and years. If the catch is known, there remain three unknown quantities in the above relationship. This underdetermined equation requires that two of these three be specified before the last one can be solved for.

Assuming the instantaneous fishing mortality is linearly dependent upon the fishing effort yields,

$$(3) \qquad F_{fya} = q_{fa}E_{fy}$$

where q_{fa} is the catchability of gear of fleet f, which includes its selectivity.

This assumed relationship between effort and fishing mortality is the basis for the direct use of effort data in tuning. It suffers from a number of problems, however. First, how should the fishing mortalities at age from the trial sequential population analysis be combined to give a time series? Second, effort measures from various fleets may not be comparable to one another and hence difficult to combine. For example, if purse seines and fish weirs exploit the same stock, how can these disparate units be combined?

The variables in Table 1 were chosen as the most commonly used or advocated measures of fishing mortality for tuning. They are all averages (weighted or unweighted) of the F's at age produced by SPA. The SPA is performed on the total catch from the stock; therefore, the f subscript is dropped.

An appropriate effort series is required for comparison to fishing mortality. If the stock is exploited by only one fleet, or at least predominated by one fleet, for which effort data are available, then this series can be used. The situation is more difficult when effort series from dissimilar fleets are to be combined or when effort data are only available from a fleet that does not dominate the exploitation.

An effort series for comparison with fishing mortality from a nondominant fleet can be obtained by dividing the catch from all fleets by the catch-per-unit-effort (CPUE) of a reference individual fleet, f^*

$$(4) \qquad Ey = \frac{\sum_f C_{fy}}{\text{CPUE}_{f^*y}}$$

In the comparisons presented below, ET1 or ET2 will be used for the "raw" effort series from simulated Fleets 1 and 2. EFL1 or EFL2 will be used to denote the effort series for a fleet that is derived from the above equation.

The problem of combining effort series may be approached by combining CPUE's for the fleets then dividing the resultant into the total catch (ICES 1981).

Before combining the CPUE's, they are first normalized to a reference year, y^*

$$(5) \qquad \gamma_{fy} = \text{CPUE}_{fy}/\text{CPUE}_{fy^*}.$$

TABLE 1. Measures of fishing mortality and effort series.

	Computer variable name		Comments
Average F	FAVE	$\frac{\sum_a F_{ya}}{\sum_a 1}$	
Catch-weighted F	FCAT	$\frac{\sum F_{ya}C_{ya}}{\sum_a C_{ya}}$	
Numbers-weighted F	FNUM	$\sum_a \frac{F_{ya}N_{ya}}{\sum_a N_{ya}}$	
Fully recruited F	FFUL	$\sum_{a\geq a_r} \frac{F_{ya}}{\sum_{a\geq a_r}}$	a_r — age of full recruitment
Inverse-weighted F	FINV	$\frac{\sum_a F_{ya}}{(S_a)}$	See equation (10) for definition of S_a
Raw effort	ET2		
Derived effort	EFL1		Equation (4) of text
	EFL2		
Combined	EGAM		Equation (6) of text

Then combine these relative catch rates by weighting them according to the proportion of the catch they represent.

$$(6) \quad \Gamma_{\cdot y} = \frac{\sum_{f} \gamma_{fy} C_{fy}}{\sum_{f} C_{fy}}$$

Finally, the resultant effort is found by dividing the averaged CPUE into the catch and "denormalizing" with regard to the reference year. This effort series is called EGAM in the comparisons that follow.

$$(7) \quad E_{\cdot y} = C_{\cdot y}/(\Gamma_y/Cy^*)$$

Effort, introduced in terms of catch per unit effort, can also be used to tune the analysis. If equations (1) and (3) are combined and rearranged, it yields:

$$(8) \quad \frac{C_{fya}}{E_{fy}} = q_{fa} \overline{N}_{ya}$$

If the catch is in units of weight, the numbers from the SPA should be multiplied by weights-at-age to give biomass. As was the case for the F's, the biomass series may be described by a number of variables (Table 2).

Three catch-per-unit effort series are used in conjunction with biomass measures: CPU1 from the dominant fleet, CPU2 from the smaller fleet, and CPU for the combined series as defined by equation (6).

As the equations defining the tuning (equations (3) and (7)) are linear without y intercepts, the goodness of fit measures are the magnitude of the correlation coefficient, the nearness of the regression intercept to the origin, and the nearness of the most recent data point to the regression line. (See Fig. 1 for an example of these measures.) In order that the dissimilar E vs. F and CPUE vs. B distances may be compared, the derived quantities, fishing mortality, and biomass are normalized by dividing by their mean values over the 20-yr simulation period.

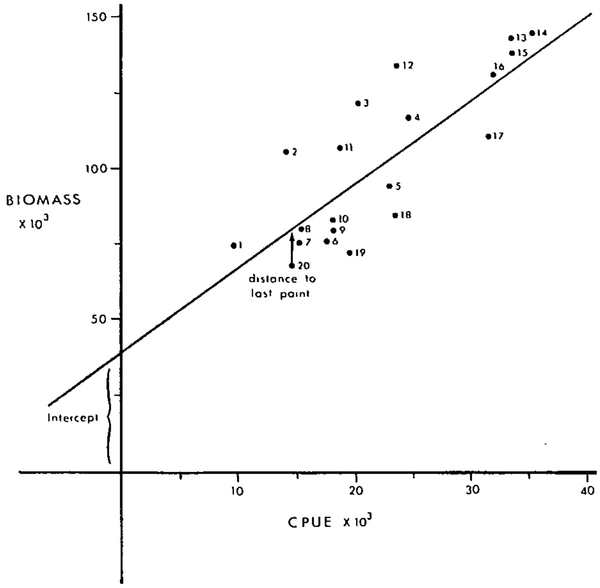

FIG. 1. Comparison of catch-per-unit effort and biomass, showing regression line, intercept, and distance of last point to regression line.

SIMULATION

The simulation has three parts: (1) generation of catch data; (2) the corruption of these data by noise; and (3) the performance of the goodness-of-fit indices in tuning the SPA.

TABLE 2. Measures of biomass and catch-per-unit effort series.

	Computer variable name	Definition	Comments
Total biomass	BIOM	$\sum_{a} N_{ya} W_a$	
Average biomass	ABIO	$\sum N_{ya} W_a \frac{(1 - e^{-M-F_{ya}})}{M + F_{ya}}$	
Spawning stock biomass	SBIO	$\sum_{a \geq a_s} N_{ya} W_a \frac{(1 - e^{-M-F_{ya}})}{M + F_{ya}}$	a_s age of spawning
Exploited biomass	XBIO	$\sum_{a} N_{ya} W_a \frac{(1 - e^{-M-F_{ya}})}{M + F_{ya}} \frac{F_{ya}}{F_{ya^*}}$	a^* reference age
Catch-per-unit effort for fleet	CPU1 CPU2		
Combined catch-per-unit effort	CPU		Equation (6) of text

A fishery exploited by two fleets is simulated over a 20-yr period with a stock that is vulnerable to the gear for 7 yr — thus the subscripts f, y, and a range from 1 to 2, 1 to 20, and 1 to 7, respectively. Fleet 1 dominates the fishery, taking between 82 and 97% of the catch. The true catch and effort series, as opposed to being corrupted with noise, for the two fleets is shown in Fig. 2 as well as the total biomass for the 20-yr period. Each fishery has its own catchability and selectivity, which remain constant. Recruitment for the 20-yr period is drawn from a uniform distribution with a range of one order of magnitude. A weight-at-age vector is used to produce biomass and yield from numbers- and catch-at-age. These weights are constant throughout the 20-yr period.

Noise is generated by randomly drawing from a normal distribution of zero mean and unit standard deviation. The random variates are then scaled to give a coefficient of variation of 20% and added independently to the catch-at-age and effort data.

Two different programs were developed to assess the ability of the effort data to tune the analysis. The first was used to screen from a large number of potential tuning methods those that did not perform well under ideal conditions. The second program more closely simulates the situation facing an assessment biologist. Cohort analysis and not virtual population analysis was used (Pope 1972). The natural mortality (0.2) and fishing mortalities are well within the limits for the cohort approximation.

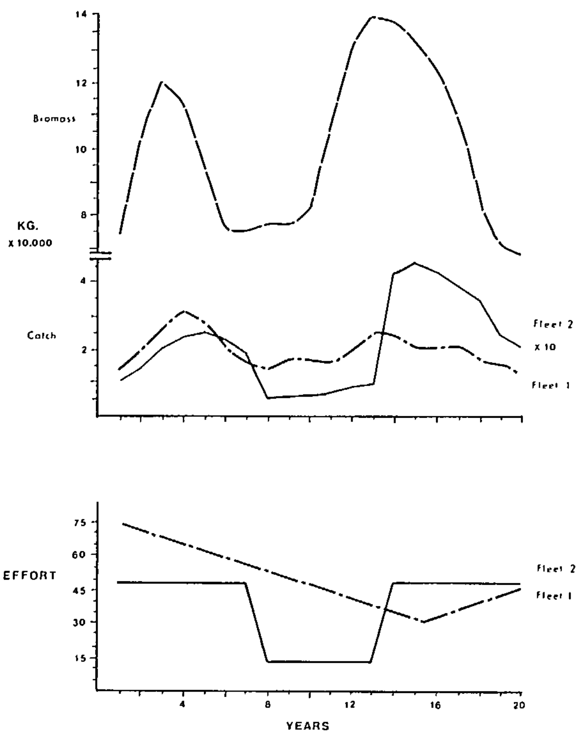

FIG. 2. Simulated data from two fleet fishery for 20-yr period.

In the first program, all data are noise-free and the selectivity and starting F values are correct. In this situation, the variables used for tuning should be linear. The regression should have a unit correlation coefficient, zero intercept, and the last point (indeed all points) fall on the regression line. Those tuning methods that perform poorly in this program do not receive further consideration.

The second analysis program is an attempt to mirror the predicament of an assessment biologist, except that the natural mortality is known and the pattern of the starting F's are better known than is the normal case. The starting F values for the oldest age ($\hat{F}_{y7}$) class are found by multiplying the ratio of the true F and effort of the dominant fleet for the first 15 yr data by the effort data of the dominant fleet. This ratio is an estimate of the catchability from which the starting F's are derived from the effort series.

$$(9)\qquad \hat{F}_{y7} = E_{1y} \times \frac{\sum_{y=1}^{15} F_{y7}}{\sum_{y=1}^{15} E_{1y}}$$

The selectivity pattern, Sa, is also taken from the true F values by summing them over the years and normalizing

$$(10)\qquad \hat{S}a = \frac{\sum_y F_{ya}}{\max_a \sum_y F_{ya}}.$$

The crux of the tuning is to find the F which when multiplied by the selectivity will be closest to the true value. In this program a range of F's, 50, 70, 90, 100, 111, 143, and 200% of the true value were tried.

Three indices of goodness of fit are used to define error functions. Locating the minimum of these error functions is known as tuning the analysis. These indices are chosen because of their widespread use and are: (1) the correlation coefficient of between effort or catch-per-unit effort and fishing mortality or biomass from the SPA; (2) the intercept of the regression line of the previously mentioned variables; and (3) the distance of the last point to that regression line. The correlation coefficient between the observed variables and those from the sequential analysis is probably the most often used index for tuning. The usual shape of an error function is U-shaped with a minimum that defines the point of best fit (see Fig. 3). To transform the correlation coefficient into such a shape, it is expressed as the coefficient of nondetermination ($1 - r^2$). The second measure of fit, the y intercept of the regression, as seen in equation (3) (effort vs. F) and equation (8) (CPUE vs. biomass), should theoretically be 0. Therefore, absolute value of the distance from 0 is used to give an error function. The loss of information in dropping the sign of the intercept is not important in the present context. The distance is normalized by dividing by the mean ordinate value of the points in the regression to make comparisons between disparate units possible. Similarly, error functions are also produced from the absolute value of the normalized distance of the last point to the regression line. This measure of error would be expected to be more sen-

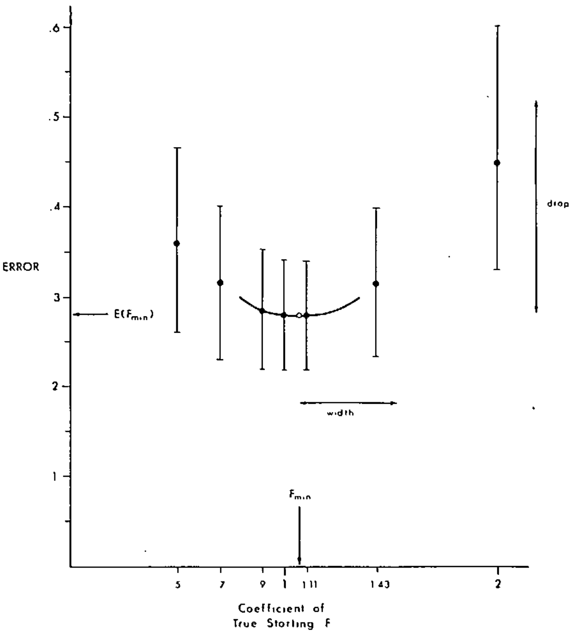

FIG. 3. Error function and the four parameters used for description and comparison in the text. The error bars are single-standard deviations, and the curve is the coefficient of nondetermination from FAVE vs. EGAM with 20% noise added to catch and effort data.

sitive to the assumed starting values than the first two defined functions. This is because the last point is the one greatest affected to changes in assumed F's and because the first two functions are defined by all the data points as opposed to a single point.

An error function (Fig. 3) is defined over the range of trial F's. It is the coefficient of nondetermination $(1 - r^2)$ for the correlation test. It is the magnitude of the normalized y distance to the origin in the intercept case and the distance to the regression line for the third test. This error function should be U-shaped with a minimum at true F value. Steeper sides would produce faster convergence if one were using an iterative technique to tune the analysis. Four parameters will be used to describe the error functions. The first two are the location (F_{min}) and magnitude [$E(F_{min})$] of the minimum of the error function over the range tested. The position of the minimum is determined by fitting a quadratic function through the three lowest points and finding its minimum algebraically. The steepness is described as the sum of the Y distances of the endpoints (0.5, 2.0) to the minimum and is called "Drop" in Tables 4 and 5. The last parameter describing the error function incorporates uncertainty in estimating the error function by dividing the average standard deviation of the estimates of the error function by the steepness of the function. This gives an indication of the probable range of the location of the minimum and is called "Width." Increasing the standard deviation or decreasing the Drop would increase the Width. A desirable tuning procedure would have an F_{min} of 1, a large Drop, and a small Width.

Results

Table 3 contains the results from the first of the two programs described above. The data are consistent with the assumptions of SPA and are error-free to the accuracy of the programs. The three indices of fit, coefficient of determination, normalized intercept, and distance of last point to the regression line are tried. Five of the comparisons are not considered further either because they fit so poorly that they would not be considered useful or because they behave identically to some of those that were kept. It is interesting to note that no 0 intercepts were produced, although six of the comparisons had unit correlation coefficients and four had zero distance to the last point.

Table 4 contains the descriptive parameters of the error functions in the absence of noise and with a 20% coefficient of variation on both catch and effort data. The F vs. E comparisons using the coefficient of nondetermination in general perform better than the CPUE vs. biomass comparisons. EGAM vs. the average F (FAVE), fully recruited F (FFUL), and inversely weighted F (FINV) perform well, with FINV showing a slight advantage over the other two. The catch-weighted F (FCAT) underestimates the starting F and has a poorer correlation, Drop, and Width than the other comparisons to EGAM. The comparison between the average F and the effort measure found by dividing the total catch by CPU2 (EFL2) seriously underestimated the starting F but performed well in terms of the other three parameters. None of these comparisons were biased by the addition of noise.

The CPUE vs. biomass comparisons using correlation did not perform as well as F vs. E. They tended to underestimate the starting F. Only XBIO, the exploited biomass, vs. CPUE had an unbiased minimum, and it was lost when the noise was added. The method also suffers from a very broad minimum, as is evidenced in the low Drop value and the largest Width of any method tested.

The distance of the last point to the regression line displays better performance than the coefficient of nondetermination. All four comparisons with EGAM did

TABLE 3. Goodness of fit indices with ideal data.

Comparison		r^2	Normalized intercept	Normalized distance	Further investigation
FAVE	EGAM	1.00	−0.01	0.00	yes
FNUM	EGAM	0.10	0.59	0.16	no
FCAT	EGAM	0.47	0.40	0.00	yes
FFUL	EGAM	1.00	−0.01	0.00	yes
FINV	EGAM	1.00	−0.02	0.01	yes
FAVE	EFL1	1.00	−0.02	0.02	no
FAVE	EFL2	0.89	0.29	0.12	yes
FAVE	ET2	0.13	0.79	0.12	no
BIOM	CPU	0.64	0.42	0.11	yes
ABIO	CPU	0.60	0.41	0.10	no
XBIO	CPU	1.00	0.02	0.01	yes
SBIO	CPU	0.87	−0.03	0.09	yes
XBIO	CPU1	1.00	−0.04	0.00	no
XBIO	CPU2	0.86	−0.16	0.18	yes

TABLE 4. Performance of coefficient of nondetermination and distance of last point from regression line tuning indices.

Comparison		Coefficient of nondetermination F_{min}	$E(F_{min})$	Drop	Width	Last point F_{min}	$E(F_{min})$	Drop	Width	C.V.
FAVE	EGAM	1.01	0.01	0.41	0.00	1.00	0.00	0.99	0.00	0.0
		1.07	0.28	0.27	0.48	1.07	0.03	0.91	0.18	0.2
FCAT	EGAM	0.73	0.48	0.31	0.00	1.00	0.01	1.03	0.00	0.0
		0.78	0.71	0.13	1.43	1.03	0.02	0.94	0.09	0.2
FFUL	EGAM	1.01	0.01	0.38	0.00	1.01	0.00	0.96	0.00	0.0
		1.07	0.28	0.24	0.50	1.09	0.03	0.88	0.18	0.2
FINV	EGAM	1.01	0.00	0.54	0.00	1.00	0.00	1.04	0.00	0.0
		1.04	0.31	0.35	0.41	1.04	0.0	0.99	0.17	0.2
FAVE	EFL2	0.77	0.09	0.44	0.00	0.81	0.04	0.86	0.00	0.0
		0.50	0.40	0.34	0.44	0.96	0.02	0.91	0.17	0.2
BIOM	CPU	0.75	0.30	0.21	0.00	0.81	0.05	0.56	0.00	0.0
		0.75	0.50	0.13	0.91	0.72	0.00	0.64	0.15	0.2
XBIO	CPU	1.02	0.01	0.05	0.00	1.02	0.01	0.30	0.00	0.0
		0.88	0.26	0.04	3.92	0.92	0.02	0.39	0.37	0.2
SBIO	CPU	0.88	0.11	0.10	0.00	0.85	0.03	0.49	0.00	0.0
		0.88	0.34	0.07	1.97	0.68	0.06	0.41	0.31	0.2
XBIO	CPU2	0.70	0.10	0.11	0.00	0.70	0.12	0.36	0.00	0.0
		0.50	0.44	0.09	1.94	0.50	0.02	0.43	0.49	0.2

well in terms of bias and width, with the catch-weighted F being surprisingly tight. The FAVE vs. EFL2 relationship is biased towards underestimation in the noise-free case but does well with the Gaussian noise used in the simulation. As in the coefficient of nondetermination, the CPUE vs. biomass tunings tend to underestimate starting F's, with the exception of the exploited biomass, XBIO, which still has the smallest Drop and greatest Width.

Table 5 shows the results for the intercept used as a tuning criterion. It performs very poorly, biasing so severely that in only one case was the minimum inside the tested range. It is included only for completeness, and its use is discouraged.

Table 6 is analogous to Table 4 except that it is the result of a different population trend over the 20-yr period. The biomass series underlying these results are appended to Table 6. Instead of a low terminal biomass, the last year's biomass is the largest in the series. The results are generally similar to Table 4 although relative advantage of F vs. E is not as pronounced. When the error function is defined by the coefficient of nondetermination, F vs. E performs about equally with biomass vs. CPUE, but it performs demonstrably better when the error function is the distance

TABLE 5. Performance of normalized y intercept.

Comparison		F_{min}	$E(F_{min})$	Drop	Width	σ
FAVE	EGAM	1.496	0.002	0.213	0	0
		0.5	0.264	0.125	1.358	0.2
FCAT	EGAM	0.5	0.265	0.202	0	0
		0.5	0.543	0.104	2.332	0.2
BIOM	CPU	2.0	0.339	0.135	0	0
		2.0	0.543	0.09	1.526	0.2
XBIO	CPU	0.5	0.035	0.114	0	0
		2.0	0.192	0.081	3.138	0.2

of the final point from the regression line. As in Table 4, such an error function worked best when the combined effort (EGAM) was compared to the average F, fully recruited F, or the inverse weighted F. The addition of 20% noise did not seriously degrade the ability to tune these comparisons. Amongst the biomass comparisons, the spawning stock biomass (SBIO) had the best error function in light of narrower width and a properly located minimum. As expected from Table 5, error functions defined by the regression intercept with these data performed very poorly and because of this are not included.

Conclusions

A small number of simulations cannot be expected to define a complex system, especially when stochastic variables are used. However, tuning techniques that worked poorly, and more importantly those that worked poorly in the absence of noise, should be labeled as at best unreliable. A number of comparisons were found for which this is true (see Table 3). Also, error functions based on the regression intercept are in general unreliable and are to be avoided. A second set of results was compiled as a first check to identify if the results in Table 4 were artifacts of the initial conditions and control parameters (recruitment, effort pattern, etc.). In both these sets, the dynamic ranges of biomass and F were forced to be equal so as not to bias one type of comparison to another.

In general terms, these simulations suggest that it is better to compare fishing mortality and effort to tune SPA's than per unit effort and biomass. Also, of the three methods used for comparison, the distance of the last point to the regression line works best. It is not clear to the author why the information content of the effort data should be diminished when it is introduced as CPUE. Both q, the catchability, and the growth rates were kept constant in

TABLE 6. Performance of coefficient of nondetermination and distance of last point from regression line tuning indices.[a]

Comparison		Coefficient of nondetermination				Last point				
		F_{min}	$E(F_{min})$	Drop	Width	F_{min}	$E(F_{min})$	Drop	Width	C.V.
FAVE	EGAM	0.96	0.00	0.27	0.00	0.95	0.02	0.69	0.00	0.0
		0.96	0.30	0.18	0.99	1.02	0.01	0.71	0.12	0.2
FCAT	EGAM	0.94	0.36	0.47	0.00	1.03	0.02	0.92	0.00	0.0
		0.83	0.58	0.26	0.90	1.14	0.01	0.91	0.10	0.2
FFUL	EGAM	0.96	0.00	0.24	0.00	0.95	0.02	0.68	0.00	0.0
		0.97	0.29	0.16	1.03	1.02	0.01	0.69	0.12	0.2
FINV	EGAM	0.95	0.00	0.37	0.00	0.93	0.02	0.69	0.00	0.0
		0.87	0.34	0.24	0.81	1.03	0.01	0.72	0.12	0.2
FAVE	EFL2	1.13	0.05	0.24	0.00	1.13	0.01	0.73	0.00	0.0
		1.26	0.41	0.14	0.86	1.20	0.03	0.71	0.20	0.2
BIOM	CPU	0.87	0.29	0.52	0.00	0.98	0.03	1.05	0.00	0.0
		0.84	0.53	0.33	0.44	1.14	0.02	1.11	0.16	0.2
XBIO	CPU	0.98	0.01	0.46	0.00	1.00	0.01	0.68	0.00	0.0
		0.50	0.42	0.22	0.76	1.26	0.06	0.87	0.32	0.2
SBIO	CPU	0.96	0.04	0.66	0.00	0.94	0.04	1.29	0.00	0.0
		0.92	0.41	0.38	0.42	1.04	0.03	1.35	0.17	0.2
XBIO	CPU2	1.00	0.10	0.40	0.00	1.04	0.03	0.67	0.00	0.0
		1.19	0.59	0.12	1.42	1.48	0.07	0.97	0.45	0.2

[a]Biomass series for the simulation used to derive the above table (simulated thousands of tonnes):

Year	Biomass	Year	Biomass	Year	Biomass
1	89	8	167	15	84
2	130	9	152	16	94
3	161	10	130	17	117
4	175	11	111	18	148
5	176	12	99	19	176
6	176	13	93	20	196
7	176	14	88		

the simulated 20-yr period. The ability of the distance to the regression line of the last point to produce a better error function is explainable in that the increased sensitivity of the method more than compensates for its instability to noise. The average, fully recruited, and inversely weighted F's all produced good estimates, with the inversely weighted average having a slight edge over the other. It is unlikely this small difference would be discernible in real data. The good performance of the catch-weighted F using the distance to the last point must be considered in light of the low correlation coefficient it has even in noise-free data. One would not know when the data were appropriate for analysis and could not discriminate good data sets.

The combined effort measures defined by equations (5)-(7) performed well in these simulations. It was used both directly as EGAM for comparison to fishing and indirectly by dividing it into the total catch to form CPU. It would be of value to try this measure in more complex and diverse simulations to see if the above observation is generally true.

The effort measure, EFL2, derived by dividing the total catch by the catch-per-unit effort of the lesser fleet had very good correlation coefficients, but the maximum of the correlation coefficient seriously underestimated the starting F in Table 4 and overestimated in Table 6. This measure did produce more reasonable estimates with the distance to the last point error function. Estimates from this distance method became less biased when noise was added in Table 4. This approach is autocorrelative, but with the simulated data generated for this study, the effect seems to be beneficial.

XBIO vs. CPU had a correlation coefficient of one with the ideal data in Table 3 but performed poorly in terms of coefficient of nondetermination. This is because of the very low Drop related to this comparison. Biomass is multiplied by the factor $(1 - e^{-Z})/Z$ to form the exploited biomass. This factor is the reciprocal of the factor relating catch to numbers-at-age; and varying the F in a sense multiplies the factor by its inverse, canceling the effect. This effect is less pronounced in Table 6, but even so the XBIO comparisons with CPU and CPU2 had the highest width of the biomass comparisons.

As was mentioned in the introduction, when one is faced with an analytically intractable system, illumination may be possible by simplifying into a tractable form or by simulation. A simulation study may give unreliable or misleading results, as may an oversimplified analytic solution, when dealing with a highly nonlinear or discontinuous system. In such a situation a slight perturbation of a descriptive parameter (e.g. natural mortality) or an initial condition (e.g. starting population) may have a large sensitivity and produce drastically different results. In the two reported runs, and in a few others which were not reported, no such critical factors were discovered. Therefore, the reported results are not special cases, nor are they knowingly biased. It may be that adjusting for equal dynamic ranges to compare F vs. E and biomass vs. CPUE produced error functions is not appropriate and some more sophisticated index of signal to noise ratio or information content is required. This remains to be demonstrated. Along similar lines, it is noted that F vs. E did best in Table 4 and in this case the fully recruited terminal F was 0.55. In Table 6, where the advantage was not so pronounced, the terminal F was 0.43. In an unreported run where the terminal F was of the order of 0.1, F vs. E was not demonstrably better. It would be an interesting future study to see the sensitivity of the choice of tuning method to terminal F.

The reported study was undertaken to determine if there were clearly preferable bases for tuning cohort analyses. Although the results are not presented as being exhaustive, some techniques must be identified as unreliable or misleading, even in the absence of contaminating noise and sensitivity to noise.

Appendix A

Postscript on Logistic Production Models

This appendix is a condensation of Mohn (1980) and is included because of its similarity to the body of the paper and the theme of this session. The logistic equation is defined as

$$\text{(A1)} \quad \frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right) - qEP$$

where P = biomass; t = time; r is the intrinsic growth rate; K is the carrying capacity; q is the catchability; and E is fishing effort. This is the simplest form for a population with density-dependent growth. Unlike cohort analysis, the catch and effort data are not aged and the dynamics of the population as a whole are being estimated from the data. The responses of a population defined by equation (A1) to a smooth series of effort data are shown in Fig. A1 and A2. Figure A1 displays data which were produced with an intrinsic growth rate of 0.6 and the other parameters set so MSY and the MSY effort (EMSY) would both equal 100 000. Figure A2 has an intrinsic growth rate of 0.2 and represents a less dynamic stock. The more dynamic stock shows a fatter oval.

The modeled biological system, described by the logistic equation, responds instantaneously to changes in the density-dependent term, P/K. The equation could be made more realistic by adding a time of delay, say 5 yr, to the relative density.

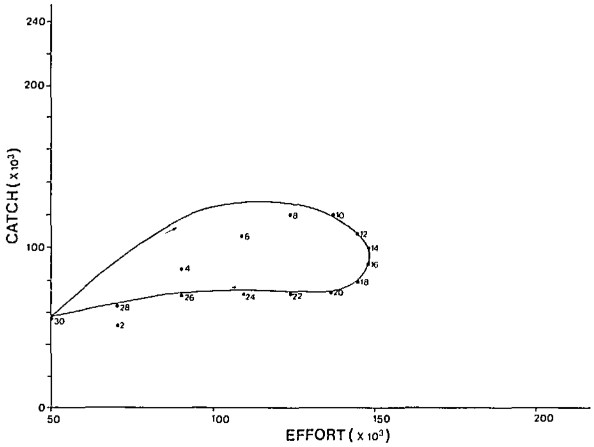

Fig. A1. Catch resultant from the smooth effort series on the dynamic, r = 0.6, stock. The even years of the first 30-yr cycle are given as dots and the limit cycle is shown as the solid line.

$$\text{(A2)} \quad \frac{dP}{dt} = rP\left(1 - \frac{P_{t-5}}{K}\right) - qEP$$

where P_{t-5} is the population 5 yr earlier. Adding a delay tends to fatten the limit cycle, but in a different way than does increasing r. In order to make the simulation more similar to real data, the effort series is made rougher so its year-to-year variation corresponds to that seen in fisheries' statistics (see Fig. A3).

The methods chosen to analyze the simulated data are: (i) the regression of CPUE vs. effort; (ii) Gulland's method (Gulland 1961); and (iii) the linear approximation presented in Schnute (1977). The basis of the first two methods is found by setting the derivative in equation (A1) to zero, which leads to the description of catch as a quadratic function of effort. This catch is an equilibrium catch as setting the derivative to zero is equivalent to keeping the biomass constant. When both sides of the quadratic expression are divided by effort, it yields catch-per-unit effort as a linear function of effort, and a linear regression can then estimate the descriptive parameters. Gulland's method is an extension of this in which the effort data are averaged and lagged to smooth the data and take into account the delays in a biological system. Both these methods estimate two parameters of the equilibrium catch relationship, which are often defined as MSY and EMSY. Schnute's method is not an equilibrium method and uses the time series of the catch and effort data to estimate all three defining parameters of equation (A1).

A reduced set of results is shown in Table A1, which contains estimates of MSY and EMSY and their standard deviations as a function of increasing noise in the data and method of estimation. The first set of results is for the dynamic stock with no time lag. CPUE vs. E greatly overestimates EMSY and overestimates MSY. Because of autocorrelation (effort appearing in both sides of the regression), the correlation coefficient does not decrease with in-

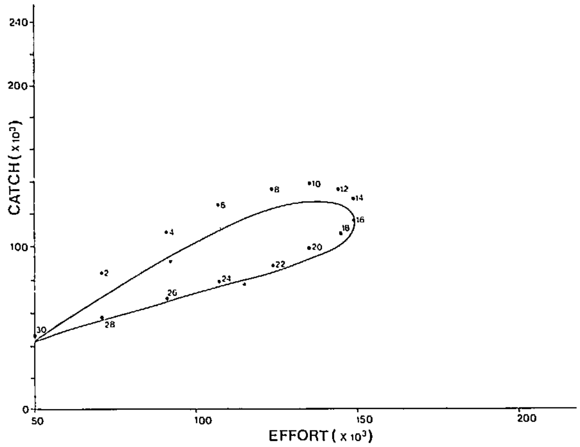

FIG. A2. Catch resultant from the smooth effort series on the less dynamic, $r = 0.2$, stock. The even years of the first 30 yr are given as dots and the limit cycle is shown as a solid line.

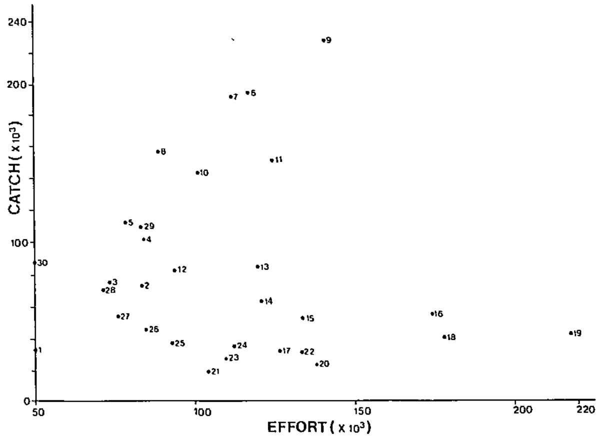

FIG. A3. Catch resultant from the rough effort series. The logistic equation has the parameter values, $q = 3 \times 10^{-6}$, $k = 666\ 667$, and $r = 0.6$, an initial condition of CPUE = 0.6 and a 5-yr delay in the density-dependent term.

creasing noise. Gulland's method, using a 5-yr average on the effort data, displays a marked improvement slightly overestimating EMSY and correctly within a few percent estimating MSY. Schnute's method gives more accurate though less precise estimates than the other two methods. This is shown in the larger standard deviations. Also, the correlations found by Schnute's method are a sensitive indication of the degree to which the data are corrupted by noise.

The next block of results is as above, only a 5-yr lag has been added to the density-dependent term. The CPUE vs. E method performs much better than in the above case, except that the correlation coefficient still does not reflect the degree of noise. Gulland's method slightly underestimates EMSY and slightly overestimates MSY. Schnute's method produced poor results with MSY being overestimated by more than 100% even with noise-free data.

A less dynamic stock ($r = 0.2$) is simulated in the bottom two blocks of Table A1. CPUE vs. E greatly overestimates EMSY and MSY, as does Gulland's to a lesser degree in the absence of a lag. The precision of

TABLE A1. EMSY and MSY estimates for increasing levels of noise, σ, EMSY, MSY, and their standard deviations are in thousands, and σ in %. R is the correlation coefficient.

	CPUE vs. E						Gulland					Schnute				
	α	EMSY	SD	MSY	SD	R	EMSY	SD	MSY	SD	R	EMSY	SD	MSY	SD	R
$r = 0.6$	0	240	0	129	0	0.50	125	0	96	0	0.93	100	0	100	0	1.00
	5	233	16	127	5	0.50	125	4	97	1	0.91	100	6	101	4	0.74
	10	223	38	123	13	0.50	126	8	97	1	0.85	97	17	99	30	0.46
	20	186	43	114	14	0.52	127	15	100	4	0.66	90	43	91	89	0.30
$r = 0.6$ lag = 5	0	117	0	93	0	0.45	81	0	118	0	0.81	68	0	205	0	0.75
	5	116	3	93	1	0.46	81	1	118	2	0.80	68	1	206	14	0.68
	10	115	6	94	2	0.47	81	2	119	5	0.80	58	2	218	60	0.52
	20	112	9	97	4	0.50	82	3	120	10	0.75	69	4	2072	16 174	0.36
$r = 0.2$	0	361	0	208	0	0.35	191	0	129	0	0.61	100	0	100	0	1.00
	5	344	48	201	21	0.36	190	13	129	4	0.61	100	18	104	10	0.40
	10	322	104	191	46	0.36	198	45	133	17	0.52	105	78	112	92	0.23
	20	261	224	169	112	0.41	938	11 547	529	5 802	0.40	64	149	96	121	0.18
$r = 0.2$ lag = 5	0	276	0	158	0	0.35	153	0	107	0	0.63	87	0	98	0	0.98
	5	266	26	154	10	0.36	153	7	107	2	0.61	87	8	100	9	0.49
	10	251	53	148	21	0.38	156	21	109	5	0.58	82	43	98	49	0.28
	20	207	76	135	32	0.42	173	99	119	41	0.47	98	179	159	947	0.19

Schnute's estimates is slightly worse than the $r = 0.6$ case.

Finally, a 5-yr lag is added to the less dynamic stock. This addition produced data that yield better estimates than the strictly logistic data for both CPUE vs. E and Gulland's method. The dramatic failure of Schnute's method to handle data produced with a lag in the defining equation in the more dynamic stock does not take place here.

In the more dynamic simulated data, CPUE vs. E is too biased to be useful and gives no indication of the degree of noise contamination. Gulland's method performed well with low bias and sensitivity to noise. Schnute's method works well on the prelogistic data but not on the 5-yr lag data. The less dynamic data cause both CPUE vs. E and Gulland's methods to give poorer estimates both in terms of bias and error variance. Although Schnute's method produces relatively unbiased estimates, its sensitivity to noise is greater than a factor of 2 at low levels and increases at least quadratically.

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An Investigation of the Relationship Between the Precision of Assessment Data and the Precision of Total Allowable Catches

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POPE, J. G., AND D. GRAY. 1983. An investigation of the relationship between the precision of assessment data and the precision of total allowable catches, p. 151–157. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

The precision of Total Allowable Catches (TACs) is investigated using a simple Monte Carlo simulation technique. This indicates the levels of variability in TACs that are generated by various levels of variability in the major input time series of fishing effort data, catch numbers at age data, and recruitment survey data. Examples are given based on various North Sea fish stocks.

POPE, J. G., AND D. GRAY. 1983. An investigation of the relationship between the precision of assessment data and the precision of total allowable catches, p. 151–157. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

La précision des estimations du total des prises admissible (TPA) est étudiée à l'aide d'une technique de simulation Monte-Carlo simple. Cette simulation sert à quantifier le degré d'incertitude des TPA, en fonction de divers niveaux de variabilité introduits dans les séries temporelles qui servent de base à une analyse donnée, comme les données sur l'effort de pêche, le nombre de poissons capturés par groupe d'âge et les estimations du recrutement au moyen de relevés. On donne des exemples pour différents stocks de poissons de la Mer du Nord.

Introduction

The assessments of fish stocks produced by fisheries scientists are necessarily based on data subject to sampling errors. It has been shown by Gulland (1955), Pope (1972), Pope and Garrod (1975) and Doubleday (1979) that the quality of assessments reflects the quality of the data available. It is therefore perhaps surprising that fisheries scientists have generally failed to set guidelines for the precision and accuracy they expect of their data bases or to indicate the error limits of their assessments.

The need for guidelines is particularly acute for those data sets that result from the sampling of commercial catches. This is because data sets such as total catch numbers at age or average weight at age are usually aggregates of results from separate fleet sectors and often aggregates of results from different countries. This often results in the responsibility, for sampling various subdivisions of the catch, lying in different hands. Clearly, sampling of part of the catch can only be optimized if there are agreed requirements for the precision of the aggregate results. Without such agreed requirements, some sectors may be wastefully oversampled while others may be poorly sampled and thus lower the overall precision of the aggregate results.

To consider what would be a sensible requirement for the precision of data sets, it is necessary to consider what they will be used to estimate and how precise this estimate should be. One obvious use of fisheries assessment data is to estimate total allowable catches (TACs).

This paper therefore considers how precisely TACs should be estimated, and investigates the relationship between the precision of the input data and the precision of the TACs for three North Sea fish stocks, using a Monte Carlo simulation technique. The method and the results should help fisheries scientists to consider how precise their assessments are and specify how precise their data sets should be.

The Appropriate Precision of Total Allowable Catches

The question of how precisely TACs should be estimated has so far received scant attention. Rivard (1981) makes some sensible financial arguments for improving current practices to achieve a coefficient of variation of 10%. Practical considerations suggest that ultimately they should have small coefficients of variation. As an example, consider a fishing fleet of the appropriate capacity to generate the optimal level of fishing mortality on a particular fish stock.

TABLE 1. Approximate percentage frequency of various events for different coefficients of variation of TACs.

Event	Coefficient of variation of TACs			
	30%	20%	10%	5%
Quota used up by end of				
June	5%	1%	—	—
July	8%	2%	—	—
August	13%	5%	—	—
September	20%	10%	1%	—
October	29%	20%	5%	?
November	40%	34%	20%	5%
Quota proportion remaining at end of year				
50%	1%	—	—	—
25%	23%	5%	1%	—
10%	35%	29%	13%	1%
5%	43%	40%	30%	15%

If the catch quota that it was allocated was subject to a coefficient of variation of 30% with a Gaussian distribution, then, as can be seen from Table 1, in 5% of years the quota would be used up by the end of June and in 20% of years the quota would be used up by the end of September; on the other hand, in 23% of years a quarter of the quota would remain unused at the end of the year. From Table 1, it is possible to see that TACs with a large coefficient of variation would make TAC management very unpopular with the fishermen. In the long term, administrators would therefore certainly opt for 10 or 5% coefficients of variation rather than 30 or 20% if the lower levels were achievable. Given that a TAC with a coefficient of variation of about 10% is a broadly sensible objective, the question then to ask is, how precise should be the data it is based upon? This question was considered by Pope and Garrod (1975) and by Rivard (1981) who provide formulae relating the variance of catch projections to the variance of various input data sets, and by Doubleday (1979) who makes a sensitivity analysis of catch projections.

While all of these contributions are extremely pertinent to the problem, they do have limitations. The first limitation is that they are concerned solely with the precision of the catch projection process rather than the precision of the total assessment. The total assessment has two main stages: the calibration of data to assess the current state of the stock and the catch projection process. The precision of both parts of the assessment influences the precision of the TAC, and the precision of both parts is influenced by the precision of input data. Unfortunately, while the latter process is amenable to an analysis of what influences the precision of outputs, the former is often recursive and somewhat subjective, and therefore difficult to analyse.

A second limitation of the Pope and Garrod (1975) and the Rivard (1981) approaches is that they are concerned with management to a fixed objective fishing mortality such as F_{max} or $F_{0.1}$. They thus do not necessarily describe the precision of TACs calculated to either maintain current levels of fishing mortality or reduce them by a certain percentage.

This approach to the calculation of TACs is a common practice of the assessment working groups of the International Council for the Exploration of the Sea (ICES), and the relationship of the precision of such status quo TACs to the precision of input data clearly deserves attention. These limitations of available methods suggest that a Monte Carlo simulation approach to investigating the relationship of the precision of TACs to the precision of input data is worth considering.

To estimate the variability of a TAC at various levels of variability of the input data using a Monte Carlo simulation technique requires many recalculations of the basic working group TAC estimation procedure. It is thus essential that these procedures be programmed for a computer and this has been done using the sequence of operations indicated in the flow chart given in Fig. 1. This follows working group procedures closely, except that a least squares method is used instead of virtual population analysis.

The mode of operation is to interpret catch-at-age data $C(i, j)$ using the least squares method of Pope and Shepherd (1982). Apart from catch-at-age data, this method requires inputs of natural mortality (M), the age of unit selection (i.e. to which the exploitation pattern is to be normalized), the exploitation rate of the oldest age, and the fishing mortality $F(t)$ in the last year (t) for which catch-at-age data are available. These are all considered fixed, except the fishing mortality $F(t)$ which is calibrated using fishing effort data as follows. Estimates of fishing mortality $F(i)$ for each year (i) are calculated using the least squares method with an arbitrary value of $F(t)$. The $F(i)$ for years $i < t - 1$ are then regressed against total international fishing effort measures for the years and the resulting regression (regressions were forced through the origin) used to predict $F(t)$. This whole process is then repeated three times using the new values of $F(t)$ in place of the previous value. After the third iteration, the values of $F(t)$, the exploitation pattern $S(j)$ and population-at-age in year i $P(i, j)$ are adopted. A regression of the population of the youngest ages in past years is made on recruitment indices for these years. This regression is used to estimate the population of the youngest age in years t, $t + 1$ and $t + 2$. This of course means that recruitment indices form the basis of the catch estimates of the youngest three ages caught in the TAC year.

The results of these assessments of the current state of the stock are then used to estimate the value of F_{max} and to project the catch in year $t + 2$ to give the TAC.

Three TACs were estimated to achieve three separate levels for $F(t + 2)$. These were:

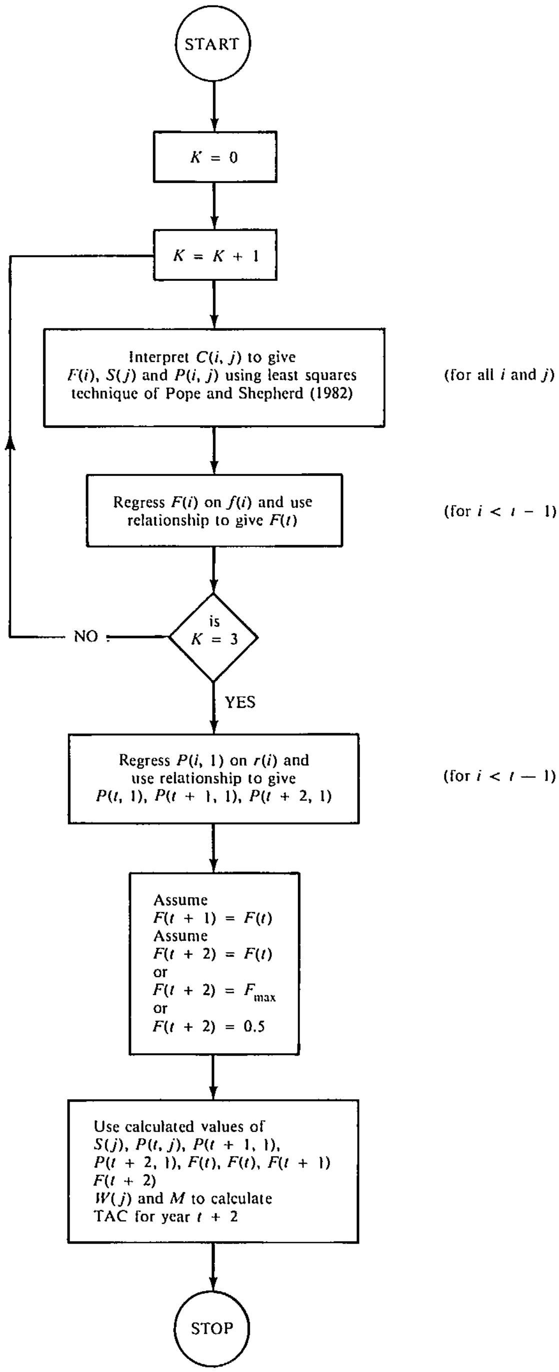
$F(t + 2) = F(t)$

$F(t + 2) = F_{max}$

$F(t + 2) = 0.5$ (an arbitrary level).

In all cases $F(t + 1) = F(t)$.

This automated TAC calculation procedure is then applied to artificial data sets constructed to represent actual North Sea fish stock data sets. These artificial data sets are constructed assuming that the levels of mortality, exploitation pattern, weight-at-age, natural mortality, and



where K is a counter
$\{C(i, j)\}$ is matrix of catch number at age j in year i
$F(i)$ is fishing mortality in year i
$S(j)$ is exploitation pattern on age j
$P(i, j)$ is population at age j in year i
$f(i)$ is fishing effort in year i
$r(i)$ is recruitment survey index in year i
t is last year of catch-at-age date
$W(j)$ is weight at age j
M is natural mortality

FIG. 1. Flow chart of TAC calculation procedure.

numbers of recruits estimated by the working group are exact.

The data sets simulated are catch-at-age data, fishing effort data, and recruitment data. The weight-at-age data of the relevant working group are adopted as though they were exact. These data sets are in effect Platonic ideals of fisheries data for North Sea plaice, North Sea cod, and North Sea sprat. The data sets are then repeatedly modified by random numbers to simulate four different levels of variability in each of the three main data sets. The random numbers used are provided by a pseudo-random number generator with a normal distribution, and transformed to give members of data sets a log normal distribution about their exact value with a specified coefficient of variation. The randomization is such that each perturbation of a member of a data set is independent of those of other members of the same set and of members of other data sets. In all, 5120 data sets are constructed to form a 4 × 4 × 4 factorial experiment on variability levels with 80 replicates. The 80 replicates enable a coefficient of variation of the TAC estimate to be calculated for each of the 64 cells. The 80 replicate data sets used in each cell of the factorial experiment are randomized using the same sequence of random numbers to maintain consistency between cells. The same 80 replicate data sets are used to generate the three TACs for the differing values of $F(t + 2)$.

Results of the Simulations

The results of these simulations for North Sea plaice are shown in Table 2 [$F(1982) = F(1980)$], Table 3 [$F(1982) = F_{max}$], and Table 4 [$F(1982) = 0.5$]. It is clear from the first row of each of these three tables that the variability of recruitment data affects the variability of the three TACs to a similar degree. The effect of variability in catch-at-age data is, however, less when $F(1982) = F(1980)$, and the effect of variability of effort data is dramatically less in this case. The highlighted figure in each table is located at the authors' personal estimate of the current level of input data variability for the stock. This suggests coefficients of variation for the plaice TACs estimated with existing data of about 12% for the status quo case [$F(1982) = F(1980)$], 20% for the F_{max} case, and 25% for the $F(1982) = 0.5$ case.

Tables 5, 6, 7 show the equivalent results for North Sea cod. Again, the effect of variability of the recruitment data is broadly the same for the different TACs, but has a much greater effect on the variability of these cod TACs than on the plaice TACs. The variability of catch-at-age data again produces less variability in the status quo TAC than in the $F(1980) = F_{max}$ or $F(1980) = 0.5$ TACs. Its overall effect on cod is less than for plaice. The variability of effort data again has a markedly smaller effect on the status quo TAC than on the other TACs. At the authors' estimate of input data variance (highlighted figures), the coefficient of variation would be 26% for a status quo TAC and 33% for both the F_{max} TAC and the 0.5 TAC.

For North Sea sprat (Tables 8, 9, 10) the effect of the variability of recruitment and catch-at-age data on the variability of the various TACs is similar to that found for cod. The effect of fishing effort data variability is again much reduced for the status quo case. The authors' estimate of the current status of input data variability (highlighted figures) suggests coefficients of variation of 39% for the status quo TAC, 50% for the F_{max} TAC, and 53% for the $F(1980) = 0.5$ TAC.

TABLE 2. Coefficients of variation of 1982 North Sea plaice TAC resulting from various coefficients of variation of inputs to TACs where $F(1982) = F(1980)$.

Fishing effort data	Catch-at-age data	Recruitment data			
		0%	15%	30%	60%
0%	0%	0	3	6	12
	10%	5	6	8	13
	20%	10	11	12	16
	40%	22	23	24	26
15%	0%	8	9	11	15
	10%	10	11	12[a]	16
	20%	14	14	16	19
	40%	26	26	27	29
30%	0%	17	17	18	21
	10%	18	18	19	22
	20%	21	22	22	25
	40%	32	33	34	37
60%	0%	29	29	30	32
	10%	29	29	30	32
	20%	31	31	31	34
	40%	37	37	38	39

[a]Highlighted cell is authors' personal estimate of current situation.

TABLE 3. Coefficients of variation of 1982 North Sea plaice TAC resulting from various coefficients of variation of inputs to TACs where $F(1982) = F_{max}$.

Fishing effort data	Catch-at-age data	Recruitment data			
		0%	15%	30%	60%
0%	0%	0	3	6	12
	10%	8	9	10	15
	20%	14	15	16	19
	40%	30	31	31	34
15%	0%	23	23	24	26
	10%	25	26	27[a]	29
	20%	30	30	31	33
	40%	45	46	47	49
30%	0%	48	49	49	51
	10%	52	53	53	56
	20%	57	58	58	61
	40%	80	80	81	84
60%	0%	112	112	113	115
	10%	115	115	116	118
	20%	122	122	123	124
	40%	136	136	137	138

[a]Highlighted cell is authors' personal estimate of current situation.

TABLE 4. Coefficients of variation of 1982 North Sea plaice TAC resulting from various coefficients of variation of inputs to TACs where $F(1982) = 0.5$.

Fishing effort data	Catch-at-age data	Recruitment data 0%	15%	30%	60%
0%	0%	0	3	6	12
	10%	7	7	9	14
	20%	13	14	15	18
	40%	28	29	30	32
15%	0%	23	23	24	27
	10%	24	25	25[a]	28
	20%	28	29	29	32
	40%	43	44	44	47
30%	0%	48	48	49	51
	10%	50	50	51	53
	20%	56	56	57	59
	40%	77	77	78	80
60%	0%	112	112	113	114
	10%	113	113	114	115
	20%	119	119	120	122
	40%	132	132	133	135

[a]Highlighted cell is authors' personal estimate of current situation.

TABLE 5. Coefficients of variation of 1982 North Sea cod TAC resulting from various coefficients of variation of inputs to TACs where $F(1982) = F(1980)$.

Fishing effort data	Catch-at-age data	Recruitment data 0%	15%	30%	60%
0%	0%	0	12	23	43
	10%	2	12	23	44
	20%	5	13	24	44
	40%	10	15	25	45
15%	0%	13	17	26	45
	10%	13	18	27[a]	45
	20%	14	18	27	46
	40%	17	21	29	47
30%	0%	23	26	32	48
	10%	24	26	33	48
	20%	24	27	33	49
	40%	27	30	35	50
60%	0%	34	36	37	49
	10%	35	36	39	49
	20%	36	37	40	50
	40%	40	39	44	53

[a]Highlighted cell is authors' personal estimate of current situation.

TABLE 6. Coefficients of variation of 1982 North Sea cod TAC resulting from various coefficients of variation of inputs to TACs where $F(1982) = F_{max}$.

Fishing effort data	Catch-at-age data	Recruitment data 0%	15%	30%	60%
0%	0%	0	12	24	44
	10%	5	13	24	44
	20%	9	15	25	45
	40%	13	18	27	47
15%	0%	22	25	33	51
	10%	22	26	33[a]	51
	20%	24	27	34	52
	40%	27	29	36	54
30%	0%	43	45	50	65
	10%	43	45	50	65
	20%	44	46	51	66
	40%	48	50	55	69
60%	0%	84	85	87	96
	10%	85	85	88	97
	20%	87	87	90	99
	40%	95	96	98	107

[a]Highlighted cell is authors' personal estimate of current situation.

TABLE 7. Coefficients of variation of 1982 North Sea cod TAC resulting from various coefficients of variation of inputs to TACs where $F(1982) = 0.5$.

Fishing effort data	Catch-at-age data	Recruitment data 0%	15%	30%	60%
0%	0%	0	12	23	44
	10%	4	13	24	44
	20%	9	15	25	45
	40%	17	21	29	47
15%	0%	22	25	33	51
	10%	22	26	33[a]	51
	20%	24	27	34	51
	40%	29	31	37	54
30%	0%	43	45	50	65
	10%	43	45	50	65
	20%	44	46	51	66
	40%	49	51	55	69
60%	0%	84	85	88	96
	10%	85	86	88	97
	20%	87	88	90	99
	40%	95	96	99	107

[a]Highlighted cell is authors' personal estimate of current situation.

Discussion and Conclusion

Given that a 10% coefficient of variation would be a broadly sensible aim for the precision of TACs, the Monte Carlo simulation method described is one way of investigating what precision would be needed in some of the input data sets to achieve this. It should be noted carefully, however, that estimating TACs with an appropriate precision may not be the most demanding use of some of these data sets. For example, Pope (1972) shows that the coefficient of variation of fishing mortality estimated by cohort analysis is approximately equal to the coefficient of variation of catch-at-age data. If estimating fishing mortality was considered to be important in its own right, this use of catch-

TABLE 8. Coefficients of variation of 1982 North Sea sprat TAC resulting from various coefficients of variation of inputs to TACs where $F(1982) = F(1980)$.

Fishing effort data	Catch-at-age data	Recruitment data			
		0%	15%	30%	60%
0%	0%	0	9	19	40
	10%	2	9	19	40
	20%	4	10	19	40
	40%	9	12	20	41
15%	0%	1	9	19	40
	10%	3	9	19	40
	20%	5	10	19	40
	40%	9	12	20	40
30%	0%	5	10	19	39
	10%	5	10	19	39
	20%	7	11	19	39[a]
	40%	11	14	21	40
60%	0%	15	18	24	40
	10%	16	18	24	40
	20%	17	19	25	40
	40%	20	22	27	42

[a]Highlighted cell is authors' personal estimate of current situation.

TABLE 9. Coefficients of variation of 1982 North Sea sprat TAC resulting from various coefficients of variation of inputs to TACs where $F(1982) = F_{max}$.

Fishing effort data	Catch-at-age data	Recruitment data			
		0%	15%	30%	60%
0%	0%	0	9	20	42
	10%	3	10	20	42
	20%	6	11	20	42
	40%	12	15	22	43
15%	0%	11	14	22	43
	10%	11	14	22	43
	20%	12	15	23	43
	40%	16	18	25	44
30%	0%	26	28	33	50
	10%	26	28	33	50
	20%	27	29	34	50[a]
	40%	29	31	35	51
60%	0%	87	88	91	100
	10%	87	88	91	100
	20%	88	89	92	101
	40%	90	92	95	103

[a]Highlighted cell is authors' personal estimate of current situation.

at-age data might well be more demanding of precise data than the estimation of TACs.

The specific results for North Sea plaice, cod, and sprat give some idea of the relative importance of these data sets for the 1982 TACs of these species. The relative importance of the different types of data will, however, change to some extent from year to year in response to changes

TABLE 10. Coefficients of variation of 1982 North Sea sprat TAC resulting from various coefficients of variation of inputs to TACs where $F(1982) = 0.5$.

Fishing effort data	Catch-at-age data	Recruitment data			
		0%	15%	30%	60%
0%	0%	0	9	18	39
	10%	3	9	18	39
	20%	7	11	19	39
	40%	14	16	22	40
15%	0%	13	15	22	34
	10%	13	16	23	41
	20%	14	17	23	42
	40%	19	21	26	40
30%	0%	32	34	38	51
	10%	33	34	38	52
	20%	33	35	39	53[a]
	40%	36	37	41	54
60%	0%	103	104	107	115
	10%	103	104	107	115
	20%	104	105	108	115
	40%	107	108	110	118

[a]Highlighted cell is authors' personal estimate of current situation.

in stock age structure. The results do not show the variability that would be generated in these TACs by variability in weight-at-age data. This is not shown because the effect of variability in weight-at-age can be readily formulated, since these data enter the TAC equation linearly. Rivard (1981) and Pope (1983) both give a formula for this effect which may be an important contribution to the variability of TACs.

Clearly, the Monte Carlo simulation aproach to studying the variability of TACs due to variability of inputs could be used as a routine method of assessing the precision of fisheries assessments. It can also be used to check the results of more theoretical approaches to the problem (cf. Pope 1983) and developments could be made to the technique to investigate the value of different methods of assessment. The technique is therefore of obvious utility although it does not have the generality of or generate the insight given by analytical formulations of the problem where these are possible.

The results from the Monte Carlo simulations of the three North Sea fish stocks suggest that TACs set to maintain the status quo will be less affected by the variability of fishing effort data and possibly of catch at-age data than TACs set to achieve F_{max} or an arbitrary level of fishing mortality. The reason for this is that an overestimate of fishing mortality in the year t will cause the population-at-age in that year to be underestimated, which will cause underestimates of the older ages in the TAC year. In the case of the status quo TAC, however, the same overestimate of fishing mortality will cause the catch of the younger ages in the TAC year (those based on recruitment estimates) to be overestimated. Thus, the effect of an overestimate or underestimate of fishing effort, and thus of fishing mortality, in year *t* will result in opposite changes in the older and younger aged portions of the TAC which will tend to cancel out. This compensatory effect does not, however, apply in the case of TACs set to achieve F_{max} or an arbitrary level of F.

The equivalent result for catch-at-age data may well be due to the calibration of fishing effort being less critical in the status quo case than in the other two cases. The calibration of fishing effort to fishing mortality is, of course, achieved using the results of virtual population analysis or least squares analysis which interpret catch-at-age data.

This feature of status quo TACs is interesting in indicating that different formulations of TAC can have very different sensitivities to some sources of random error. Since the compensation effect in a status quo TAC for effort error would also apply if a TAC was set to reduce current levels of fishing by some set amount, e.g. 90%, there might be some argument for using such formulations in preference to setting TACs to achieve F_{max} or $F_{0.1}$ directly. More generally, the result suggests that a search needs to be made for TAC formulations which are as insensitive as possible to the variation of input data.

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Subsampling Catches to Estimate Age, Sex, Maturity, and Other Biological Parameters

Sous-échantillonnage des prises afin d'évaluer l'âge, le sexe, la maturité et autres paramètres biologiques

A Method to Select Optimum Numbers for Aging in a Stratified Approach

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BAIRD, J. W. 1983. A method to select optimum numbers for aging in a stratified approach, p. 161–164. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat 66.

The method defined herein calculates the coefficient of variation associated with the estimated population number at age, given that a number of parameters are defined in advance. This method is one of trial and error and the parameters that need be defined are: a population "shape," an age-length key applicable to the population, and lastly a scheme of stratified selection of ages from the population. The population frequency and the age-length key remain constant throughout a particular analysis, but one is required to change the stratified selection of ages to adjust the coefficient of variation. A case study of NAFO Division 3L cod, with the population frequency and the age-length key obtained from commercial data from 1976 to 1980, is also presented in this paper.

BAIRD, J. W. 1983. A method to select optimum numbers for aging in a stratified approach, p. 161–164. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Le présent rapport porte sur une méthode de calcul du coefficient de variation associé avec le niveau estimatif de la population à un âge donné. Cette méthode, qui procède par tâtonnements, exige que les paramètres suivants soient définis à l'avance: la «forme» de la population, la clé des âges en fonction des longueurs applicable à la population et le plan de sélection stratifiée des âges de la population. La fréquence de la population et la clé des âges en fonction des longueurs demeurent constantes au cours d'une analyse donnée; la sélection stratifiée des âges doit donc être changée afin d'ajuster le coefficient de variation. Une étude-type des morues capturées dans la division 3L de l'OPANO, où la fréquence de la population et la clé des âges en fonction des longueurs ont été obtenues à partir des données commerciales de 1976 à 1980, est aussi exposée.

Introduction

According to Gulland (1955) the objective of sampling for ages is to obtain similar coefficients of variation (C.V.) for all ages of fish that contribute significantly to the population. In addition, in the "Report of Working Party on Minimum and Desirable Levels of Sampling" (ICNAF Redbook 1974), this same suggestion was made with some idea as to what would be a desirable level of sampling. It was stated tentatively that 10% C.V. was the order of magnitude that would be moderately satisfactory. The largest problem with using some function to optimize the selection pattern for a stratified scheme, is that there is considerable overlap of lengths and ages. As an example, the number of otoliths required at a particular length to obtain a C.V. of 10% may not be adequate to obtain the desired precision for another age. As it is the coefficient of variation that is calculated to ensure adequate levels of age sampling, as stated above, it would seem feasible to use this statistic as the focal point of any optimization. Hence, to obtain the results shown in this paper, different stratified schemes were adopted, and the one that came "closest" to the desired levels of precision with the expenditure of similar financial effort was deemed best.

In stratified sampling for ages, the major concern is that of selecting the appropriate numbers in each length group to ensure a specified level of precision at a given age. Any level of precision can be obtained by simply increasing the numbers of otoliths collected at each length group. This brings us to the question of cost benefits, in that it may not be feasible, for example, to double the present sampling to gain little in precision. On the other hand, a small increase in sampling may well indeed have a drastic effect on the levels of precision obtained. A method to select optimum numbers for aging is presented in this paper.

The Method

The method used in this paper involves the calculation of the coefficient of variation for catch at age given that the "shape" of the catch frequency is known and is accompanied by an appropriate age-length key. These parameters, for the purpose of this calculation, can be obtained from historical data.

The notation:

N_i — catch number at length
n_i — number aged at length
p_i — proportion at length for a given age
n_ip_i — number aged at length that are a given age
N_ip_i — catch at length for a given age

The catch at age is calculated simply by summing the catch at each length for that age.

$$N = \sum_i N_i p_i$$

In finding the coefficient of variation it is necessary to first find the variance of the catch at each length group (i.e. Var $N_i p_i$).

$$\text{Var}(N_i p_i) = N_i^2 \text{Var}(p_i) + p_i^2 \text{Var}(N_i) \qquad \text{(Gulland 1955)}$$

The first term of the equation refers to the sampling error of the aging and the second term refers to the sampling error of the length measurement.

As stated by Pope and Knights (1975) the second term of this equation can be ignored because of the magnitude of the first term. Thus an adequate approximation for Var $(N_i p_i)$

$$\text{Var}(N_i p_i) = N_i^2 \text{Var}(p_i)$$

where Var $p_i = p_i(1 - p_i)/n_i$ by assuming the binominal distribution.

The variance of the total number caught at any age is determined by summing the variance at each length group.

$$\text{Var}\, N = \sum_i N_i^2 \text{Var}\, p_i$$

From this the coefficient of variation is readily calculated.

$$(\text{Var}\, N)/N$$

This method is followed for each age and the coefficient of variation examined. If in fact the magnitude of the coefficient of variation is not adequate or the level of precision is better than is needed, then the number that are aged at each length group (i.e. n_i) can be adjusted accordingly. This method is shown in a case study of NAFO Division 3L cod in the next section.

A Case Study

In this example commercial otter trawl cod from NAFO Division 3L was used. The catch frequency and the age-length key were obtained by combining data collected from 1976 to 1980. In calculating the coefficient of variation, the total number in the frequency is not important, as the coefficient of variation does not change whether there is a frequency of 50 000 or 500 000. What is important is the shape of the frequency, so the frequency that is used in the calculations should be one that best represents the catch. The frequency used in this example contained 100 000 fish with the applicable age-length key containing approximately 6600 ages.

The scheme of stratification used to determine the most consistent coefficients of variation, for all ages, was that of selecting 15 otoliths from length groups up to 54–56 cm and 30 otoliths from 57 to 59 cm to the highest length. These calculations are very tedious to compute manually, but with the aid of a computer program they can be completed easily. Sample output for ages 6, 10, and 14 are shown in Tables 1, 2, and 3, respectively. It can be seen from the output, that if the level of precision is not what is desired, then one can see exactly which length group contributes most to the total variance. By then adjusting the stratified selection for that particular length group, one can arrive at an appropriate coefficient of variation. Table 4 shows the coefficient of variation for catch at age for the complete analysis.

It can be seen from Table 4 that the ages that contribute the majority of the catch are estimated precisely, using the standard of 10% coefficient of variation for catch at age. This, indeed, would be the ideal situation for stock assess-

TABLE 1. Sample output of calculation of coefficient of variation for numbers at age 6.

Age 6					
Length	Catch frequency	Stratified selection of otoliths	$n_i p_i$	$N_i p_i$	Var $N_i p_i$
49	12 009	15	1.0	801	598 229
52	14 704	15	2.0	1 961	1 665 598
55	14 423	15	5.0	4 808	3 081 820
58	12 409	30	13.0	5 377	1 260 381
61	9 569	30	16.0	5 103	759 656
64	6 712	30	15.0	3 356	375 425
67	4 492	30	14.0	2 096	167 403
70	3 027	30	11.0	1 110	70 926
73	1 999	30	7.0	466	23 828
76	1 421	30	3.0	142	6 058
79	1 011	30	1.0	34	1 098
82	692	30	1.0	23	514

Number at age = 25 277
Total variance = 8 010 932
Coefficient of variation = 11.20

TABLE 2. Sample output of calculation of coefficient of variation for numbers at age 10.

Age 10					
Length	Catch frequency	Stratified selection of otoliths	$n_i p_i$	$N_i p_i$	Var $N_i p_i$
76	1421	30	1.0	47	2169
79	1011	30	3.0	101	3066
82	692	30	4.0	92	1845
85	495	30	5.0	82	1134
88	344	30	7.0	80	706
91	300	30	8.0	80	587
94	264	30	9.0	79	488
97	199	30	5.0	33	183
100	166	30	10.0	55	204
103	161	30	4.0	21	100
106	146	30	3.0	15	64
109	102	30	2.0	7	22
115	78	30	1.0	3	7
124	65	30	1.0	2	5

Number at age = 699
Total variance = 10 578
Coefficient of variation = 14.72

TABLE 3. Sample output of calculation of coefficient of variation for numbers at age 14.

Age 14					
Length	Catch frequency	Stratified selection of otoliths	n_ip_i	N_ip_i	Var N_ip_i
94	264	30	2.0	18	145
97	199	30	3.0	20	119
100	166	30	2.0	11	57
103	161	30	3.0	16	78
106	146	30	3.0	15	64
109	102	30	2.0	7	22
112	107	30	6.0	21	61
115	78	30	3.0	8	18
118	97	30	3.0	10	28
121	96	30	4.0	13	35
124	65	30	3.0	6	13

Number at age = 144
Total variance = 640
Coefficient of variation = 17.53

TABLE 4. Coefficient of variation for catch numbers at age using the stratified scheme described in the case study (1976–80).

Age	No. caught	Coefficient of variation (%)
3	1 264	34.69
4	20 700	13.29
5	37 266	9.54
6	25 277	11.20
7	8 049	13.30
8	4 101	17.52
9	1 142	16.37
10	699	14.72
11	446	17.71
12	221	17.09
13	170	16.47
14	144	17.53
15	110	19.70
16	109	17.56
17	60	21.38
18	57	21.23
19	47	26.10
≥20	139	10.60

TABLE 5. Coefficient of variation for catch numbers at age using the stratified scheme described in the case study (1981).

Age	No. caught	Coefficient of variation (%)
3	952	31.90
4	5 356	21.65
5	14 757	16.66
6	38 417	8.50
7	31 535	9.04
8	6 312	17.52
9	1 670	24.68
10	584	26.77
11	99	30.11
12	121	27.39
13	72	26.65
14	31	34.74
15	9	64.73
16	27	38.90
17	27	30.02
18	9	66.59
≥19	18	51.67

TABLE 6. Repeat of 1981 analysis with 5% random error with 0–10% range introduced into the catch frequency.

Age	No. caught	Coefficient of variation (%)
3	961	32.95
4	5 599	21.42
5	14 924	16.97
6	38 015	8.52
7	31 223	9.03
8	6 355	17.37
9	1 676	24.16
10	598	26.73
11	100	29.59
12	120	27.24
13	72	26.72
14	29	34.98
15	9	64.69
16	25	39.07
17	28	29.80
18	9	66.77
≥19	19	51.85

ment, but for other studies (i.e. growth, food, and feeding) it would be necessary to obtain some degree of precision in the older ages as well. For ages greater than 7, in Table 4 it is shown that the coefficient of variation for catch at these ages approaches 20% as opposed to 10% for ages 4–7. Considering the additional cost of reducing the C.V.'s in the older ages, it may be best to consider C.V.'s in the range of 20% to be adequate in these cases.

To show how well this stratified scheme applies to a more current situation, Table 5 shows the results for the 1981 data. It can be seen that ages 6 and 7 contain approximately 70% of the population and have C.V.'s of slightly less than 10%. The contribution of ages 5 and 8 is about 20% of the population, and the C.V.'s for these ages are less than 20%.

It should be noted that frequencies used in the analysis are not the actual catch frequencies estimated for the period used. For simplicity and comparison, the catch frequencies all contain approximately 100 000 fish, and these frequencies were estimated from the samples taken in the time frames being analyzed. So, in fact the catch frequencies used are only a small proportion of the actual landed catch. As the ratio of the standard deviation and the numbers of age does not change, taking various proportions of the catch frequency to determine the C.V. for the numbers at age, it would suffice to take any proportion of the catch frequency even if this proportion is unknown.

Earlier it was stated, for the variance of the numbers at age, that the component of the variance that refers to the sampling error of the length measurements can be ignored because of the magnitude of the first term or the sampling error of the aging. To add some validity to this statement, an approximate 5% random error with a range from 0 to 10% was introduced to the 1981 catch frequency

TABLE 7. Coefficient of variation for individual years (1976–80) using stratified scheme described in the case study.

	1976		1977		1978		1979		1980	
Age	No.	C.V.	No.	C.V.	No.	C.V.	No.	C.V.	No.	C.V.
3	5 158	23.08	2 364	35.14	925	39.19	721	42.70	190	57.60
4	34 821	8.06	26 619	10.84	28 576	11.82	17 616	15.63	3 812	30.71
5	19 782	13.80	36 893	8.91	36 689	10.68	46 062	8.11	28 086	11.77
6	12 063	15.45	17 103	11.99	21 794	12.93	24 458	12.12	50 329	6.91
7	8 504	14.77	7 412	13.60	6 317	14.59	6 810	13.46	11 907	14.85
8	9 228	11.90	3 876	15.38	3 333	20.02	2 081	17.21	3 679	15.31
9	2 315	18.86	2 481	12.42	849	26.51	778	18.50	771	16.73
10	1 398	19.07	1 386	20.18	772	20.85	581	13.92	260	20.52
11	709	25.69	729	17.57	283	16.91	308	17.26	265	20.49
12	1 176	19.70	306	25.11	116	40.75	168	19.87	212	20.78
13	647	26.80	164	25.55	125	20.67	129	21.08	53	46.23
14	1 226	19.04	180	23.41	78	27.61	36	38.06	49	41.04
15	416	39.38	88	32.72	45	36.42	37	38.38	114	29.46
16	532	33.94	87	33.33	39	35.09	53	29.76	79	34.37
17	283	48.48	115	28.56	8	64.38	31	40.57	18	62.38
18	575	29.86	51	40.62	12	62.36	10	97.01	56	42.02
19	358	43.22	33	55.82	8	64.38	25	45.61	40	43.84
20	808	23.80	112	22.07	31	28.54	60	20.18	81	24.42

and the analysis was repeated with the results shown in Table 6. It is seen that the results are very similar to those for the original data shown in Table 5, and using a chi-square test of the numbers at age it is apparent that there is insufficient evidence to reject the null hypothesis of no difference at the 5% level. (Estimated $x^2 = 20.91$, $x^2_{16,\ 0.05} = 26.30$.)

In an effort to see what degree the variation in year-class size has on the stratified scheme selected, the analysis was completed for each year from 1976 to 1980 individually (Table 7). Again a population size of 100 000 was used for each year and it can be seen that the stratified scheme derived from the 5 yr combined data adequately suits each of the 5 yr.

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Estimating the Variance of Length Composition Samples

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SMITH, S. J., AND J. J. MAGUIRE. 1983. Estimating the variance of length composition samples, p. 165–170. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Definition of the variance and covariance structure of combined length frequency samples from commercial cod landings was attempted by assuming that either a simple multinomial or a compound multinomial distribution fit the data. It was found that the simple multinomial could not adequately accommodate the large amount of variation present. The compound multinomial distribution may prove to be more flexible in this regard once the estimation theory has been fully established. Future research is outlined.

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En partant de l'hypothèse qu'une distribution multinomiale simple ou composée décrirait les données, on tente de définir la variance et la covariance des échantillons combinés de fréquence de longueurs pris sur les débarquements commerciaux de morue. On a découvert que la distribution multinomiale simple ne peut pas contenir adéquatement la grande variation présente. Sous cet aspect, la distribution multinomiale composée pourrait se révéler plus flexible une fois la théorie d'évaluation complètement définie. Le rapport esquisse les futurs plans de recherche.

1. Introduction

To determine the precision and accuracy of the management advice (i.e. TACs) provided for fish stocks using analytical models, it is necessary to assess first the variability and bias at each step of the data processing. The basic data used for the construction of a catch matrix required for cohort or VPA analysis are length frequencies obtained from samples of commercial catches. Age determination of subsamples of these samples are made and an age-length key is constructed to convert catch-at-length estimates to catch-at-age estimates.

Previous studies of the characteristics of the data have for the most part concentrated on examining the variability at the age-length key level (e.g. Bormann 1974; Kimura 1977) or at the catch-at-age level (e.g. Brennan and Palmer 1976; Warring 1976). The age-length keys and catch-at-age tables are usually obtained from the combination of a number of length frequency samples taken over the year for specific gear types and management areas. The practice of taking more than one sample is carried out so that the combined length frequencies are more "representative" of the catches over a given period.

We define "representative" in the sense that the combination of many samples provides reasonable estimates of population parameters (e.g. means, variances, covariances, etc.) which for obvious reasons cannot be supplied by a single length composition sample. Since the age-length keys and catch-at-age tables consist of combinations of length frequency samples, it would seem to us that definition of the variance at the age level cannot be done until it has been defined at the length frequency level.

The ideal way to estimate the variance at the length frequency stage would be to carry out a two-stage sample survey (or subsampling survey) in the following manner. From the N landings that occur for a specific species, gear type, time period, and management area choose n ($n < N$) landings to be sampled. For each of the n landings take m_i ($m_i > 1$; $i = 1, \ldots, n$) subsamples from the M_i possible subsamples and measure the lengths of the fish thus obtained. Standard sampling texts (e.g. Cochran 1977) provide methods for the analysis of data collected in this manner. At present, the length data collected by the Marine Fish Division (MFD) are not amiable to this sort of approach because only one subsample is taken from each of the n landings, precluding therefore an estimate of the variance at the subsample stage.

In this paper, we studied the problem of variance estimation for length composition samples in the one subsample case by hypothesizing that the observed length frequencies are realizations from a probability model. In Section 2, the appropriateness of assuming that this model is the simple

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multinomial model was considered by carrying out a series of comparisons between selected length composition samples taken from commercial landings of Atlantic cod (*Gadus morhua*) in 1980. These comparisons indicated that the simple multinomial model was not satisfactory and in Section 3 the more flexible compound multinomial model was investigated. From our results it appears that this latter model has potential application to data of this type. Future research is discussed in Section 4.

2. The Simple Multinomial Model

Define:

x_{ij} = the number of fish observed in length category "j" (j = 1, 2, ..., J) in sample "i" (i = 1, 2, ..., I). For convenience we will represent the ith sample as the vector $\underset{\sim}{x}_i = \{x_{i1}, x_{i2}, \ldots, x_{iJ}\}'$

$n_i = \sum_j x_{ij}$ = the total number of fish measured for length in sample "i"

θ_{ij} = the proportion of fish in the ith length category in the population being sampled, $\underset{\sim}{\theta}_i = \{\theta_{i1}, \theta_{i2}, \ldots, \theta_{iJ}\}'$

$\hat{\theta}_{ij} = \dfrac{x_{ij}}{n_i}$ = the estimate of θ_{ij}.

Length frequency data are structured such that from the ith sample, fish are observed in each of the J mutually exclusive length classes. Data organized in this manner are often assumed to follow the simple multinomial model whose discrete density function is given by:

$$(1) \quad f(\underset{\sim}{x}_i) = \frac{n_i!}{\prod_{j=1}^{J} x_{ij}!} \prod_{j=1}^{J} \theta_{ij}^{x_{ij}}$$

with mean $E[x_{ij}] = n_i\theta_{ij}$ and variance and covariance, respectively,

$$\mathrm{Var}[x_{ij}] = n_i\theta_{ij}(1 - \theta_{ij}),$$

$$\mathrm{Cov}[x_{ij}, x_{ij}'] = -n_i\theta_{ij}\theta_{ij}', \; j \neq j'$$

If this type of model can be used we would have a well-defined covariance structure which would be useful in defining the variance at the age-length key level where age groups can overlap many length categories.

Therefore, we were interested in determining whether the proportion observed in each length category in each of several samples exhibits some consistency within the constraints of the model in (1). If this is shown to be otherwise, then this model cannot be used due to the fact that a sum of samples from multinomial distributions with unequal parameters θ_{ij} does not result in a final multinomial distribution.

For I samples a test of homogeneity between samples consists of testing the null hypothesis H_o: $\theta_{1j} = \theta_{2j} = \ldots = \theta_j$, $\forall_j$, versus the alternative that at least one of the above equalities does not hold. This test can be carried out in totality by comparing all the samples at once by the following test statistic (Mood et al. 1974),

$$(2) \quad X^2 = \sum_{i=1}^{I} \sum_{j=1}^{J} \frac{(x_{ij} - n_i\hat{\theta}_j)^2}{n_i\hat{\theta}_j}$$

where $\hat{\theta}_j = \sum_i x_{ij} / \sum_i n_i$ and is the maximum likelihood estimator of θ_j under the null hypothesis. The test statistic X^2 has a limiting χ^2 distribution with $(I - 1) \times (J - 1)$ degrees of freedom. Rejection of the null hypothesis by the use of this test criterion will only indicate that there are differences between samples but not where the differences are. In order to determine this a second test can be carried out. This test forms pairwise contrasts between samples for the null hypothesis H_o: $\theta_{ij} - \theta_{i'j} = 0$ $(i \neq i' : \forall j)$ (Goodman 1964). The estimated contrasts are defined as $\hat{\Delta}_j = (\hat{\theta}_{ij} - \hat{\theta}_{i'j})$ and confidence intervals are calculated by:

$$(3) \quad \hat{\Delta}_j \pm s(\hat{\Delta}_j)Z$$

where $s(\hat{\Delta}_j) = ((\hat{\theta}_{ij}(1 - \hat{\theta}_{ij})/n_i) + ((1 - \hat{\theta}_{i'j})\hat{\theta}_{i'j}/n_{i'}))^{1/2}$ and Z is the 100 $(1 - \beta)$th percentile of the unit gaussian distribution. The significance level of the test for all J contrasts is set to some value α (here 0.05) and therefore each contrast is carried out at $\beta = \alpha/2J$ (Goodman 1964).

A number of length composition samples, routinely collected by Marine Fish Division port technicians, were selected for study. Details concerning these samples are presented in Table 1. The samples chosen consist of between 250–650 fish (cod) measured for length. The individual length frequencies are depicted in Fig. 1 according to the sets outlined in Table 1. The null hypothesis of homogeneity within sets with respect to the multinomial model was tested by the χ^2 test described above. In all cases, the null hypothesis was rejected ($p < 0.00001$). The contrast test (2) was then applied to these data sets to determine where the differences occurred. The results of this

TABLE 1. Details of the length composition samples studied in this paper. Samples were obtained by port technicians of the Marine Fish Division from fishing vessels at the port of landing.

Data set	No. of samples	Month	NAFO area	Type of vessels sampled	Tonnage class[a]
A	4	Jan.	4Vn	Side trawlers	4
B	5	Jan.	4Vn	Stern trawlers	5
C	3	Feb.	4Vn	Stern trawlers	5
D	6	Mar.	4Vs	Side trawlers	4
E	4	Oct.	4Vs	Stern trawlers	5
F	5	Nov.	4Vs	Stern trawlers	5

[a]Tonnage class of vessel: 4 = 151–500 Gross Tonnage; 5 = 500 Gross Tonnage

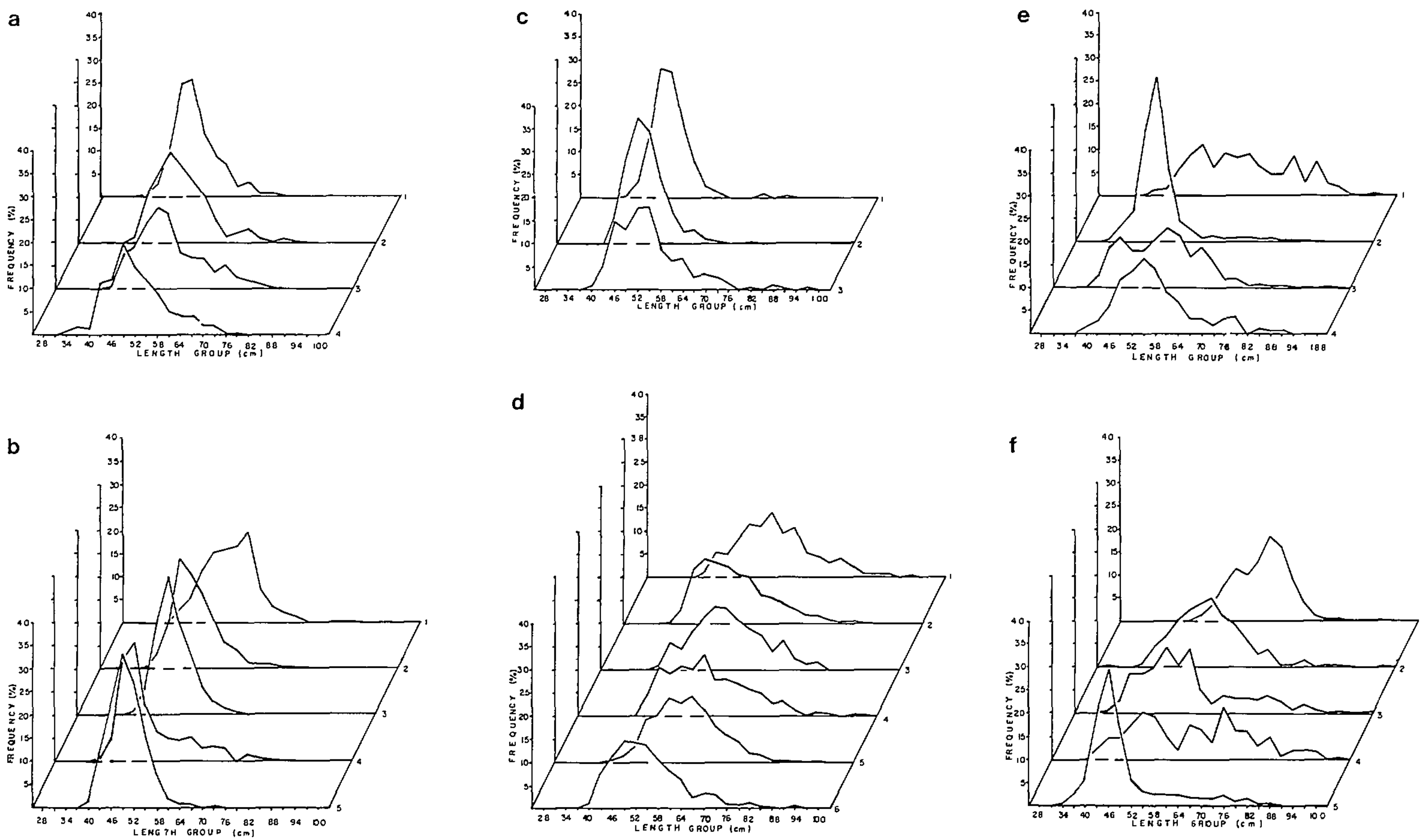

FIG. 1. Percent frequency polygons of length composition samples in (a) data set A, (b) data set B, (c) data set C, (d) data set D, (e) data set E, and (f) data set F (see Table 1 for details).

TABLE 2. Results of contrasts (entries are the number of times a significant difference was found in that length category; I = number of samples).

Length group (cm)	Set A $I = 4$	Set B $I = 5$	Set C $I = 3$	Set D $I = 6$	Set E $I = 4$	Set F $I = 5$
28	—	—	—	—	—	0
31	—	—	—	—	—	0
34	0	0	—	—	—	0
37	0	0	0	0	0	0
40	0	3	1	1	3	4
43	0	6	2	3	4	3
46	3	5	2	7	5	4
49	1	6	1	0	3	4
52	0	4	0	0	1	0
55	0	4	1	0	2	2
58	0	4	2	0	3	3
61	0	3	1	1	3	3
64	1	0	2	0	3	4
67	0	0	0	2	3	4
70	1	1	0	0	2	4
73	0	0	0	0	0	1
76	0	0	0	0	1	2
79	0	0	0	0	2	0
82	0	0	0	0	0	3
85	0	0	0	0	3	0
88	—	0	0	0	0	0
91	—	—	0	0	0	0
94	—	—	—	0	0	0
97	—	—	0	0	0	—
100	0	—	—	0	0	0
103	—	—	—	—	—	—
106	—	—	—	—	—	—
109	—	—	—	—	—	—
112	—	—	—	—	—	0

test for each data set are presented in Table 2. From this table some gross patterns are evident; for example, the 46-cm length group figured prominently as a local for heterogeneity for all of the data sets. In addition, major differences tended to be confined to length groups in the middle of the frequencies and not in the tails. More detailed patterns can be seen when the contrast results are compared with Fig. 1a–f.

3. The Compound Multinomial Model

From the comparisons carried out in Section 2, it appears that the observed proportions from the cod length composition data exhibit greater variation than expected under the multinomial model. In this section, we present a model that offers more flexibility with regard to this extra variation.

In the multinomial model defined in (1) the $\underset{\sim}{\theta}_i$ were assumed to be constants. In the development here it will be assumed that the $\underset{\sim}{\theta}_i$ are random variables from some distribution $h(\underset{\sim}{\theta})$ with mean $\underset{\sim}{\mu} = \{\mu_1, \mu_2, ..., \mu_J\}'$ and variance $\underset{\sim}{\sigma}^2 = \{\sigma_1^2, \sigma_2^2, ..., \sigma_J^2\}$. Given this assumption, then, the distribution of the $\underset{\sim}{x}_i$, $g(\underset{\sim}{x}_i)$ say, is found by compounding $f(\underset{\sim}{x}_i)$ defined in (1) with $h(\underset{\sim}{\theta})$ to give

$$(4) \qquad g(\underset{\sim}{x}_i) = \int f(\underset{\sim}{x}_i)h(\underset{\sim}{\theta})d(\underset{\sim}{\theta}).$$

The unconditional mean and variance for $g(\underset{\sim}{x}_i)$ are

$$E[x_{ij}] = n_i\mu_j$$

$$\mathrm{Var}[x_{ij}] = n_i\mu_j(1 - \mu_j) + \sigma_j^2 n_i(n_i - 1).$$

In terms of $\hat{\theta}_{ij} = x_{ij}/n_i$ the above can be rewritten to obtain

$$E[\hat{\theta}_{ij}] = \mu_j$$

$$(5) \qquad \mathrm{Var}[\hat{\theta}_{ij}] = \mu_j(1 - \mu_j)/n_i + \sigma_j^2\,(n_i - 1)/n_i.$$

The σ_j^2 in (5) is the variance associated with the random assumption for $\underset{\sim}{\theta}_i$ and has been called the "extraneous" variance by Kleinman (1973). This type of model has been investigated most recently by Southward and Van Ryzin (1972) and Kleinman (1973) for the binomial case ($J = 2$) and by Mosimann (1962) for the multinomial case ($J > 2$). For the case of equal samples sizes ($n_i = n; \forall i$) all of the above studies obtain the same estimator via the method of moments for μ_j and its associated variance, that is

$$(6) \qquad \hat{\mu}_j = \sum_{i=1}^{I} \hat{\theta}_{ij}/I$$

and

$$\mathrm{Var}(\hat{\mu}_j) = \sum_{i=1}^{I} (\hat{\theta}_{i1} - \hat{\mu}_j)^2/I(I - 1).$$

It is interesting to note that the same results were arrived at even though Southward and Van Ryzin (1972) assumed that $h(\underset{\sim}{\theta})$ was of a general form with domain of support (0,1) whereas Kleinman (1973) and Mosimann (1962) assumed that the $\underset{\sim}{\theta}_i$ were distributed according to the Beta distribution (or Dirichlet distribution in the multinomial case).

In the unequal sample size situation, a weighted method of moments must be used, and results are only available for the binomial form of the model. Both Kleinman (1973) and Southward and Van Ryzin (1972) approach the estimation problem in the same way by first defining an optimal weight w_i in terms of the inverse of the variance in (5). Because of the differing assumptions with respect to $h(\underset{\sim}{\theta})$ the form of estimators derived are not the same. In Kleinman (1973), $h(\underset{\sim}{\theta})$ is assumed to be of the following form:

$$h(\underset{\sim}{\theta}) = \frac{\Gamma\left(\sum_{j=1}^{2} \alpha_j\right)}{\prod_{j=1}^{2} (\alpha_j)} \prod_{j=1}^{2} \theta_j^{\alpha_j - 1}$$

where $\sum_{j=1}^{2} \theta_j = 1$

$$E[\theta_j] = \frac{\alpha_j}{\sum_j \alpha_j} = \mu_j$$

and

$$\mathrm{Var}[\theta_j] = (1 + \sum \alpha_j)^{-1}\mu_j(1 - \mu_j)$$
$$= \delta\mu_j(1 - \mu_j)$$

the variance in (5) is now rewritten so that $\sigma_j^2 = \delta\mu_j(1 - \mu_j)$. The optimal weight then is expressed as (with $\mu_j(1 - \mu_j)$ removed since it is a constant),

$$(7) \quad w_i = \frac{n_i}{1 + \delta(n_i - 1)}$$

Since δ is unknown and must be estimated, Kleinman proposed an empirical estimation procedure. Initially set $w_i = n_i$ and let

$$(8) \quad \hat{\mu}_j = \sum_{i=1}^{I} w_i\hat{\theta}_{ij}/w \quad , \quad w = \sum_{i=1}^{I} w_i$$

$$S^2 = \frac{(I - 1)}{I} = \sum_{i=1}^{I} w_i(\hat{\theta}_{ij} - \hat{\mu}_j)^2.$$

Then estimate δ by

$$(9) \quad \hat{\delta} = \frac{S^2 - \hat{\mu}_j(1 - \hat{\mu}_j)\left[\sum_{i=1}^{I} \frac{w_i}{n_i}\left(1 - \frac{w_i}{w}\right)\right]}{\hat{\mu}_j(1 - \hat{\mu}_j)\left[\sum_{i=1}^{I} w_i\left(1 - \frac{w_i}{w}\right) - \sum_{i=1}^{I}\frac{w_i}{n_i}\left(1 - \frac{w_i}{w}\right)\right]}$$

If $\hat{\delta}$ is equal to or less than zero, Kleinman (1973) suggests setting $\hat{\delta}$ equal to zero.

Redefine w_i, w_i^* say, by substituting $\hat{\delta}$ for δ in (7). Finally, form a new estimate for μ_j, $\hat{\mu}_j^*$ by using w_i^* in (8). The variance of $\hat{\mu}_j^*$ can be estimated by

$$(10) \quad \widehat{\mathrm{Var}}[\hat{\mu}_j^*] = \sum_{i=1}^{I} w_i^{*2}(\hat{\theta}_{ij} - \hat{\mu}_j^*)^2/(w^{*2} - \sum_{i=1}^{I} w_i^{*2}).$$

This estimate is unbiased if δ is known and w_i is as defined in (7), otherwise the bias is of order $1/I$. It may be possible to remove this bias by forming a jackknife version of (10) but as Miller (1974) has pointed out negative pseudovalues can result from treating variance estimators this way; a transformation of some sort is therefore required.

With respect to the approach taken by Southward and Van Ryzin (1972), we must first rewrite (5) in a more general form

$$(11) \quad \mathrm{Var}[\hat{\theta}_{ij}] = \tau/n_i + \sigma^2.$$

The weight w_i is then defined as the inverse of (11) with τ and σ^2 estimated as follows (binomial case set $j = 1$),

$$(12) \quad \hat{\tau} = \frac{1}{I}\sum_{i=1}^{I} \frac{n_i}{(n_i - 1)}\hat{\theta}_{i1}(1 - \hat{\theta}_{i1}),$$

$$\hat{\sigma}^2 = \max\{(\sigma^*)^2, I^{-1}\},$$

$$(13) \quad (\sigma^*)^2 = \left[\sum_{i=1}^{I}(\hat{\theta}_{i1} - \bar{\mu}_1)^2/(I - 1)\right] - \hat{\tau}\frac{1}{I}\sum_{i=1}^{I}\frac{1}{n_i},$$

$$\bar{\mu}_1 = \frac{1}{I}\sum_{i=1}^{I}\hat{\theta}_{i1}.$$

Equation (8) is used to estimate $\hat{\mu}_j$ with $w_i = [\hat{\tau}/n_i + \hat{\sigma}^2]^{-1}$ and $w = \sum_{i=1}^{I} w_i$. The variance of the estimate $\hat{\mu}_j$ is simply estimated by

$$(14) \quad \widehat{\mathrm{Var}}[\hat{\mu}_j] = w^{-1}.$$

Southward and Van Ryzin (1972) show that $\hat{\tau}$ and $\hat{\sigma}^2$ are consistent estimators, i.e. $\hat{\tau} \to \tau$, $\hat{\sigma}^2 \to \sigma^2$ as $I \to \infty$. Since I is at most equal to 6 in the cod data presented here, large sample properties such as consistency are of limited value in assessing the above estimators. Use of equation (12) has serious ramifications with regard to small samples. In cases where τ accounts for a large proportion of the total variation observed implying that σ^2 in (11) is small, equation (12) would set $\hat{\sigma}^2$ equal to I^{-1}. For large samples i.e. as $I \to \infty$, this procedure may not be a problem since as a consequence $\hat{\sigma}^2 \to 0$ but for small samples I^{-1} would tend to dominate the estimate of (11) leading to inflated variance estimates. To avoid this it would seem reasonable to set $\hat{\sigma}^2$ equal to zero whenever $(\hat{\sigma}^*)^2$ is less than or equal to zero.

The two approaches discussed above were directly extended to the compound multinomial model. With respect to Kleinman's method, this required estimating $\hat{\delta}_j$ (equation (9)) for each length class. For the second method, that of Southward and Van Ryzin equation (12) was not used due to the problems outlined above; instead $\hat{\sigma}^2$ was set to zero whenever $(\hat{\sigma}^*)^2$ was less than or equal to zero. Variances were estimated by both methods for data set D (see Table 1) and compared to the simple multinomial model estimates. This comparison was carried out by dividing the estimates from the compound model by the estimates from the simple model, and is presented in Table 3. The estimates obtained from the generalization of equations (10) and (14) differed very little from each other in that they both provided large variances for those length classes that had significant differences by the contrast method (Table 2). For 18 of the 22 length classes presented in Table 3, the method of Southward and Van Ryzin (1972) resulted in slightly larger variances than those from Kleinman's technique. Since the small sample properties are not well established for either set of estimators, it is difficult to choose one over the other.

4. Future Research

The main objective of this paper was to find a way of estimating the variances of length frequencies when only one sample was taken from a landing. The compound

TABLE 3. Comparison of variance estimates for the compound multinomial model discussed in text with variance estimate obtained from simple multinomial model. Data set D was used for this example. (Results presented here are ratios of compound multinomial model estimate to simple multinomial estimate. Asterisk indicates length group where differences were found by the contrasts method. See Table 2.)

Length group (cm)	Equation (10) Simple multinomial	Equation (14) Simple multinomial
37	0.73	1.36
40*	3.40	3.91
43*	7.67	8.03
46*	9.11	9.26
49	2.91	2.98
52	0.99	0.87
55	1.08	1.36
58	1.03	1.20
61*	3.79	3.99
64	3.04	3.16
67*	3.29	3.44
70	1.29	1.65
73	2.43	2.61
76	1.96	1.64
79	2.35	2.67
82	1.06	0.86
85	1.11	1.16
88	1.06	0.82
91	1.18	1.60
94	1.20	1.31
97	0.79	0.94
100	0.79	0.94

multinomial model appears to offer a means to do this, albeit further work on finding estimators with well-established properties (especially for small samples) is required.

In addition, since length composition samples form the basic data for stock assessment analysis, a model such as that presented here could offer a means of exploring the effects of variances and covariances at the length frequency stage on the estimated age structures of the catch and of the population. This term could help in defining the precision of total allowable catch estimates (TACs).

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NOTE ADDED IN PRESS: A paper appeared in the December issue of the Journal of the American Statistical Association (p. 707–713, 1982) by P. J. Smith and J. Sedransk which also proposed the use of the Dirichlet distribution for the observed proportion at length. In addition this paper investigated the optimal choice of sample sizes.

Aging Capelin: Enhancement of Age-Length Keys and Importance of Such Enhancement

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In the estuary and western Gulf of St. Lawrence, available information suggests that problems of interpretation of growth rings on the otoliths of capelin, rather than biological events, create important overlaps between ages in age-length keys. These overlaps lead to errors in the estimation of number of fish at age, mean length, and mean weight at age. The Doubleday method permits reduction of overlaps between ages in age-length keys and normalization of length at age distribution. The enhanced age-length keys obtained by this method give better estimations of the age-related parameters.

LABONTÉ, S. S. M. 1983. Aging capelin: enhancement of age-length keys and importance of such enhancement, p. 171–177. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Dans l'estuaire et l'ouest du golfe du Saint-Laurent, l'information disponible suggère que des problèmes d'interprétation des anneaux de croissance des otolithes de capelan, plutôt que des facteurs biologiques, entraînent un chevauchement important des âges dans les clés âge-longueur. Ces chevauchements induisent ultérieurement des erreurs lors des estimations de la longueur moyenne, du poids moyen et du nombre d'individus dans chaque classe d'âge. L'utilisation de la méthode de Doubleday nous permet de réduire le chevauchement des âges dans les clés âge-longueur et normalise les distributions de fréquence de longueur à l'âge. Les nouvelles clés âge-longueur obtenues par cette méthode permettent des estimations plus précises des paramètres liés à l'âge.

Introduction

Accurate aging is one of the main keys leading to effective management of fisheries. In the aging of capelin, otoliths have traditionally been used (Hansen 1943; Templeman 1948; Prokhorov 1965; Winters 1974). However, correct interpretation of growth rings on the otoliths of capelin from the western Atlantic has proved difficult, and Templeman (1968) called for further validation of the technique. In the mid-1970s, Bailey et al. (1977) tried to validate the technique, but even with this study, it is still extremely difficult to age capelin accurately in the estuary and western Gulf of St. Lawrence.

Different sources of error may lead to underestimation or overestimation of ages. For instance, age will be underestimated if annual rings fail to form. Carlander (1973) showed that this phenomenon occurred for many species of fish. Because of the opaqueness of otoliths, which increases with size and age, growth rings may be obscured. This would also lead to underestimation of age. On the other hand, false annuli may deposit, and this would produce an overestimation of the age. Bailey et al. (1977) showed that a false annulus is deposited when capelin metamorphose. This metamorphic annulus is well known and ignored during the process of aging this species. However, it is possible that other false annuli may be formed during the life of capelin. For haddock and other gadoids, Thompson (1926) showed that such annuli occurred under conditions of physiological or physical stress. Hatch (1961) reported that 60–90% of the brook trout in four New York lakes showed false annuli, not detectable except by position and knowledge that the fish could not be as old as indicated.

Incorrect aging may introduce important bias into stock assessment. Age-length keys may be distorted and subsequently number of fish at age, mean length, and mean weight at age. To overcome such bias, Doubleday (1975) developed a method to enhance age-length keys. The method smooths sampling fluctuations and considerably reduces the effects of incorrect aging. In this paper, the Doubleday method is used to enhance age-length keys for capelin and the importance of such enhancement is discussed.

Materials and Methods

Each day between 13 April and 22 June, 1981, random samples of 200 adult capelin were collected from a weir at Isle Verte in the St. Lawrence estuary (Fig. 1). Each fish was measured (total length to the nearest mm), weighed to the nearest 0.1 g, and the sex determined.

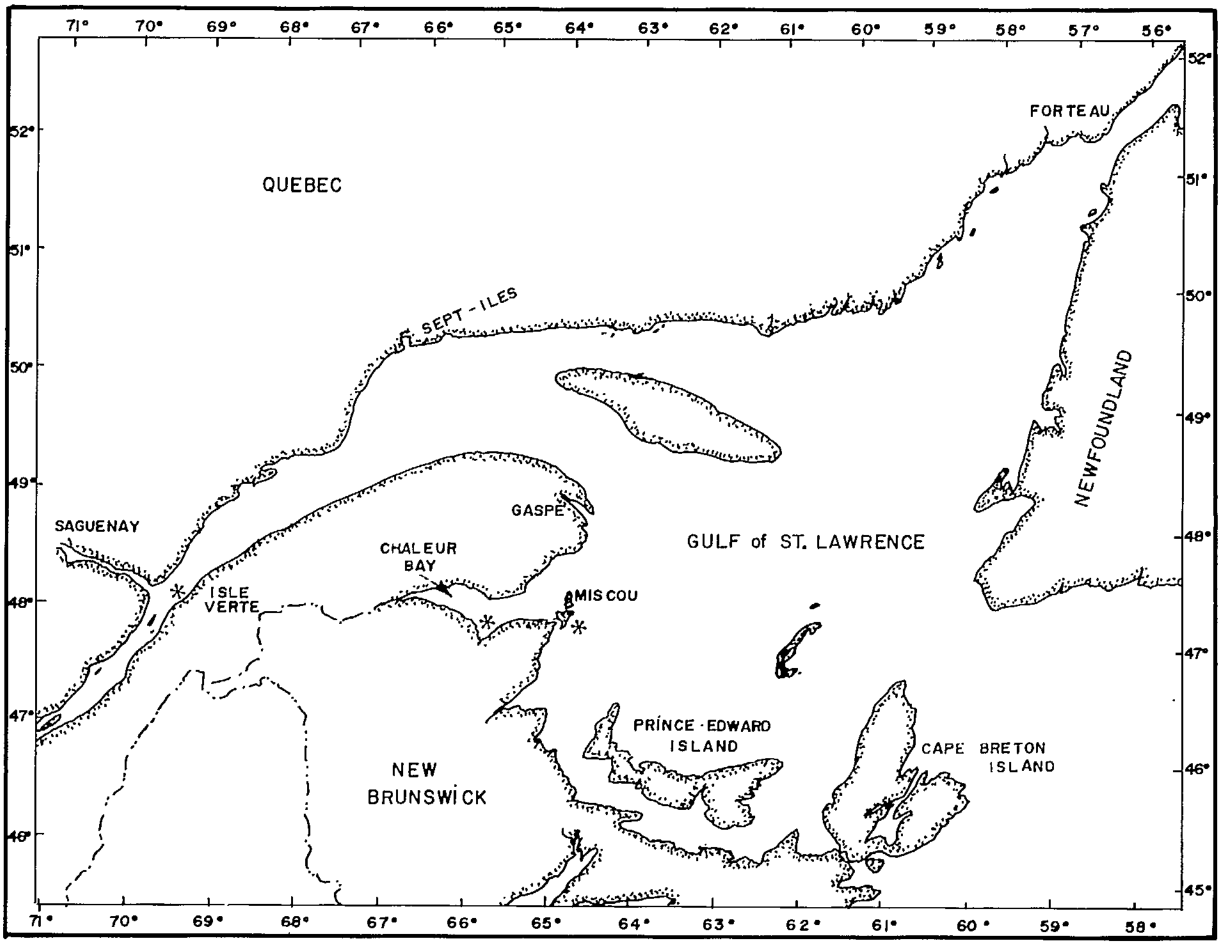

FIG. 1. Sampling locations of adult (Isle Verte) and juvenile (Chaleur Bay–Miscou) capelin.

Once per week, we subsampled four males and females per 5 mm length group from which we removed otoliths for aging. Two random samples of 200 juvenile capelin were also collected with a midwater trawl during the last week of May 1981 in the area of Baie des Chaleurs and Miscou (Fig. 1). Each fish was measured, weighed, and otoliths were removed. Reading of otoliths was done later in the laboratory following the method of Bailey et al. (1977). Otoliths were read independently by two readers and if disagreement occurred, the otoliths were reread and either accepted after common agreement or rejected.

Original age-length keys were then constructed for males and females from Isle Verte, and for juveniles from the Baie des Chaleurs–Miscou area. These keys were applied to samples to check for normality in length at age data. The Doubleday (1975) method, which consists in fitting normal curves over age frequency distributions, was used to enhance the original keys for adult capelin. Finally, original and enhanced age-length keys were applied to monthly length frequency distribution of adult capelin caught at Isle Verte during April, May, and June 1981. Proportions (%) at age and mean length at age were calculated from both keys. Mean weight at age was obtained from monthly length–weight relationships for the region.

Results

Normality in Length at Age

Adult capelin from Isle Verte ranged from 130 to 180 mm for females, and from 140 to 190 mm for males. Otoliths revealed males and females of 2, 3, and 4 yr of age. However, more than 95% of capelin were 3-4-yr-olds. Juvenile capelin from Baie des Chaleurs–Miscou ranged from 40 to 130 mm and were all immature. These young capelin were 1, 2, and 3 yr of age.

Original age-length keys show overlaps between ages (Tables 1, 2). This overlap is small for the youngest age-classes (Table 1) but becomes more important as capelin grow older. In fact, for adult capelin, most length groups contain fish belonging to each age-class (Table 2). The application of the original age-length key of juvenile capelin (Table 1) to their own length frequency distribu-

TABLE 1. Original age-length key (%) for juvenile capelin. Chaleur Bay–Miscou, May 1981.

5 mm length group	Age 1	2	3
40	100	0	0
45	100	0	0
50	100	0	0
55	100	0	0
60	100	0	0
65	100	0	0
70	100	0	0
75	100	0	0
80	67	33	0
85	33	58	9
90	0	75	25
95	0	75	25
100	0	83	17
105	0	100	0
110	0	83	17
115	0	83	17
120	0	77	23
125	0	78	22
130	0	55	45

tion shows that the distribution of length at age is normal for age 1 (Fig. 2). Length at age distribution seems also normal for age 2, but an area of distortion appears around 115 mm. Moreover, the mode corresponding to age 3 is practically the same as the age 2 mode. The application of original age-length keys of adult capelin (Table 2) to their own monthly length frequency distributions shows that the distributions of length at ages 3 and 4 depart increasingly from normality (Fig. 3, 4). This is mainly evident in April where length at age distributions of 3- and 4-yr-old females are bimodal and perfectly superimposed (Fig. 3). Furthermore, for both males and females, length at age distributions of 2- and 4-yr-olds are completely overlapped by 3-yr-old distributions, and modes of these distributions are practically the same (Fig. 3, 4).

As capelin grow older, there in an increasing departure from normality in length at age distribution and this corresponds exactly with the increasing overlaps between ages in age-length keys.

ENHANCED AGE-LENGTH KEYS

Length at age distributions are normalized when the enhanced age-length keys are applied to length frequency distributions. Compared to original age-length keys, enhanced keys for adult capelin show that overlaps between ages are greatly reduced (Table 2). Overlaps between ages 3 and 4 extend only from 160 to 175 mm for females, and from 165 to 190 mm for males. Capelin belonging to age 2 are completely eliminated from length groups over 135 mm. The application of enhanced age-length keys of adult capelin (Table 2) to their own monthly length frequency distributions shows normal or near-normal distributions of length at ages 3 and 4 (Fig. 3, 4). There are still overlaps between length at age distributions, but modes of these distributions are significantly different.

AGE-RELATED PARAMETERS

Important changes occur in age-related parameters following the use of enhanced age-length keys instead of original keys.

The first change is the difference in proportion of fish at age (Table 3). The use of the enhanced keys produces the following results: for females — 3-yr-olds are 7% less abundant in April and 4 and 7%, respectively more abundant in May and June; 4-yr-olds are 9% more abundant in April and 2 and 5% less abundant in May and June; and 2-yr-olds, which are not presented in Table 3, are 1.5% less abundant for the 3 mo; for males — proportions of 3-yr-olds remain approximately similar for all months; 4-yr-olds are 5% more abundant in April and May and remain the same in June; and 2-yr-olds are not present.

The second and most important change observed is the difference in mean length at age. For both males and females, the application of the enhanced keys gives smaller mean length at age for the 3-yr-olds and higher mean length at age for the 4-yr-olds (Table 3). This is mainly evident for 4-yr-old females which have a higher mean length of 5 mm in April, 11 mm in May, and 13 mm in June. Original keys produce mean length at age, which decreases from April to June. In most cases, mean length at age shows a decrease of 4–5 mm and up to 9 mm for females of age 4. The use of enhanced age-length keys produces mean length at age much more stable which length decreases only by 3 mm between April and June.

TABLE 2. Original (a) and enhanced (b) age-length key (%) for adult capelin. Isle Verte, April-May-June 1981.

5 mm length group	Females 2 a	Females 2 b	Females 3 a	Females 3 b	Females 4 a	Females 4 b	Males 2 a	Males 2 b	Males 3 a	Males 3 b	Males 4 a	Males 4 b
120												
125												
130	44	56	54	44	2	0						
135	13	0	80	100	7	0						
140	7	0	85	100	8	0	0	0	100	100	0	0
145	4	0	88	100	8	0	0	0	99	100	1	0
150	0	0	93	100	7	0	1	0	96	100	3	0
155	1	0	89	100	10	0	2	0	93	100	5	0
160	1	0	86	93	13	7	2	0	91	99	7	1
165	1	0	77	54	22	46	2	0	90	92	8	8
170	0	0	67	16	33	84	3	0	82	84	15	16
175	0	0	54	5	46	95	3	0	74	68	23	32
180	0	0	32	0	68	100	1	0	72	50	27	50
185							0	0	83	35	17	65
190								0		21		79
195								0		0		100

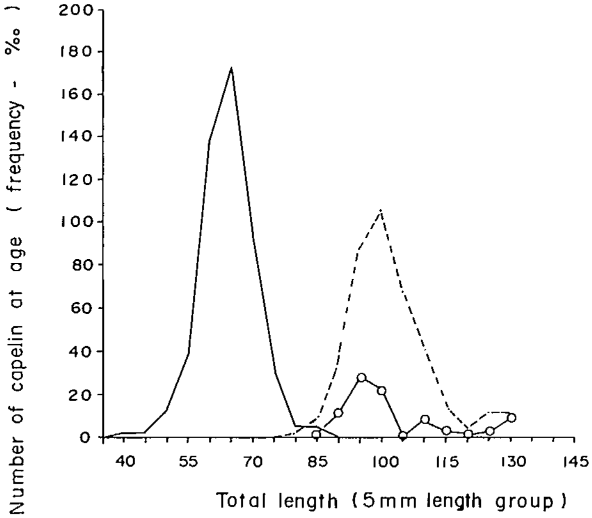

FIG. 2. Age-frequency distributions of juvenile capelin obtained from original age-length key. Chaleur Bay-Miscou area, May 1981. The following lines represent: 1-yr-olds (——), 2-yr-olds (----), and 3-yr-olds (o——o).

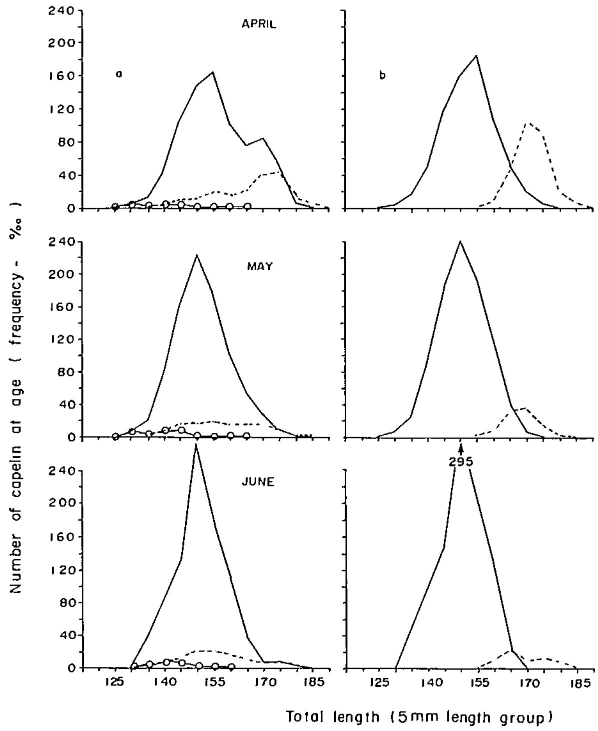

FIG. 3. Age-frequency distributions of female capelin obtained from original (a) and enhanced (b) age-length keys. Isle Verte, 1981. The following lines represent: 2-yr-olds (o——o), 3-yr-olds (——), and 4-yr-olds (----).

The third effect is the difference in mean weight at age. Since weight is directly related to length (Fig. 5), tendencies observed for mean length at age are reflected in mean weight at age. However, spawning occurs during the April–June period, and length–weight relationships change. Consequently, for similar length at age from April to June, weight at age decreases.

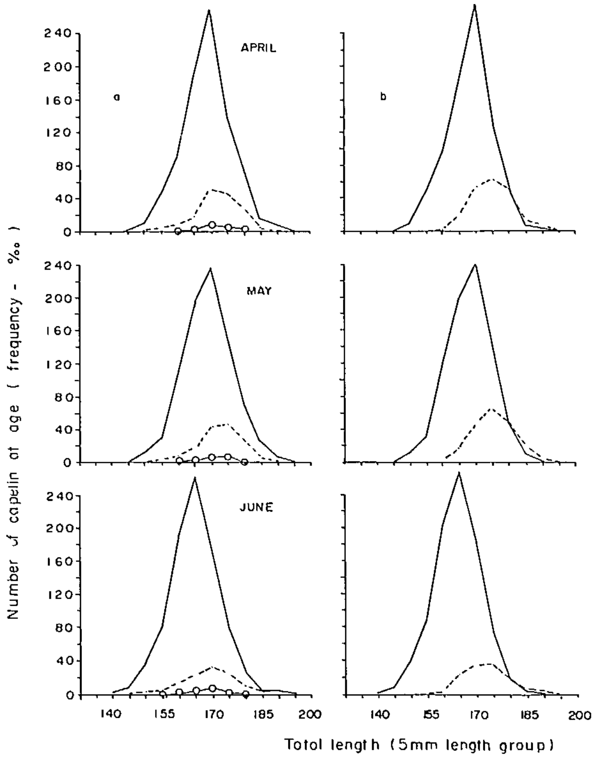

FIG. 4. Age-frequency distributions of male capelin obtained from original (a) and enhanced (b) age-length keys. Isle Verte, 1981. The following lines represent: 2-yr-olds (o——o), 3-yr-olds (——), and 4-yr-olds (----).

Discussion

Length frequencies at age should normally agree well with observed peaks in length frequency distributions if length at age has a normal distribution. However, following the application of original age-length keys to the length frequency distributions, length at age distributions increasingly depart from normality as capelin grow older.

At first glance, this nonnormality of length at age distribution of older capelin could be related to biological events. For instance, one might assume that fast-growing capelin belonging to a particular year-class mature as 3-yr-olds, and the slow-growers of this same year-class mature only as 4-yr-olds. Since most capelin die after spawning (Winters and Campbell 1974), the bulk of mature capelin should be represented by only 2 year-classes: the fast-growing 3-yr-olds and slow-growing 4-yr-olds. Consequently, the mean length of these 3- and 4-yr-olds could be quite similar, and this would produce important overlap between their age distributions. However, this cannot explain why there are two length modes of 3-yr-olds and two modes of 4-yr-olds among mature capelin. For a particular year-class, these two modes could be biologically explained only by the presence of two stocks which have different growth rates or two hatching periods well apart. However, adult capelin caught at Isle Verte between April and June are probably part of the same stock. A study of morphometric and meristic characters (S. S. M. Labonté and L. Savard, unpublished data.) shows that all mature capelin caught in that area between April and June 1980 belonged to the same group. On the other hand, in the estuary and western Gulf of St. Lawrence, capelin spawn during a short period beginning in late April and ending in early June. The observations presented here show that there is only one normal length distribution representing 1-yr-olds in the Baie des

TABLE 3. Proportions, mean length, and mean weight at age resulting from the application of original (a) and enhanced (b) keys. Adult capelin — Isle Verte, April–May–June 1981.

			April		May		June	
		Age	a	b	a	b	a	b
Females	Proportion (%)	3	79.6	72.0	85.7	89.9	87.1	94.2
		4	18.6	27.4	11.4	9.2	10.6	5.7
	Mean Length (mm)	3	157.2	154.7	153.9	152.5	153.0	152.2
		4	168.1	173.5	159.2	170.5	157.3	170.6
	Mean Weight (g)	3	20.3	19.3	18.2	17.8	15.8	15.6
		4	25.7	29.9	19.9	23.6	17.1	21.6
Males	Proportion (%)	3	81.9	80.0	82.8	79.5	86.8	88.0
		4	15.0	20.0	14.9	20.5	11.1	12.0
	Mean Length (mm)	3	171.5	170.1	172.0	170.1	166.1	166.3
		4	175.1	177.0	175.3	177.7	171.3	174.9
	Mean Weight (g)	3	29.0	28.3	29.3	28.3	24.6	24.7
		4	31.0	32.1	30.9	32.2	26.7	28.3

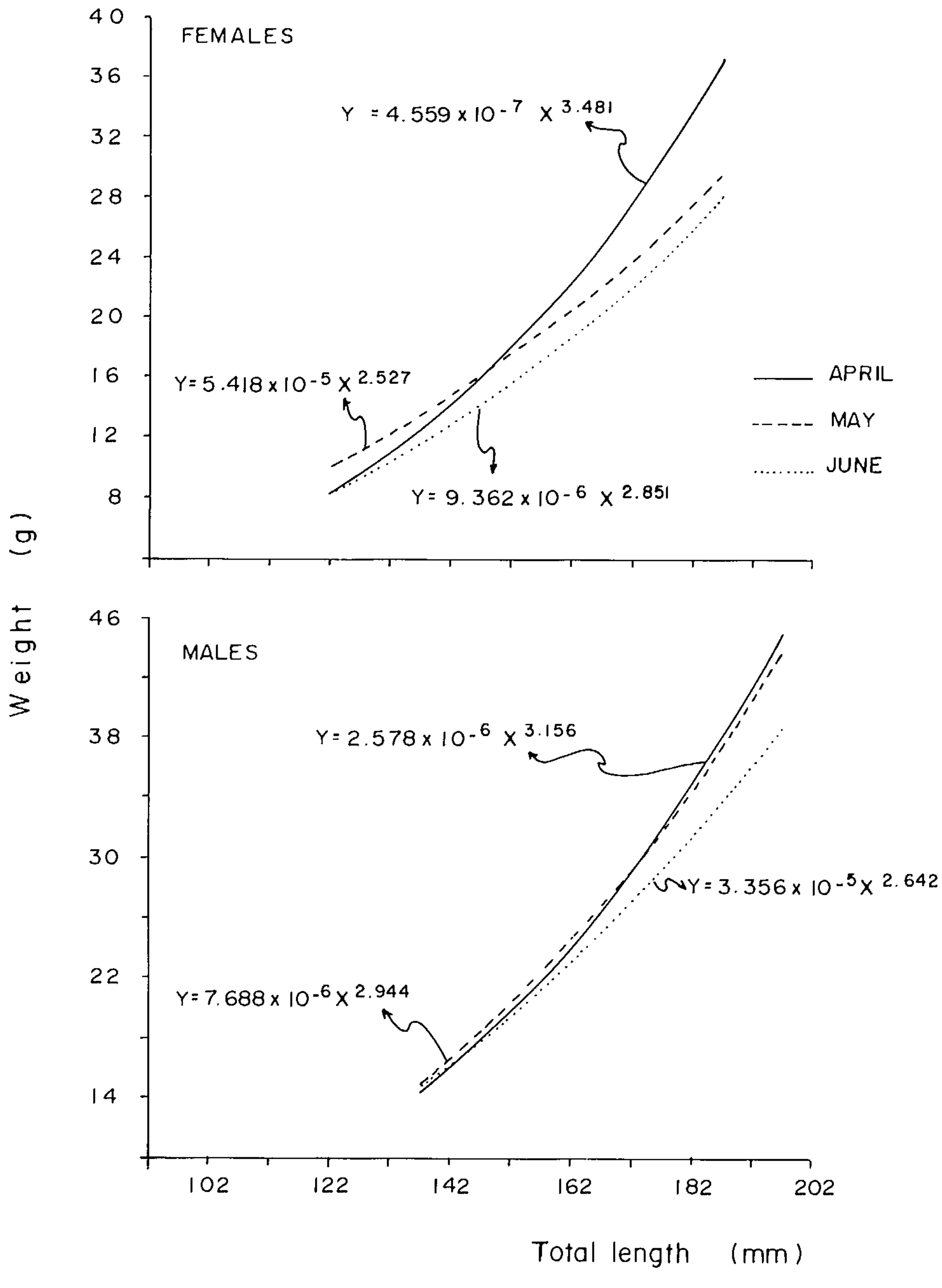

FIG. 5. Length–weight relationships for capelin in April, May, and June 1981. Isle Verte.

Chaleurs–Miscou area. One-year-old capelin collected from other areas of the Gulf also show a unique normal distribution (Labonté, unpublished data) and this tends to confirm that there is only one hatching period.

Consequently, it seems reasonable to assume that the nonnormality of length at age distributions of older capelin results from incorrect aging. Following the absence of effective aging procedure for older capelin, length frequency samples were treated as a mixture of normal distributions of length at age with one component per year-class. Doubleday's (1975) method enables us to normalize length at age distribution and reduce overlaps between age in age-length keys.

The enhanced age-length keys may introduce important changes in age-related parameters. Results presented for capelin show that proportions of fish at age may vary by 10% following the use of enhanced age-length keys. Such variations could be extremely important in population analysis mainly when the number of age-classes in the fishery is low. Capelin in the estuary and western Gulf of St. Lawrence are a typical case, with 3- and 4-yr-olds representing more than 95% of the fishable stock. Mean length at age also shows noticeable changes following the use of the enhanced keys. Due to extensive overlap in the original keys, mean length at age was biased positively for age 3 and negatively for age 4 and this resulted in similar mean length at age for both ages. Reduced overlap in the enhanced keys gives significant difference between mean length at ages 3 and 4. These changes may be extremely important since growth parameters will be affected. On the other hand, since weight is directly related to length, mean weight at age follows a similar trend. Consequently, biomass at age will change and yield per recruit calculation may show a significant difference.

Conclusion

In this particular study, the effects of enhancement occur mainly on 4-yr-olds, which are relatively few in number; therefore, the enhancement may seem unnecessary. However, bias may be introduced by imprecise age-length keys, and for other species, the types of bias identified in this study could be much more important and even lead to inaccurate assessment of certain fish stocks.

When normality of length at age is respected, only one stock is involved and length distributions of age groups do not overlap for biological reasons alone; the method presented can considerably improve the reliability of age-length keys and the estimations of age-related parameters. With the computer science techniques available today, this exercise can be performed very rapidly and may increase the reliability of stock assessment.

Acknowledgments

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Estimation of Catch at Age and its Variance for Groundfish Stocks in the Newfoundland Region

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GAVARIS, S., AND C. A. GAVARIS. 1983. Estimation of catch at age and its variance for groundfish stocks in the Newfoundland region, p. 178–182. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

The age composition of the commercial catch forms an important basis for the assessment of the status of a stock. An estimate of the variance of catch at age is derived so that the reliability of such data may be evaluated. The effect of this imprecision on catch projections can then be examined. In the case study, the cod stock in NAFO Area 4RS + 3Pn in 1981, present sampling levels resulted in estimates of catch at age with low variability such that the projected yield in 1983, assuming other input parameters known, had a coefficient of variation of 3%. For this stock, other factors contributing to variability in the projected yield estimate, such as average weight at age, may be a more significant source of error.

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La composition par âge des prises commerciales représente un élément important de l'évaluation de l'état d'un stock. On procède ici à l'évaluation de la variance des prises pour chacun des groupes d'âge afin d'obtenir une mesure de la précision de telles données. L'incidence d'une faible précision sur les prises projetées peut alors être étudiée. Dans le cas étudié, soit le stock de morue des divisions 4RS et 3Pn de l'OPANO en 1981, les niveaux d'échantillonnage actuels ont entraîné des estimations des prises relativement précises pour chacun des groupes d'âge. Ainsi en supposant les autres paramètres connus, le rendement projeté en 1983 a un coefficient de variation de 3 %. Pour ce stock, d'autres facteurs contribuant à la variabilité des projections du rendement, tel le poids moyen estimé pour chaque groupe d'âge, peuvent constituer une source d'erreur plus importante.

Introduction

The determination of the age composition of the commercial catch forms an important basis for the assessment of the status of a stock. Estimates of the numbers caught at age are typically used in sequential population analysis and in catch projections to determine possible management strategies. To date, the assessment of stocks in the northwest Atlantic has not regularly included estimates of the variance of catch at age although there have been some cases analyzed (Brennan and Palmer 1978). Such information would be useful in qualifying the advice given to managers to reflect the precision of knowledge concerning a stock.

Using the double sampling scheme outlined in Cochran (1963), Southward (1976) showed how the variance of the proportion at age could be computed and used to obtain the variance of the catch at age. Double sampling is a special case of stratified sampling where the stratum weights are unknown. A sample is taken to estimate these weights, the proportion at length in our case, and is then subsampled for the characteristic of interest, the proportion at age. Double sampling is generally advantageous when the characteristic of interest is expensive to sample. Kutkuhn (1963) presented a cost comparison of simple random sampling and double sampling for salmon. Kimura (1977) compared the relative precision of three strategies, simple random sampling, double sampling with fixed size subsample, and double sampling with random size subsample.

This paper briefly outlines the commercial sampling design presently in use for groundfish at the Northwest Atlantic Fisheries Centre, Fisheries Research Branch, Canada. Estimates of the catch at age and its variance were obtained following the general procedure given by Southward (1976). Data for the cod stock in NAFO Area 4RS + 3Pn in 1981, as presented by Gavaris and Bishop (1982), were used in an example. The influence of the estimated variance of the catch at age on the precision of the projected yield is examined.

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Methods

NOTATION

Basic samples, denoted by m, were classified into area–time–gear units, denoted by k (i.e. Div. 4R — January — cod trap). These units may be, and usually were, smaller than the area–time–gear strata to be defined later (i.e. Area 4RS + 3Pn — 1st quarter — inshore gears). The following notation was used.

n_{km} = number sampled for length
n_{jkm} = number at length j in sample
p_{jkm} = n_{jkm}/n_{km} proportion at length j in sample
n'_{jkm} = number at length j subsampled for age
n'_{ijkm} = number at length j and age i in subsample
p_{ijkm} = n'_{ijkm}/n'_{jkm} = proportion at length j and age i in subsample
w_{km} = weight of sample
W_{km} = weight of landing from which sample was taken
$\bar{w}_{km}$ = w_{km}/n_{km} = average weight of fish in sample
W_k = total weight landed in unit
W = total weight landed in stratum
$\bar{\omega}_j$ = average weight at length j obtained from a weight–length relationship
$\bar{\omega}_{it}$ = average weight at age i and year t
Y_t = yield in weight during year t
N_{it} = population numbers at age i in the beginning of year t
M_{it} = natural mortality at age i during year t
F_{it} = fishing mortality at age i during year t.

COMMERCIAL SAMPLING DESIGN

The landings from a particular stock are divided into strata defined by area, time, and gear, such that a stratum is homogeneous with respect to the proportion at age for a given length. For the example, stock area–quarter–gear was used to stratify. Since the entire landings for a stratum are not available for sampling at any one time and place, basic samples are taken from the individual vessel landings and subsequently combined. Basic samples are distributed over the entire stratum because the stratum is not necessarily homogeneous with respect to proportion at length.

Vessels, which are assumed to return to port in a random order within strata, are selected as they land and a basic sample is chosen randomly as the catch is unloaded. The weight of the basic sample is taken and all fish in the sample are counted and measured for length. A subsample is selected for aging. Current practice dictates that a fixed, but not necessarily equal, subsample size be taken for each length in a stratum. The basic samples are classified into units which, for the example, were defined as NAFO Division–month–gear. For further details on the sampling procedure, see Stevenson (1983).

ESTIMATION

Basic samples within a stratum are combined in two steps. First, basic samples within a unit are combined.

(1) $$n_k = \sum_m n_{km}$$

(2) $$n'_{jk} = \sum_m n'_{jkm}$$

(3)[1] $$p_{jk} = \frac{\sum_m p_{jkm} W_{km}/\bar{w}_{km}}{\sum_m W_{km}/\bar{w}_{km}}$$

(4) $$p_{ijk} = \sum_m n'_{ijkm} / \sum_m n'_{jkm}$$

(5)[1] $$\bar{w}_k = \frac{\sum_m W_{km}}{\sum_m W_{km}/\bar{w}_{km}}$$

Second, the units within a stratum are combined.

(6) $$n = \sum_k n_k$$

(7) $$n'_j = \sum_k n'_{jk}$$

(8) $$p_j = \frac{\sum_k p_{jk} W_k/\bar{w}_k}{\sum_k W_k/\bar{w}_k}$$

(9) $$p_{ij} = \sum_k \sum_m n'_{ijkm} / \sum_k \sum_m n'_{jkm}$$

(10) $$\bar{w} = \frac{\sum_k W_k}{\sum_k W_k/\bar{w}_k}$$

Note that in combining the data, length frequencies and average weights are weighted by estimated numbers in basic samples (equations (3), (5)) and estimated numbers in units (equations (8), (10)). This is necessary because the sampling design is not self weighting i.e. proportional allocation is not strictly enforced.

Estimates for each stratum can then be obtained. Finite population corrections for variances will be ignored since, in practice, these are generally negligible. Assuming that the proportion at length, p_j, is a multinomial variate and that subsampling for ages is random within each length category, an unbiased estimate of the proportion at age is:

(11) $$\hat{p}_i = \sum_j p_j p_{ij}$$

[1]For some gear types in the example W_{km} was not known; therefore samples could not be weighted. The possibility of obtaining W_{km} in the future for these gear types is currently being investigated.

and the variance of $\hat{p}_i$ is given by:

$$(12) \quad \text{Var}(\hat{p}_i) = \sum_{j:p_{ij}\neq 0} \frac{p_j^2 p_{ij}(1 - p_{ij})}{n_j' - 1} + \frac{p_j(p_{ij} - p_i)^2}{n}$$

(Southward 1976)

An approximate unbiased estimate of the total number of fish landed and its approximate variance, found by using the delta method (Seber 1973), are:

$$(13) \quad \hat{C} = W/\bar{w}$$

$$(14) \quad \text{Var}(\hat{C}) = \frac{W^2}{\bar{w}^4}\text{Var}(\bar{w})$$

Individual fish in the samples were not weighed; therefore, the variance of the average weight could not be obtained directly. Using weight–length relationships which have been obtained from special studies, an approximate estimate of the variance of $\bar{w}$ is:

$$(15) \quad \text{Var}(\bar{w}) = \sum_j np_j(\bar{\omega}_j - \bar{w})^2/n(n-1)$$

No account has been taken of error in the weight–length relationship. Assuming that $\hat{C}$ and $\hat{p}_i$ are independent and that the bias in $\hat{C}$ is negligible, an unbiased estimator of catch at age is:

$$(16) \quad \hat{C}_i = \hat{C}\hat{p}_i \qquad \text{(Kendall and Stuart 1969, p. 269)}$$

An exact unbiased estimator of the variance of a product of two independent variables was derived by Goodman (1960).

$$(17) \quad \text{Var}(\hat{C}_i) = \hat{C}^2\text{Var}(\hat{p}_i) + \hat{p}_i^2\,\text{Var}(\hat{C}) - \text{Var}(\hat{p}_i)\,\text{Var}(\hat{C})$$

Total catch at age and its variance for the stock can be obtained by summing $\hat{C}_i$ and $\text{Var}(\hat{C}_i)$ over all area–time–gear strata.

PROJECTION

Management of groundfish stocks in the northwest Atlantic is generally affected by the setting of catch quotas. These quotas are based on estimates of projected yield at some reference fishing mortality (i.e. $F_{0.1}$).

The projected yield for year t is given by

$$(18) \quad Y_t = \sum_i \bar{\omega}_{it}F_{it}N_{it}(1 - \exp - (F_{it} + M_{it}))/(F_{it} + M_{it})$$

where the summation is over all ages. The population numbers in the beginning of year t are found by applying the recursive relationship.

$$(19) \quad N_{it} = N_{i-1\,t-1}\exp - (F_{i-1\,t-1} + M_{i-1\,t-1})$$

Estimates of population numbers at the beginning of year t_o are obtained from the estimated catch at age in that year using

$$(20) \quad \hat{N}_{it_o} = K_{it_o}\hat{C}_i$$

TABLE 1. The catch at age ($\times 10^{-3}$) and its variance for the cod stock in NAFO Area 4RS+3Pn in 1981 were computed using the equations developed in the text. The coefficient of variation for the dominant ages was less than 5%. For the ages flagged by asterisks, one or more lengths had a subsample size, n_j, of 1 for aging.

Age	Catch	Var (catch)	STD. error	C.V.
2	3	2.993	1.73	0.52
3	540	11 593.809	107.67	0.20
4	10 382	135 992.270	368.77	0.04
5	11 398	319 264.225	565.03	0.05
6	23 991	494 631.808	703.30	0.03
7	14 921	315 622.623	561.80	0.04
8	5 076	92 919.660	304.83	0.06
9	1 961	24 890.635	157.77	0.08
10	670	6 709.527	81.91	0.12
11	152	511.468	22.62	0.15
*12	98	204.157	14.29	0.15
*13	78	157.436	12.55	0.16
14	38	73.330	8.56	0.22
15	38	132.786	11.52	0.31
*16	19	14.385	3.79	0.20
*17	16	13.338	3.65	0.23
18	4	17.365	4.17	0.98
19		0.051	0.23	1.03
20	1	0.283	0.53	0.74

where

$$(21) \quad K_{it_o} = (F_{it_o} + M_{it_o})/F_{it_o}(1 - \exp - (F_{it_o} + M_{it_o}))$$

In practice t_o is taken as the last year for which sampling of the commercial catch is available and projections are done for 1 or 2 yr ahead. Assuming that F_{it_o} and M_{it_o} are known without error, the variance of $\hat{N}_{it_o}$ is estimated by

$$(22) \quad \text{Var}(\hat{N}_{it_o}) = K_{it_o}^2\,\text{Var}(\hat{C}_i)$$

Using the delta method, Rivard (1981) provided an estimator for the variance of Y_t which was a function of, among other things, $\text{Var}(\hat{N}_{it_o})$. Using the variance obtained from equation (22), which assumes F_{it_o} and M_{it_o} are known constants, the variance of Y_t can be calculated and the direct effect of uncertainty in $\hat{C}_i$ on the precision of Y_t can be determined.

Results and Discussion

Following the same scheme employed by Gavaris and Bishop (1982), the catch at age and its variance were computed for cod in NAFO Area 4RS+3Pn (Table 1). The coefficient of variation for the dominant ages (4–7) was 5% or less. The aim of the sampling scheme was to obtain a fixed number of age samples at each length in each stratum; however, the number of age samples at each age peaked for ages 4–7, resulting in the lower coefficients of variation for these ages. The coefficient of variation exceeded 20% only for those ages that formed an insignificant part of the catch. For some lengths the subsample size, n_j, was 1. Consequently, the contribution to the variance

TABLE 2. The contribution to the variance of the catch at age by the various components is given. The greatest part was due to A, the "within length" component.

Age	Variance components A	B	C	D	Total variance
2	2.595	0.397	$1.102^{E}-3$	$3.031^{E}-4$	2.993
3	11 490.470	90.656	$1.376^{E}1$	$1.073^{E}0$	11 593.809
4	128 244.830	4 157.508	$3.597^{E}3$	$7.420^{E}0$	135 992.270
5	315 105.163	2 946.008	$1.225^{E}3$	$1.168^{E}1$	319 264.225
6	486 648.804	3 606.768	$4.391^{E}3$	$1.455^{E}1$	494 631.808
7	312 187.493	2 023.256	$1.421^{E}3$	$9.082^{E}0$	315 622.623
8	92 042.030	732.035	$1.482^{E}2$	$2.681^{E}0$	92 919.660
9	24 663.419	198.011	$3.009^{E}1$	$8.831^{E}-1$	24 890.635
10	6 631.018	73.815	$4.975^{E}0$	$2.805^{E}-1$	6 709.527
11	493.790	17.091	$6.244^{E}-1$	$3.741^{E}-2$	511.468
12	189.473	14.499	$1.954^{E}-1$	$1.019^{E}-2$	204.157
13	145.598	11.685	$1.645^{E}-1$	$1.109^{E}-2$	157.436
14	68.093	5.203	$4.005^{E}-2$	$5.891^{E}-3$	73.330
15	129.652	3.126	$1.329^{E}-2$	$4.392^{E}-3$	132.786
16	13.573	0.801	$1.157^{E}-2$	$8.885^{E}-4$	14.385
17	12.456	0.872	$1.202^{E}-2$	$1.022^{E}-3$	13.338
18	16.430	0.935	$1.517^{E}-3$	$1.603^{E}-3$	17.365
19	0.048	0.003	$1.429^{E}-6$	$1.528^{E}-6$	0.051
20	0.266	0.017	$1.953^{E}-5$	$2.078^{E}-5$	0.283

A. $\hat{C}^2 \sum_{j:p_{ij}\neq 0} \frac{p_j^2 p_{ij}(1 - p_{ij})}{n_j' - 1}$

B. $\hat{C}^2 \sum_{j:p_{ij}\neq 0} \frac{p_j(p_{ij} - p_i)^2}{n}$

C. $\hat{p}_i^2 \,\mathrm{Var}(\hat{C})$

D. $\mathrm{Var}(\hat{p}_i)\,\mathrm{Var}(\hat{C})$

of the catch at age by that length could not be calculated. This is not a serious problem as it occurs only when the number caught at length in a stratum is small.

A breakdown of the variance into its components (Table 2) indicated that the estimate of proportion at age accounted for most of the variation. A further decomposition of this component showed that the within length variance was the dominant factor. This is mostly due to the size of n relative to the size of the n_j's. It is necessary for n to be so large because of the nature of sample collection. To ensure that the estimated proportion at length is representative of the catch, basic samples have to be distributed over time and area within each unit and stratum, resulting in a fairly large number of length measurements (Stevenson, personal communication). Reducing the number of specimens measured per basic sample would not reduce costs and could possibly deteriorate estimates. For this stock, therefore, the variance of the catch at age could more effectively be controlled by adjustment of the subsample size for aging, n_j.

The estimators for the mean and variance of the catch at age require that subsampling for ages be random. The assumption that the area–time–gear strata are homogeneous with respect to proportion at age for a given length implies that fish within a stratum are mixed with respect to this property. Consequently the method used for selecting the subsample (see Stevenson 1983) will be random. In practice, growth is continuous over time; therefore, strata are not perfectly homogeneous, but the time span of strata is selected so as to minimize any effect. Furthermore, samples are generally spread over time thereby averaging small differences.

Besides the above criterion, it is necessary for the estimates of proportion at length and average weight of fish for the area–time–gear strata to be unbiased. Equations (3), (5), (8), and (10), although biased because the size of the sampling units is estimated, are consistent; therefore, for large sample size the bias is negligible. For the variance of the catch at age it must also be assumed that the proportion at length is a multinomial variate. Although in general this is not true for cluster sampling, it may be closely approximated when the sampling is representative and intra-class correlation within a cluster is small. Further study should be conducted to examine the

TABLE 3. A decomposition of the variance for the projected yield (*t*) of cod in NAFO area 4RS + 3Pn in 1983 shows that the variance of the average weight at age could potentially contribute more to the imprecision of estimated yield than the variance of the catch at age in 1981. The variance for the catch at age in 1981 was computed from data for this stock while the variance for the average weight at age was inferred from information on an adjacent stock.

Age	Projected yield	Variance components		Total variance
		Catch	Average weight	
4	808	3.8×10^6	1.9×10^5	4.0×10^6
5	5 019	1.1×10^6	4.3×10^6	5.3×10^6
6	37 495	6.4×10^5	8.0×10^7	8.1×10^7
7	16 121	3.1×10^5	3.7×10^7	3.7×10^7
8	16 319	1.6×10^5	4.0×10^7	4.0×10^7
9	7 474	8.1×10^4	6.1×10^6	6.2×10^6
10	3 595	4.2×10^4	2.2×10^6	2.2×10^6
11	1 967	4.0×10^3	9.9×10^5	1.0×10^6
12	909	2.3×10^3	1.3×10^5	1.4×10^5
13	182	5.2×10^2	1.3×10^4	1.4×10^4
14	141	1.8×10^2	1.4×10^4	1.4×10^4
Total	90 030	6.1×10^6	1.7×10^8	1.8×10^8

appropriateness of this last assumption for the sampling design being used.

The effect that the error of the catch at age in 1981 had on the yield projection for 1983 was calculated using a program supplied by Rivard (1982). The projected yield for 1983 was 90 030 t with a variance of 6.14×10^6 giving a coefficent of variation of 3%. Remember that this variance is due only to error in the catch at age and it was assumed that all other input was known without error. The imprecision of the catch at age estimates for ages 4 and 5 accounted for about 80% of the total variance in the yield projection (Table 3). It is interesting to note that the coefficient of variation of the projected yield was approximately equal to the coefficient of variation of the catch at age for the dominant ages.

Of other factors affecting yield projections, the average weight at age would be most directly affected by commercial sampling. Rivard (1981) found that the relative error in average weight at age for cod in NAFO Area 4TVn, an adjacent stock, ranged between 20 and 50%. These values included variation due to changes between years as well as to sampling error. Assuming similar relative errors for the average weight of cod in NAFO Area 4RS + 3Pn, the variance of the yield projection increased to 1.77×10^8, or a coefficient of variation of 15%. Over 85% of the variance in the yield projection was due to the imprecision of average weight at age for ages 6–8 (Table 3).

In conclusion then, the sampling scheme being used resulted in low coefficients of variation for the estimates of catch at age of the dominant ages. Further investigation could be directed toward determining the sampling error of the average weights at age and how the sampling plan affects these. Additional studies could address problems such as the assumption of homogeneity within strata with regard to proportion at length *j* which are age *i*, collection methods of basic samples with respect to representative sampling for proportion at length or the appropriateness of using an average weight at length from a separate experiment.

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Sampling Techniques and Related Analyses

Techniques d'échantillonnage et analyses connexes

Levels of Precision — Sea Versus Shore Sampling

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Three different sampling designs involving commercial groundfish catch sampling at sea and on shore are considered. Levels of precision for estimated catch numbers at length based on these designs are calculated for a case study involving the NAFO Div. 3L American plaice fishery. The results indicate that the levels of precision do not differ greatly for the various sampling techniques described and, thus, the most desirable sampling design is probably the one that is less demanding on available resources.

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Le présent rapport examine trois différentes méthodes d'échantillonnage en mer et à quai des prises commerciales de poissons de fond. Les niveaux de précision des nombres estimatifs des prises d'une longueur donnée, fondés sur ces méthodes, sont calculés pour un cas-type, soit la pêche de la plie canadienne dans la division 3L de l'OPANO. Les résultats portent à croire que les niveaux de précision ne diffèrent pas beaucoup pour les diverses méthodes d'échantillonnage décrites. La méthode la plus souhaitable est donc probablement celle qui exige le moins de ressources.

Introduction

There are some obvious practical advantages and disadvantages associated with both sea and port sampling programs. Sampling at sea enables the collection of such associated set detail information as position, depth, and dates fished, first hand rather than through interviews with captains or from logbooks after a vessel lands. Where a vessel's catch is different from what is actually landed (i.e. if there is processing of the catch occurring on board or discarding taking place) sea sampling is obviously the more appropriate approach. Sea sampling also allows for a more extensive coverage of a particular trip in terms of the number of samples collected, thus reducing the possibility of bias in the estimate of a particular vessel's catch. Shore sampling, on the other hand, has the advantage of allowing more between vessel sampling mobility and normally greater control in planning and carrying out a sampling strategy. It is also considerably less expensive in terms of time and money to sample on shore when a vessel lands as opposed to sending an observer to sea for a 10–12-d fishing trip.

Biological sampling of the groundfish catches from Newfoundland's large offshore mobile fleet is currently being carried out through a combination of at sea and port sampling. All captains of vessels in this fleet are required to report their fishing activities daily to the Department of Fisheries and Oceans and to complete detailed logbooks on a daily basis. These reports provide sufficient information on position, depth, and dates fished to allow sampling to be carried out when the vessel returns to port. No extensive processing of the catch is carried out on board these vessels, thus allowing the sampling of either gutted or round fish when a vessel lands. Discard survey studies in recent years have shown that there are only certain sectors of the Newfoundland offshore groundfish fishery where discarding is a significant problem (e.g. Kulka 1982; Stevenson 1982); therefore, in those particular areas, there is perhaps only a need to sample at sea. Taking into consideration that sending an observer to sea for a 10–12-d trip is generally more expensive than sampling that vessel's catch when it lands, the extra expense of sea sampling should be weighed against any gain in the precision of the estimates obtained from sea sampling compared to port sampling. This paper will attempt to measure the relative precision of sea versus shore sampling so that such a comparison can be made.

The ultimate aim of any biological catch sampling program is the elimination of all bias and the obtaining of as small a variance as possible commensurate with available resources. The question thus arises that, given a fixed amount of resources, which method of data collection (i.e. at sea or on shore) gives the optimum results? This paper will preclude the analysis of bias as a source of sampling error and compare the relative levels of precision associated with length composition estimates derived from sea and shore sampling.

Methods

This paper gives variance estimates for three different sampling techniques, one of which deals with sampling at sea and two with sampling at port. The sea sampling involves a three-stage sampling design, and both port sampling designs are two-stage. The estimate of interest is that of a length-frequency distribution for a particular quarter, gear, and area. The sampling design that is generally used in the Newfoundland fishery is one of the two-stage port sampling designs.

A major problem encountered in obtaining variance estimates for any of the above designs is that the population total is not known. There are in fact two estimates involved, one being the proportion of fish at a particular length, the other being the population total itself.

The estimate of the population total

(1) $$\hat{T} = \frac{W}{\bar{w}}$$

W = total weight in time, area, gear stratum.
$\bar{w}$ = average weight of fish calculated from samples.

With approximate variance using the delta method

(2) $$\text{Var } \hat{T} = \frac{W^2}{\bar{w}^4} \text{Var } (\bar{w})$$

(Seber 1973, p. 8)

(3) $$\text{Var } (\bar{w}) = \sum_j \frac{(z\hat{R}_j(w_j - \bar{w})^2)}{z(z-1)}$$

z = number of fish measured in samples.
$\hat{R}_j$ = estimated proportion or ratio of number of fish at length j of all fish measured.
w_j = weight of fish at length j from length weight curve.

The estimate of the number of fish at length is now simply

(4) $$\hat{T}_j = \hat{T} \times \hat{R}_j$$

with approximate variance

(5) $$\text{Var } (\hat{T}_j) = \hat{T}^2 \text{ Var } \hat{R}_j + \hat{R}_j^2 \text{ Var } \hat{T} - \text{Var } \hat{T} \text{ Var } \hat{R}_j$$

(Goodman 1960)

The estimator for the population variance does not differ for any of the three sampling designs, but the variance of the ratio changes with the sampling design. In all three designs, the estimate of $\hat{R}_j$ is the ratio of the weighted mean number of fish sampled at length j over the total number of fish measured.

The Sampling Designs

Sea Sampling (Three-Stage)

In the three-stage sea sampling design, the primary sampling units are the vessels fishing in the area of concern. A number of these vessels are selected randomly, and a number of sets then selected from the sampled vessels. The third stage of sampling involves taking a sample from the sampled sets. Since only one sample is taken from each set the within set variability cannot be obtained; thus, a conservative estimate for the variance of $\hat{R}_j$ is

(6) $$\text{Var } \hat{R}_j = \frac{1}{\bar{X}^2} \frac{N^2}{n} \frac{\sum^n (Y_{ij} - \hat{R}_j X_i)^2}{n-1}$$

(Cochran 1977, p. 288, 311–312)

where

N = number of vessels in the population.
n = number of vessels sampled.
Y_{ij} = number of fish in ith vessel which are length j.
X_i = number of fish in ith vessel.

Port Sampling (Two-Stage)

In this design the vessels again are selected randomly, but instead of sets being selected as the second stage units, 227-kg (500-lb) samples are selected. Each of these samples is measured in its entirety. There are two cases to be considered here, one being when there is only one sample selected from each sampled vessel, and the other when two or more samples are selected. When two or more samples are taken the variance of $\hat{R}_j$ is

(7) $$\text{Var } \hat{R}_j = \frac{1}{\bar{X}^2} \left(\frac{N^2}{n}(1-f_1) \frac{\sum^n (Y_{ij} - \hat{R}_j X_i)^2}{n-1} + \frac{N}{n} \frac{\sum^n M_i^2(1-f_{2i}) s^2_{d'2i}}{m_i} \right)$$

$$s^2_{d'2i} = \frac{\sum^{m_i}((y_{ikj} - \hat{R}_j x_{ik}) - (\bar{y}_{ij} - \hat{R}_j \bar{x}_i))^2}{m_i - 1}$$

(Cochran 1977, p. 311–312)

where

f_1 = n/N = first stage sampling fraction.
M_i = number of 227-kg samples in i^{th} vessel.
m_i = number of 227-kg samples selected from vessel i.
f_{2i} = m_i/M_i = second stage sampling fraction.
y_{ikj} = number of fish which are length j from sample k and vessel i.
x_{ik} = number of fish from sample k and vessel i.
$\bar{y}_{ij}$ = $\sum y_{ikj}/m_i$.
$\bar{x}_i$ = $\sum x_{ik}/m_i$.

The variance here is made up of two components: the between vessel variation which is the left-hand side of equation (7), and the within vessel variation which is the right-hand side of the equation. When only one sample is taken from each vessel the within vessel variation cannot be obtained, and in this case a conservative estimate for the variance is calculated from the primary units as in the sea sampling design.

$$\text{(8)} \qquad \text{Var}\,\hat{R}_j = \frac{1}{\bar{X}^2}\,\frac{N^2}{n}\,\frac{\sum^{n}(Y_{ij} - \hat{R}_j X_i)^2}{n-1}$$

(Cochran 1977, p. 155)

$f = n/N$
Y_{ij} = number of fish at length j in vessel i.
X_i = number of fish in vessel i.

Case Study

The second quarter 1981 NAFO Div. 3L American plaice fishery was chosen for study. An experiment was designed in which two vessels taking part in this fishery were sampled both at sea and on shore. The sea sampling included length frequencies for 15 out of 36 and 16 out of 29 sets made for each of the vessels considered. A sample of ~200 fish was selected randomly from the marketable portion of each sampled set and the length frequency obtained adjusted to the entire set. The estimates for the sampled sets were further adjusted to the turnout for the particular vessel. The shore sampling consisted of four samples of ~350–500 fish each, selected at random from a total of 172 and 174 such samples discharged from each of the respective vessels. Each of the four samples chosen from a particular vessel was given equal weight and adjusted to the turnout for that specific vessel. Other data used were obtained from the regular port sampling program and consisted of one sample of ~300–500 fish from each of 24 vessels fishing Div. 3L American plaice during the quarter. These samples were adjusted directly to the turnouts for each of the respective trips. A total of 343 vessels fished American plaice in NAFO Div. 3L in the second quarter of 1981.

Results and Discussion

The variance estimates and the coefficients of variation for sea sampling and the port sampling experiment are given in Tables 1 and 2, respectively. The precision of the estimated number of fish landed was adequate in both cases. Coefficients of variation of 15% or less were calculated for 82% of the estimated population in the sea sampling design and 88% in the experimental port design. Equation (7), used in the experimental port sampling design, gives the within and between vessel components of the variance. From this equation it was seen that the between vessel component contributed much more to the total variance than the within vessel component (i.e. more than 90% at most lengths). It can be inferred from this that more emphasis should be placed on the number of vessels sampled as opposed to the amount of sampling on a particular vessel.

TABLE 1. Coefficients of variation for estimated numbers at length — sea sampling.

Length	Variance × 10^6	Estimated No. × 10^3	C.V.
18.5	39	8	0.78
26.5	53	9	0.81
28.5	11	4	0.83
30.5	557	307	0.08
32.5	62 264	1 558	0.16
34.5	94 011	3 361	0.09
36.5	8 667	3 772	0.02
38.5	746	3 626	0.01
40.5	14 977	3 108	0.04
42.5	9 449	2 728	0.04
44.5	299	2 106	0.01
46.5	73 890	1 637	0.17
48.5	9 414	1 098	0.09
50.5	1 537	866	0.05
52.5	13 337	623	0.19
54.5	4 706	407	0.17
56.5	2 603	270	0.19
58.5	574	186	0.13
60.5	111	53	0.20
62.5	9	38	0.08
64.5	120	21	0.52
66.5	63	10	0.79
68.5	11	4	0.83
		25 800	

Table 3 presents the results derived from present port sampling procedures, taking a single sample from each of 24 vessels. In this case 83% of the population was estimated with C.V.'s of 15% or less. Although a great deal more vessels were sampled in this design, the levels of precision were very similar to that in the previous designs; this may be due to the homogeneity of the size distribution of American plaice in this particular area. Whether or not these results are applicable to other fisheries is uncertain. With regard to the present port sampling program, these results would indicate that increasing the number of samples taken per vessel would not significantly increase the precision of the estimate.

It was seen in the discussion above that the precision of the estimates from the three sampling designs were all extremely high and very similar. Thus, any of the described techniques would be adequate, if all were free from bias. It would appear, that this being the case, the technique to use would be the one that costs the least. However, further studies should be conducted to define any bias associated with sea and port sampling designs.

TABLE 2. Coefficients of variation for estimated numbers at length — port sampling experiment.

Length	Variance × 10^6	Estimated No. × 10^3	C.V.
22.5	51	9	0.79
28.5	3 244	71	0.80
30.5	46 400	674	0.32
32.5	186 760	2 474	0.17
34.5	7 312	4 480	0.02
36.5	54 253	4 542	0.05
38.5	2 761	4 152	0.01
40.5	99 730	3 541	0.09
42.5	27 377	2 328	0.07
44.5	44 908	1 953	0.11
46.5	20 342	1 190	0.12
48.5	577	1 047	0.02
50.5	9 689	746	0.13
52.5	87	559	0.02
54.5	21	293	0.02
56.5	255	204	0.08
58.5	389	142	0.14
60.5	36	44	0.14
62.5	255	36	0.44
64.5	51	9	0.79
66.5	51	9	0.79
		28 503	

TABLE 3. Coefficients of variation for estimated numbers at length — regular port sampling.

Length	Variance × 10^6	Estimated No. × 10^3	C.V.
18.5	145	9	1.34
24.5	202	9	1.58
26.5	173	9	1.46
28.3	13 560	208	0.56
30.5	53 484	814	0.28
32.5	136 549	2 213	0.17
34.5	100 489	3 718	0.09
36.5	43 399	4 023	0.05
38.5	58 972	3 770	0.06
40.5	66 210	3 327	0.08
42.5	61 021	2 676	0.09
44.5	15 644	1 950	0.06
46.5	28 533	1 595	0.11
48.5	21 663	1 100	0.13
50.5	9 707	755	0.13
52.5	6 563	458	0.18
54.5	3 933	345	0.18
56.5	2 783	214	0.25
58.5	2 020	169	0.27
60.5	1 349	139	0.26
62.5	271	46	0.36
64.5	73	15	0.57
66.5	81	12	0.75
68.5	64	8	1.00
70.5	87	6	1.55
		27 588	

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Comparison of Finfish Length-Frequency Distributions Estimated from Samples Taken at Sea and in Port

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Estimates of length-frequency distributions of commercial catches of finfish were obtained using two sampling schemes. One samples the catch on a set by set basis at sea, while the other samples the same catch once it reaches its port of landing. With the onboard sampling scheme significantly different length-frequency distributions were observed from set to set for a single species indicating spatial heterogeneity, or clumping of length classes in the populations being harvested. We compared the onboard estimates to the appropriate onshore estimate using a method that calculates simultaneous confidence intervals for contrasts between multinomial populations. These indicated that the estimates were significantly different in the majority of cases. Whether these differences resulted from the patchiness of the harvested populations, or some intervening onboard process, could not be determined from the present data. We identified four classes of onboard events that could result in changing the length-frequency distribution of the catch between the time of capture and the time of landing; discarding of selected length-classes at sea, onboard fish processing procedures, onboard storage procedures such as icing or freezing, and finally the manner in which fish are stored and unloaded on these large offshore vessels. We concluded that onboard sampling for estimation of catch length-frequency distributions is sensitive to set by set variations imparted by the spatial distribution of length categories in the population and must be tailored to this variation. Onboard processing procedures can then alter or mask the catch length-frequency distribution prior to its estimation by onshore sampling. Several experiments designed to quantify these latter effects are outlined.

ZWANENBURG, K. C. T., AND S. J. SMITH. 1983. Comparison of finfish length-frequency distributions estimated from samples taken at sea and in port, p. 189–193. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Les distributions estimatives des fréquences de longueur chez les poissons capturés au cours de pêches commerciales ont été obtenues à l'aide des deux méthodes suivantes: échantillonnage en mer après chaque relevage du filet et échantillonnage de la même prise au port de débarquement. Selon les résultats générés par la première méthode, les distributions des fréquences de longueur diffèrent de façon significative d'une capture à l'autre pour la même espèce, ce qui porte à croire à une hétérogénéité spatiale, ou groupement des classes d'âge, des populations exploitées. Nous comparons les évaluations obtenues à bord aux évaluations pertinentes recueillies à quai en calculant les intervalles simultanés de confiance pour obtenir des contrastes entre les populations multinomiales. Ces intervalles portent à croire que les évaluations varient de beaucoup dans la plupart des cas. Les données actuelles ne permettent pas de déterminer si ces différences sont causées par la discontinuité des populations exploitées ou par d'autres circonstances à bord. Nous avons classé ces dernières en quatre catégories, soit: rejet à la mer de certaines classes de longueur, méthodes de traitement des poissons à bord, procédures d'entreposage à bord telles que mise en glace et congélation, et méthodes d'entreposage et de débarquement utilisées à bord des grands bateaux hauturiers. Ces circonstances peuvent modifier la distribution des fréquences de longueur dans la prise entre le moment de la capture et celui du déchargement. Nous concluons que l'échantillonnage à bord pour évaluer les distributions des fréquences de longueur chez les poissons capturés est fonction des variations qui se produisent d'un relevage du filet à l'autre et qui découlent de la répartition spatiale des catégories de longueur dans la population et, de ce fait, il faut l'ajuster à ces variations. Les procédures de traitement à bord peuvent donc modifier ou dissimuler la distribution des fréquences de longueur dans la prise avant son évaluation à l'aide d'un échantillonnage à quai. Nous présentons plusieurs expériences conçues pour quantifier ces derniers effets.

Introduction

Two major sources of information on the length and age-frequency distributions of commercial finfish landings are available. The first is a shore-based sampling program operating at all the major and a large proportion of the secondary ports of landing in Nova Scotia and New Brunswick. The second is generated by deployment of observers on domestic fishing vessels. The data gathered by the observer program, to date, have not been extensively used in stock assessment procedures but are potentially valuable sources of information that could be incorporated into the stock assessment data base.

In this paper we compare estimates of the length-frequency distributions of several finfish landings, obtained both by onshore and onboard sampling procedures. The major difference between these two sampling regimes is that the onboard scheme samples the catch on a set by set basis, whereas the onshore scheme samples only the landed portion of the total catch. The emphasis in these comparisons was to determine if the two sampling programs resulted in similar estimates of length-frequency distribution for any one given catch. If the estimates are similar for both programs, this may indicate that the onboard data could be readily incorporated into the existing stock assessment data base. If on the other hand these two programs give significantly different estimates, questions arise as to how these differences may be generated.

Material and Methods

Catches from eight Canadian trawlers operating between October 1980 and April 1981 were sampled at sea and at the port of landing. At sea, sampling was carried out on a set (catch) by set basis although not all sets made during a given trip were sampled. Onshore, the landings from these same vessels were sampled by port technicians. Due to operational differences, the sampling schemes for the two programs were not the same.

On board the vessels an observer would obtain a random sample of a given species from a catch (a set) and measure each fish for length. However, upon landing, most species are culled into market categories (overlapping size-classes) before the port technician can take a sample. Therefore a weighed sample was obtained from each available market category and either all or a known proportion of the sample was measured. To estimate the length frequency over all size-classes, the frequencies for each market category were combined in the following manner. First define:

n_j = the total number of fish in the sample from market category j ($j = 1, ..., J$).

f_{ij} = the total number of fish measured in the sample at length i in market category j ($i = 1, ..., I$).

$n = \sum_i^I \sum_j^J f_{ij}$ = the total number of fish measured over all market categories.

$S_j = \dfrac{\sum_i^I f_{ij}}{n_j}$ = the sampling fraction in market category j.

W_{cj} = the total landed weight in market category j.

W_{sj} = the weight of the sample in category j.

Combining across market categories and weighting the observations by the proportions which each category represents of the total weight gives

$$(1) \quad F_i = \sum_{j=1}^{J} f_{ij} \left(\frac{W_{cj}}{W_{sj}} \right) \Big/ S_j$$

The estimated proportion at length i is then expressed as

$$(2) \quad F_i^* = \frac{F_i}{\sum_i^I F_i}$$

The estimated proportion at length for individual sets sampled on board the vessels is given by

$$(3) \quad N_{ik} = \frac{n_{ik}}{\sum_{i=1}^{I} n_{ik}}$$

where n_{ik} = the total number of fish measured at length i in set $k (i = 1, ..., I, k = 1, ..., K)$.

The differences between the sampling schemes used by the two programs complicate the choice of comparative techniques. In the absence of a well-defined model that would describe the expected behavior of length frequencies, the analysis is confined to exploration rather than confirmation. As a naive approach we assumed that the length frequencies were realizations of a multinomial process. Comparisons between length frequencies were carried out by testing the null hypothesis that the frequencies were drawn from the same multinomial population. This hypothesis was tested using the Chi-square test in Smith and Maguire (1983). When differences were found, that is, the null hypothesis was rejected, contrast tests were carried out to determine which length-classes were contributing to the significant differences (Goodman 1964; Smith and Maguire 1983).

Results and Discussion

When comparing length-frequency distributions generated by these two sampling strategies, one must consider how each one samples the population and what are the potential sources of bias. The onshore procedure is to measure an assumed stratified random subsample of the landing. The stratification scheme is such that many different portions of the landing can contribute to the sample. Each individual onboard sample is assumed to be a simple random sample taken from a single set. Each set is usually a relatively small subsample of the total landing. These approaches are each vulnerable to a set of influences that may cause them to produce biased estimates of the true length-frequency distribution of a particular landing of fish.

Estimates of length-frequency distribution derived from onshore sampling and those derived from sampling a single set should show no differences if the following conditions are met. The original fish population being harvested must have a very uniform length distribution in space and time;

TABLE 1. Comparison of length-frequency distributions derived from the onboard sampling procedure. The number of significant contrasts refers to the total number of length-classes for which significant differences between estimates were observed.

Vessel name	Species	Number of sets sampled	Number of length-classes showing significant contrasts
Cape LaHave	Haddock	3	1
	Pollock	2	1
Cape Hunter	Cod	2	0
	Pollock	3	1
	Haddock	2	0
Cape Beaver	Redfish	3	8
Cape Wrath	Cod	2	0
Gulf Georgetown	Cod	6	4

no processes that alter the original length distribution (i.e. discarding or onboard processing) should be operating. If one or both of these conditions are not satisfied then the probability of these two sampling strategies estimating different length-frequency distributions for a single landing is increased.

We could estimate the spatial variation of size-classes within the population being harvested by comparing consecutive estimates of length-frequency distributions obtained on board. If set to set variation in these estimates is minimal, then we may assume that the population has the same length distribution from sample to sample. If the set to set variation is large, this would indicate a population with a clumped length distribution. Table 1 summarizes the set to set contrasts for each trip where more than one set was sampled. These results show that, in most cases observed, significantly different estimates of length-frequency distribution were found on a set to set basis. In other cases, no significant contrasts were observed. On the basis of the small number of sets sampled for most trips, it would be presumptuous to draw any firm conclusions regarding the actual spatial patterns of these populations. In addition, the small number of sets sampled were usually sampled consecutively in time, thus minimizing their access to the range of potential variability. Given these caveats it suffices to note that significant contrasts between set to set estimates do occur.

Given that we had observed significant set to set variation in estimates of length-frequency distributions, the question arose as to the magnitude of these differences. Since our objective was to determine whether or not these two sampling schemes result in different estimates of length-frequency distribution for a single landing, we next compared the individual onboard estimates to the onshore estimates for each trip. Table 2 summarizes these contrasts. From these comparisons we noted that the variation observed between sets is perpetuated in comparisons between sets and onshore samples. For this analysis and the previous set of contrasts (Table 1), no consistent pattern of contrasts was observed, that is differences were not confined solely to particular length-classes.

We attributed the variations in length frequencies observed between sets to spatial heterogeneity within the population; however, the differences observed between

TABLE 2. Comparisons of length-frequency distributions obtained by sampling single landings both on board and on shore. For these comparisons the shore-based sample is compared to each individual sample taken on board. The number of significant contrasts refers to the number of length-classes showing a significant difference.

Vessel name	Species	Number of sets sampled	X^2	df	P	Number of significant contrasts with set no. 1	2	3	4	5	6
Cape York	Haddock	1	49.52	17	0.00005	1					
	Redfish	1	64.96	19	0.00000	2					
Cape LaHave	Haddock	3	79.69	42	0.00040	1	0	1			
	Pollock	2	122.94	34	0.00000	2	5				
	Cod	1	21.34[a]	19	0.31854	0					
Cape Hunter	Cod	2	104.82	40	0.00000	3	3				
	Pollock	3	152.58	54	0.00000	1	1	3			
	Haddock	2	60.55	26	0.00014	1	1				
Cape Charles	Haddock	1	20.71[a]	18	0.29405	0					
Cape Beaver	Redfish	3	477.95	87	0.00000	8	3	9			
	Cod	1	73.77	22	0.00000	1					
Bedeque	Redfish	1	138.60	26	0.00000	9					
Cape Wrath	Cod	2	69.15	46	0.01520	1	0				
Gulf Georgetown	Cod	6	474.66	168	0.00000	5	6	5	2	3	0

[a]Not significant (5%).

individual onboard and onshore estimates are not so readily categorized. It may be that all the variation is attributable to the clumped length distributions within the population being harvested. Conversely, some processes that occurred between the time of capture and sampling of the landing could be the reason for the observed differences. These intervening processes could be in the form of selective discarding at sea, fish processing techniques that alter the lengths of individual fish, or storage and unloading practices which preclude equal accessibility to all portions of the catch for onshore sampling.

Discarding practices would likely be evidenced by consistent differences in the smaller length-classes since these are most often discarded. Examination of the onshore and onboard length-frequency distributions for all trips showed no evidence of consistent differences at any length-classes for any of the species observed. Although we concluded that discarding did not result in the differences observed for these trips, the possibility that it may occur on other trips is not precluded and should be considered as a potential source of bias.

The influences of any onboard fish processing procedures are less readily ascertained. Fish caught by these large offshore vessels are gutted within a very short time of being caught. The gutting procedures used aboard these vessels are reasonably standard between vessels. Both automated and manual gutting procedures begin by opening up the body cavity with an incision running from the isthmus, located on the ventral midline between the opercular flaps, to approximately the level of the anus. Next, all internal organs are removed and the gutted fish are placed in holding pens with crushed ice. Removing the internal organs makes the carcass much less rigid. In particular it allows the head, which is now only narrowly attached to the vertebral column, to move more freely. The flexible carcasses are then frozen semi-solid in the holds where they take on a variety of shapes from the pressure of the other fish. Measuring these fish once the vessel is unloaded can be difficult. Curved carcasses have to be straightened, heads that remain attached only by the skin need to be arranged on the body, etc. The combined effects of these procedures could be responsible for generating some of the observed variability between onboard and onshore estimates of length-frequency distribution. Besides these gross changes in fish morphology, more subtle changes such as shrinkage due to dehydration or swelling due to excessive hydration may cause changes to the length-frequency distribution.

With the present data, it was not possible to separate this process or storage induced variability from that of the spatial heterogeneity of the harvested population. This source of variation could be quantified by measuring and tagging samples of fish immediately after they are brought aboard and then remeasuring this sample once the vessel lands.

Another potentially major source of variability relates to the manner in which fish are stored and removed from the holds of the fishing vessel. Since we have observed that the fish populations demonstrate some degree of patchiness with regard to length frequencies, this patchiness may be reflected in the pattern of length frequencies in the hold of the vessel. In most modern offshore fishing vessels, fish caught at different times during a trip are stored in separate pens in the hold. If this is the case, the section of the hold from which an onshore sample is taken could contain certain size-classes of fish in proportions that differ significantly from their overall proportions in the entire landing. If we examine the contrasts for the Gulf Georgetown samples, we find that the onshore sample shows significant contrasts with all but one set (Table 2). The set that shows no differences was sampled on the final day of fishing. The trip record indicates that in 5 of the 6 d in which sets were sampled for cod, the vessel was fishing to a depth of 100–140 m. On the final day it fished in 40 m of water. Comparing the sets taken on the first 5 d with those taken on the sixth resulted in a greater number of significant contrasts than comparing the first five sets amongst themselves. The similarity between the onshore estimate of length-frequency distribution and that of the final set, and their collective difference from the previous five sets, seems to indicate that in this case sampling conducted onshore was nonrandom. This results in the length-frequency distribution of that final day's catch being used to characterize the previous days' catches even though these are shown to differ significantly. The limitations of the present data set preclude this form of analysis for the other trips but this one instance does raise the question of whether or not the present shore-based sampling program can, at all times, obtain a truly random sample of a landing for a particular species. This is particularly important in sampling large vessels that store many days catch in the hold prior to landing.

It would be informative to investigate and quantify this source of variation. Its potential for creating biased estimates of length frequencies is large since these large vessels often account for very large proportions of the total yearly landings for a particular species. Erroneous characterization of such a large portion of a species' total landing could have major consequences on estimates of its abundance.

Since most modern offshore vessels do store their catches separated on a day to day basis, the variability between various sections of the hold could be quantified by sampling each section separately.

Summary and Conclusions

We have identified several processes which could potentially alter finfish length-frequency distribution between the time of capture and landing. Given the present data, detecting the occurrence of all but discarding at sea, is improbable. Experiments designed to establish the effects of onboard fish processing procedures on estimates of population length frequencies are relatively simple. Determining the extent of variation in length-frequency distributions within the hold of the vessel presents much greater problems, most of a logistic nature. We feel that studies into this latter source of bias will be most fruitful in improving our estimates of population length-frequency distributions from sampling of commercial landings.

From this study, we have concluded that the onboard and onshore sampling procedures, presently employed, resulted in estimating different length-frequency distributions for a single landing in the majority of cases observed. The most probable reasons for these differences relate to patchiness in the harvested fish populations. As a result, onboard estimates of length-frequency distributions are highly variable between sets. If the length frequency of the landing is to be described using these onboard data, all or a large proportion of the sets containing the species of interest must be sampled to ensure that all the potential variation is observed. These individual estimates must then be combined into a composite estimate describing the total catch of a particular species. Since each set captures a unique proportion of the total amount of a species caught during a trip, each estimate must be weighted by that proportion. At present, procedures used to estimate the weight of fish caught in any one set are not sufficiently accurate to allow these weights to be used as weighting factors. No alternative weighting factor has as yet been identified.

We have also presented some evidence which indicates that the patchiness of the harvested population is reflected, to some degree, in the distribution of length-classes in the hold of the vessel. Studies should be undertaken to determine the extent of this, and to establish onshore sampling procedures that will alleviate this problem.

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Port Sampling for Age Composition of Pacific Halibut Landings

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The International Pacific Halibut Commission (IPHC) samples landings from commercial catches of Pacific halibut at ports along the coast of the northeast Pacific Ocean to construct detailed information about age composition, average fish weight, and catch numbers by age. This paper provides an overview of current sampling procedures with emphasis on factors considered in annual evaluations of sampling representativeness. Statistical formulae are presented for estimating parameters for each month–region stratum based on a representative sample of fish lengths and random subsample of ages within each length category. Two methods of combining data over strata are compared. The first method projects age composition estimates to the total fish caught in the stratum and adds across strata (project-and-add). The second method pools raw data first and then projects to the total fish caught in all strata (add-and-project). The estimator from the first method is unbiased but generally more variable. Certain conditions are given which must be satisfied for the second method to be unbiased. The methods are illustrated with data from IPHC regulatory area 2. The project-and-add method is preferred for Pacific halibut data because significant differences are found in age and length distributions between months and regions, and there is not a great increase in variability as compared to the add-and-project method. However, the project-and-add method requires determination of a minimum sample size for aging and a missing data algorithm for unsampled strata. Sample size formulae to achieve four criteria of precision result in a requirement of 600 otoliths to be aged per stratum.

QUINN, T. J., II, E. A. BEST, L. BIJSTERVELD, AND I. R. MCGREGOR. 1983. Port sampling for age composition of Pacific halibut landings, p. 194–205. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Le personnel de la Commission internationale du flétan du Pacifique (CIFP) échantillonne les débarquements des prises commerciales de flétan du Pacifique dans les ports le long de la côte nord-est de l'océan Pacifique afin d'obtenir des données détaillées sur la composition par âge, le poids moyen des poissons et les prises par classe d'âge. Le présent rapport résume les méthodes actuelles d'échantillonnage, en mettant l'accent sur les facteurs étudiés lors des évaluations annuelles du caractère représentatif de l'échantillonnage. Les auteurs donnent des formules statistiques pour évaluer des paramètres pour chaque strate correspondant à un mois et à une région particulière, selon un échantillon représentatif des longueurs de poisson et un sous-échantillon des âges choisi au hasard dans chaque catégorie de longueur. On compare deux méthodes d'association des données en fonction des strates. La première méthode applique les évaluations de la composition par âge au total des prises dans la strate et additionne les strates (projection et addition). La deuxième méthode rassemble d'abord les données brutes puis les applique au total des prises dans toutes les strates (addition et projection). L'évaluation générée par la première méthode est sans biais mais généralement plus variable. Le rapport donne certaines conditions à satisfaire pour éliminer tout biais de la seconde méthode. Les méthodes sont illustrées à l'aide de données recueillies dans la zone 2 de la CIFP. On préfère la méthode de projection et d'addition pour les données sur le flétan du Pacifique parce que des différences significatives sont présentes dans les distributions âge-longueur entre les mois et les régions et parce qu'il n'y a pas d'augmentation marquée de la variabilité par rapport à la méthode d'addition et de projection. Toutefois, la méthode de projection et d'addition requiert la détermination de la taille minimale de l'échantillon pour connaître l'âge et d'un algorithme pour les données manquantes des strates non échantillonnées. Afin de réaliser les quatre critères de précision, il faut lire 600 otolithes pour chaque strate.

Introduction

Port sampling, the collection of biological data from commercial fishery landings, was started by the International Pacific Halibut Commission (IPHC) in 1933 to provide detailed information about size and age composition and average fish weight of the catch. Initially, only landings at the port of Seattle were sampled which came from two "indicator grounds" thought to be representative of IPHC's two principal regulatory areas (areas 2 and 3). As landings shifted northward into British Columbia and Alaska, additional ports were added. Currently, samples

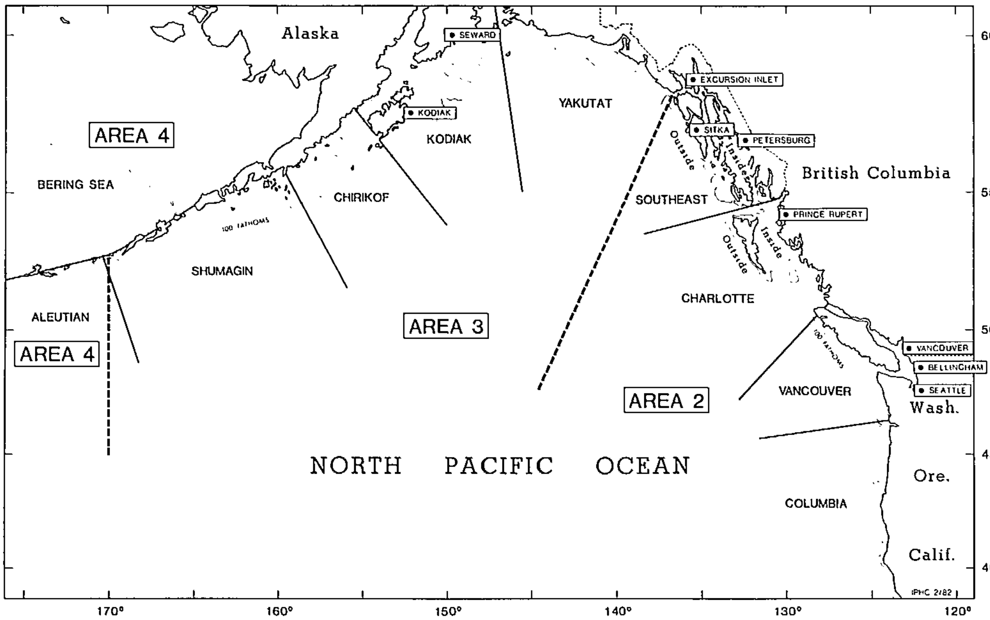

FIG. 1. IPHC regions, regulatory areas, and sampled ports, 1981.

are obtained at nine ports: Seattle and Bellingham, Washington; Vancouver and Prince Rupert, British Columbia; and Petersburg, Sitka, Excursion Inlet, Seward, and Kodiak, Alaska (Fig. 1).

This report is an overview of current port sampling procedures used by IPHC, and provides a description of factors considered in annual evaluations of sampling representativeness. The basic sampling methodology is two-stage or double sampling (Cochran 1963), where a sample of fish lengths is taken in the first stage and a subsample of the length sample is taken for aging in the second stage. Formulae are given for estimates of age composition, average fish weight and catch in numbers by age derived in Quinn et al. (1983). Methods are presented for com-

TABLE 1. Number of landed trips/sampled trips over 5000 lb by port and region, 1980.

	Region											
Port	Col	Van	Ch/Out	Ch/In	SEIn	SEOu	Yak	Kod	Chi	Shu	Ale	BSea
[a]Vancouver	—	4/1	19/4	100/22	—	—	4/1	1/0	—	—	—	—
Port Hardy	—	—	—	22	—	—	—	—	—	—	—	—
Namu	—	—	1	4	—	—	—	—	—	—	—	—
[a]Prince Rupert	—	—	17/6	102/32	14/5	1/0	11/4	1/0	—	—	—	—
Masset	—	—	3	—	—	—	—	—	—	—	—	—
[a]Seattle	—	—	1	11/2	—	2/1	13/6	24/8	—	—	1/1	—
[a]Bellingham	—	—	2	4/1	1/1	1/0	13/6	10/1	—	—	—	3/0
Ketchikan	—	—	—	—	5	—	2	—	—	—	—	—
Metlakatla	—	—	—	—	1	1	—	—	—	—	—	—
[a]Petersburg	—	—	—	—	30/8	10/5	24/4	14/4	—	—	—	—
Wrangell	—	—	—	—	21	1	2	—	—	—	—	—
[a]Sitka	—	—	—	—	2/2	32/11	44/12	—	—	—	—	—
Juneau	—	—	—	—	12	2	10	—	—	—	—	—
Hoonah	—	—	—	—	5	—	8	—	—	—	—	—
Excursion Inlet	—	—	—	—	12	—	12	—	—	—	—	—
[a]Pelican	—	—	—	—	7/0	2/0	34/9	1/1	—	—	—	—
Cordova	—	—	—	—	—	—	23	16	—	—	—	—
[a]Seward	—	—	—	—	—	—	14/5	44/15	—	—	1/0	2/0
Homer	—	—	—	—	—	—	—	33	—	—	—	—
[a]Kodiak	—	—	—	—	—	—	4/3	31/8	—	—	8/6	8/3
All others	—	2	—	1	—	—	6	8	1	—	—	1

[a]Indicates a port sampled at some time in 1980.

bining data over basic month–region strata to obtain estimates for regions (basic biological units) and regulatory areas (basic management units) shown in Fig. 1. Two methods are compared theoretically and by application to Pacific halibut data from regulatory area 2: (1) project-and-add (project age composition to stratum total catch; add across strata); and (2) add-and-project (pool data across strata; project to the total catch).

Port Sampling Design

The current design for port sampling has evolved out of results of past evaluations (Hardman and Southward 1965; Southward and Hardman 1973; Southward 1976; Quinn et al. 1983). The large number of vessels fishing for halibut (IPHC 1981, table 3) and lack of space for samplers aboard commercial vessels preclude the sampling of commercial catches at sea. Landings from vessels occur at ports along the coast of the northeast Pacific Ocean. At the beginning of each year, a list of ports for sampling that anticipates the distribution of landings from regions of the coast is compiled. Landings at ports do not necessarily come from the closest fishing region, but regions with major catches are generally represented in samples collected at current ports (Table 1). Samples are obtained in rough proportion to the landings, as shown by 1980 data (Table 1). Logbook information is collected from sampled trips in order to assign regions.

For the most part, the rate of sampling, the proportion of collected otoliths to total number of fish, is set at $^1/_{18}$ (5.6%) of landings over 1000 lb in areas 2 and 3 for these ports. Smaller trips are an insignificant portion of the total fishery. This rate represents an overall sampling rate of about 3% of the total landings at all ports. However, landings from area 4 are sampled at the rate $^1/_3$, because these landings are subdivided into six different regions and generally involve a smaller number of total fish. If necessary, these rates are increased on a port by port basis to ensure that sufficient samples are collected from regions of low catch: currently Columbia, Vancouver, Shumagin, and Aleutian.

The commercial fishery is made up of vessels fishing with hook-and-line gear exclusively. Although there are different types of hook-and-line gear, samples are taken from all gear types in proportion to their landing frequency. Thus, the pooled samples are properly weighted with respect to gear type for estimating length and age composition of the total catch. The sampling rate is to be achieved individually for four trip size classes (1000–4999, 5000–14 999, 15 000–39 999, 40 000+ lb) to prevent samplers from choosing smaller trip sizes.

Fish are unloaded from the vessel at port in slings, or tubs, or with straps. The sampling is carried out by selecting a vessel and taking a systematic random sample of slings. Otoliths (ear stones) from all fish in the sampled sling are taken (discounting broken or crystallized otoliths, or missed fish). Fish unloaded with tubs and straps are also sampled systematically. For the 1000–4999 class, the vessel sampling rate is set at $^1/_9$ and the sling sampling rate is set at $^1/_2$, resulting in the desired overall rate of $^1/_{18}$. For the other classes, the vessel sampling rate is $^1/_3$ and the sling sampling rate is $^1/_6$. For area 4 landings, the vessel sampling rate is set at $^1/_1$ (all vessels) and the sling sampling rate is $^1/_3$. The starting sling is chosen at random and subsequent slings are chosen based on the sling sampling rate.

Although the vessel sampling rate should be the same throughout the fishing season, this ideal is difficult to achieve in practice due to manpower limitations and concentrated fishing periods. The peak number of trips is landed at the end of a fishing period and the maximum vessel sampling rate per day is generally lower than the desired rate that can be achieved at that time. Hence, the sampling rate in practice must be met on a cumulative rather than a daily basis by oversampling trips before the period closes and adjusting the daily rate at the end of the period to obtain the overall vessel sampling rate. For example, in the port of Sitka, 1980, trips 5000 lb and over were sampled at a rate of about $^1/_2$ in the beginning of each period, but the large number of trips landed at the end of the period resulted in the desired overall rate of $^1/_3$ (Fig. 2). The desired overall rate for trips 1000–4999 lb, $^1/_9$, is easier to obtain because fewer trips to be sampled are involved. These samples are obtained as time permits during the period (Fig. 2).

Besides otoliths from sampled trips, other information is collected to evaluate the sampling procedure, including the total number of slings in the trip, the number of sampled slings, and the number of fish unloaded by other means. A new method of estimating average fish weight involves extrapolation of the total number of fish from the number of otoliths in a trip; this requires information on the number of missed fish and otoliths in sampled slings, and if possible sling counts from nonsampled slings (McGregor and Quinn 1982). These trip estimates permit

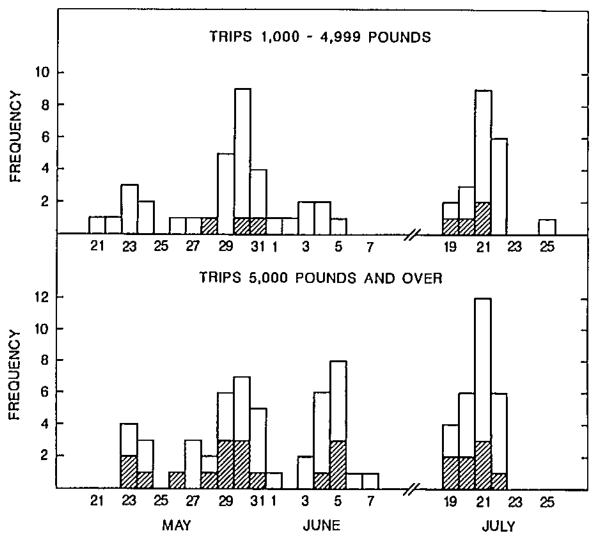

FIG. 2. Frequency of trips and sampled trips (shaded) by date and two trip size classes, Sitka, 1980. The fishing periods were May 20-30 for U.S. waters in area 2, and May 19–June 4 and July 15–19 for area 3.

annual evaluation of fish weight relationships described below.

After processing in Seattle, the samples are grouped into month–region strata, because there is too much variability in the estimated age composition of a single trip (Southward 1976). Each fish's length and weight are predicted from otolith weight using established relationships (Quinn et al. 1983). A subsample of 600 otoliths for aging, if available, is taken from each stratum based on formulae for sample size requirements given below. No direct information by sex is available from port sampling, because fish are eviscerated at sea. However, a study has been initiated to determine whether discriminant analysis on otolith measurements can be used to predict sex ratio.

The sampling design should result in a representative sampling of regions of the coast over months of the year. However, the overall sampling rates obtained are not exactly equal to specified levels because of logistical problems and shifts in the distribution of landings among ports and/or regions. For example, sampling rates for regions in IPHC regulatory area 2 in 1980 are higher than average in the regions Charlotte-Inside, Charlotte-Outside, and SE-Alaska Outside and lower in the other regions (Table 2). On the other hand, month–region strata with large catches are well sampled, which implies the bulk of the catch is represented by the sampling. Thus, although the goal of exact proportional sampling is not achieved in practice across months and regions, the discrepancies in sampling rate are not considered a major problem.

Within-Stratum Estimation

Catch Numbers

For each stratum i, the total catch in weight T_i is known from landing records, and the average of the predicted weights $\overline{W}_i$ from otoliths is calculated, assuming the sample of otoliths is representative of the total catch. The estimate of the total catch in numbers

(1) $\hat{C}_i = T_i / \overline{W}_i$

is approximately unbiased for a large sample size.
The estimated variance from the delta method (Seber 1973, p. 9) is

(2) $s^2(\hat{C}_i) = \hat{C}_i^2 s^2(\overline{W}_i) / \overline{W}_i^2$

where $s(\overline{W}_i)$ is the typical standard error of the mean. Although otoliths are collected with a systematic sampling design, its variance estimator cannot be used for $s^2(\overline{W}_i)$, because otoliths are not kept separate by sling during sampling. However, as long as fish are loaded randomly into slings, the standard error estimator from simple random sampling is valid.

Age Composition

Estimation of age composition is based upon two inherent specifications in the sampling design (Southward

Table 2. Number of otoliths, estimated total number of fish, and sampling rate for month–region strata in area 2, 1980.

	May			July			August			September			November			1980		
	No. of otoliths	No. of fish	%	No. of otoliths	No. of fish	%	No. of otoliths	No. of fish	%	No. of otoliths	No. of fish	%	No. of otoliths	No. of fish	%	No. of otoliths	No. of fish	%
Columbia	—	169	0	—	—	—	—	—	—	—	—	—	—	—	—	—	169	0
Vancouver	—	3 220	0	—	2 712	0	—	819	0	54	650	8.3	—	—	—	54	7 401	0.7
Charlotte-Inside	1439	42 278	3.4	1468	58 566	2.5	1443	34 899	4.1	1686	24 038	7.0	166	1108	15.0	6202	160 889	3.9
Charlotte-Outside	448	10 298	4.4	144	7 875	1.8	240	5 500	4.4	26	1 992	1.3	178	641	27.8	1036	26 306	3.9
SEAK-Inside	1358	93 466	1.5	—	—	—	—	—	—	—	—	—	—	—	—	1358	93 466	1.5
SEAK-Outside	1063	28 109	3.8	—	—	—	—	—	—	—	—	—	—	—	—	1063	28 109	3.8
Area 2	4308	177 540	2.4	1612	69 153	2.3	1683	41 218	4.1	1766	26 680	6.6	344	1749	19.7	9713	316 340	3.1

1976): (1) the length frequency of the samples for each stratum is proportional to that of the total catch; and (2) a random subsample of otoliths for aging is taken from each length category. Generally, the number aged in each length category is either constant or proportional to the length frequency, although any random sample is sufficient for estimation. IPHC uses proportional selection. This sampling framework is known as two-stage or double sampling (Cochran 1963). A good treatment of age composition estimation is found in Kutkuhn (1963).

The estimated proportion of age k fish in length category j is

$$(3) \qquad \hat{\theta}_{ijk} = A_{ijk}/A_{ij}$$

where A represents the number of aged otoliths categorized by subscripts, and a lack of a subscript implies summation over the subscript. The estimated proportion of otoliths in length category j is

$$(4) \qquad \hat{\alpha}_{ij} = L_{ij}/L_i$$

where L is the number in the length sample categorized by subscripts. Then, the estimated proportion of age k fish is obtained by projecting the age distribution within length category to the total length frequency (Southward 1976), which results in

$$(5) \qquad \hat{\theta}_{ik} = \sum_j \hat{\alpha}_{ij}\hat{\theta}_{ijk} = \sum_j r_{ijk}$$

with estimated variance

$$(6) \qquad s^2(\hat{\theta}_{ik}) = \sum_j \hat{\alpha}_{ij}^2\hat{\theta}_{ijk}(1 - \hat{\theta}_{ijk})/(A_{ij} - 1) + \sum_j \hat{\alpha}_{ij}(\hat{\theta}_{ijk} - \hat{\theta}_{ik})^2/L_i = \sum_j \text{Var}(r_{ijk}).$$

The estimators $\hat{\theta}_{ijk}$, $\hat{\alpha}_{ij}$, and $\hat{\theta}_{ik}$ are unbiased (Quinn et al. 1983). Finally, total catch in numbers by age is estimated by

$$(7) \qquad \hat{C}_{ik} = \hat{C}_k\hat{\theta}_{ik}$$

with estimated variance from Goodman (1960)

$$(8) \qquad s^2(\hat{C}_{ik}) = \hat{C}_{ik}^2[\text{C.V.}^2(\hat{C}_i) + \text{C.V.}^2(\hat{\theta}_{ik}) - \text{C.V.}^2(\hat{C}_i)\text{C.V.}^2(\hat{\theta}_{ik})]$$

where C.V.^2 is the squared coefficient of variation. The last term in (8) is usually small and ignored.

The estimation of average weight by age can be constructed in similar fashion (Quinn et al. 1983), which results in an approximately unbiased, weighted average

$$(9) \qquad \hat{\overline{W}}_{ik} = \sum_j r_{ijk}\overline{W}_{ijk}/\hat{\theta}_{ik}$$

where $\overline{W}_{ijk}$ is the average of the predicted weights of otoliths in category ijk. The estimated variance from the delta method of an estimator $\hat{T} = \sum w_i T_i/\sum w_i$, where the w_i's and T_i's are both random variables, is

$$(10) \qquad s^2(\hat{T}) = \sum[w_i^2 s^2(\hat{T}_i) + (\hat{T}_i - \hat{T})^2 s^2(w_i)]/(\sum w_i)^2$$

(Quinn et al. 1983, appendix 1).

Hence, noting that $\hat{\theta}_{ik} = \sum r_{ijk}$, the estimated variance of $\hat{\overline{W}}_{ik}$ is

$$(11) \qquad s^2(\hat{\overline{W}}_{ik}) = \sum_j [r_{ijk}^2 s^2(\overline{W}_{ijk}) + (\overline{W}_{ijk} - \hat{\overline{W}}_{ik})^2 s^2(r_{ijk})]/\hat{\theta}_{ik}^2$$

where $s(\overline{W}_{ijk})$ is the typical standard error of the mean. In practice $\overline{W}_{ijk}$ is not a function of age in the prediction relationship and is replaced by $\overline{W}_{ij}$ in (9) and (11).

Combined-Strata Estimation

Project-and-Add

For this method, combined estimates are obtained by projecting to each stratum catch and adding over strata. Thus, total catch of age k fish is estimated by

$$(12) \qquad \hat{C}_k = \sum_i \hat{C}_i\hat{\theta}_{ik} = \sum_i \hat{C}_{ik}$$

(which weights each stratum's age composition by estimated catch numbers) with estimated variance

$$(13) \qquad s^2(\hat{C}_k) = \sum_i s^2(\hat{C}_{ik}).$$

Similarly, the estimated total catch in numbers is

$$(14) \qquad \hat{C} = \sum_i \hat{C}_i$$

with estimated variance

$$(15) \qquad s^2(\hat{C}) = \sum_i s^2(\hat{C}_i).$$

The estimated percentage of age k fish over strata is

$$(16) \qquad \hat{\theta}_k = \hat{C}_k/\hat{C} = \sum_i \hat{C}_i\hat{\theta}_{ik}/\hat{C}$$

with estimated variance, using the general equation (10),

$$(17) \qquad s^2(\hat{\theta}_k) = \sum_i [\hat{C}_i^2 s^2(\hat{\theta}_{ik}) + (\hat{\theta}_{ik} - \hat{\theta}_k)^2 s^2(\hat{C}_i)]/\hat{C}^2 = \hat{\theta}_k^2[\text{C.V.}^2(\hat{C}_k) + \text{C.V.}^2(\hat{C}) - 2\sum_i \hat{C}_i\hat{C}_{ik}\text{C.V.}^2(\hat{C}_i)/\hat{C}\hat{C}_k].$$

Estimated average weight of the catch is

$$(18) \qquad \hat{\overline{W}} = T/\hat{C}$$

with the same coefficient of variation as $\hat{C}$.

Average weight at age is estimated by weighting by catch numbers, or

$$(19) \qquad \hat{\overline{W}}_k = \sum_i \hat{C}_{ik}\hat{\overline{W}}_{ik}/\hat{C}_k$$

with estimated variance, using the general equation (10),

$$(20) \qquad s^2(\hat{\overline{W}}_k) = \sum_i [\hat{C}_{ik}^2 s^2(\hat{\overline{W}}_{ik}) + (\hat{\overline{W}}_{ik} - \hat{\overline{W}}_k)^2 s^2(\hat{C}_{ik})]/\hat{C}_k^2.$$

The estimators are approximately unbiased for a large sample size, because each component is approximately or exactly unbiased.

Add-and-Project

For this method, estimates are obtained by pooling ("adding") all samples together across strata and projecting to the total of all strata, which essentially treats the data as coming from a single stratum. Thus, the estimation framework for add-and-project is the same as that for within-stratum estimation deleting the stratum subscript i.

The add-and-project estimates are biased in general, but under certain conditions derived in Quinn et al. (1983), they are approximately unbiased. The estimator of catch numbers (C^*) is approximately unbiased, if either average weight or the sampling rate of otoliths (in the first stage) is the same for all strata. The pooled proportion of otoliths (α_j^*) is unbiased for the true proportion of the catch in each length category j if either the length-frequency distribution or the sampling rate of otoliths is the same for all strata. The pooled proportion of otoliths of age k within length category j (θ_{jk}^*) is unbiased if the distribution of ages within each length category is the same for all strata. The estimated proportion of age k fish (θ_k^*) is unbiased only if both α_j^* and θ_{jk}^* are unbiased. Furthermore, the amount of bias in add-and-project estimates is a function of differences between strata and deviations from the sampling rate.

Comparison of Methods

The project-and-add method produces nearly unbiased estimators, assuming that all strata are sampled. In practice, some strata may not be sampled or may not have large sample sizes. These problems are unimportant as long as strata with large catches have large sample sizes, because project-and-add estimators are weighted by catch. The add-and-project method produces biased estimators, but they may be less variable than project-and-add estimators because of the pooling. The add-and-project estimator of the proportion of age k fish θ_k^* requires no information on catch numbers in contrast to project-and-add, which may be desirable if catch sampling data are processed before landing data (as is true for IPHC). The trade-offs in bias and variability between the two methods can be best addressed in application to data.

Precision of Combined Strata Estimates

If the coefficient of variation for catch at age is set below a prescribed limit P for each stratum, then general results can be derived for the C.V. of the combined-strata estimate using project-and-add methodology. The add-and-project estimate is generally more precise than the limits established below because of data pooling. From equation (13) and assuming $\text{C.V.}^2(\hat{C}_{ik}) \leq P^2$:

$$\begin{aligned} \text{C.V.}^2(\hat{C}_k) &= \sum_i s^2(\hat{C}_{ik})/\hat{C}_k^2 \\ &= \sum_i \hat{C}_{ik}^2 \text{C.V.}^2(\hat{C}_{ik})/(\sum_i \hat{C}_{ik})^2 \qquad (21) \\ &\leq [\sum_i \hat{C}_{ik}^2/(\sum_i \hat{C}_{ik})^2]P^2 \leq P^2, \end{aligned}$$

because a sum of squares is less than a square of sums of non-negative terms. Thus, the precision of a combined-strata estimate is always greater or equal to the precision set for a stratum, with equality if and only if the catch comes from a single stratum.

Furthermore, the Cauchy-Schwarz inequality yields

$$(\sum_i \hat{C}_{ik})^2 \leq S \sum_i \hat{C}_{ik}^2$$

where S is the number of strata, and assuming $\text{C.V.}(\hat{C}_{ik}) = P$ in (21), the following lower bound is obtained:

$$P^2/S \leq \text{C.V.}^2(\hat{C}_k)$$

with equality if and only if $\hat{C}_{ik}$ is the same for all strata. Thus, the C.V. of a combined-strata estimate may be as low as $P/\sqrt{S}$ for an individual stratum C.V. of P. For example, the combined C.V. is one-half of individual C.V.'s for four strata with equal catches at age.

Application to Pacific Halibut

The analysis of age composition data is illustrated by use of data from regions in regulatory area 2 (Fig. 1) in 1980. Auxiliary studies (Quinn et al. 1983) with Pacific halibut data show differences in sampling rates, length frequency, and age distribution within length category between months and regions. Three methods of combining data based on project-and-add and add-and-project methodology are used:

1. Project-and-add over months and regions (project-and-add method);
2. Add-and-project over months within region, project-and-add over regions (combined method);
3. Add-and-project over months and regions (add-and-project method).

The ordering represents an increasing amount of data pooling. The first two methods have missing data in some month-region strata; a missing data algorithm has been developed to fill in strata (Quinn et al. 1983).

Estimates of average weight from the three methods for 1980 area 2 data are 27.43 lb (C.V. 0.0086), 27.70 lb (C.V. 0.0086), and 28.11 lb (C.V. 0.0080). The add-and-project estimate is significantly different from the project-and-add estimate ($P = 0.04$). The apparent reason for the differences is that the region SEAK-Inside was undersampled in 1980 (Table 2) and had a relatively small average weight. Hence, the add-and-project estimate is biased upward, which results in an underestimate of the number of fish in the catch. Data from other years and areas show that the add-and-project method has the lowest C.V. because of data pooling, followed by the combined and project-and-add methods.

Age composition estimates from the three methods are shown in Fig. 3 and C.V.'s are shown in Fig. 4. Estimates for the three methods are very close, except for ages 7–11, which unfortunately, represent the bulk of the catch. The C.V.'s for the bulk of the catch are lowest for the add-and-project method, followed by the combined method and then the project-and-add method, although differences in

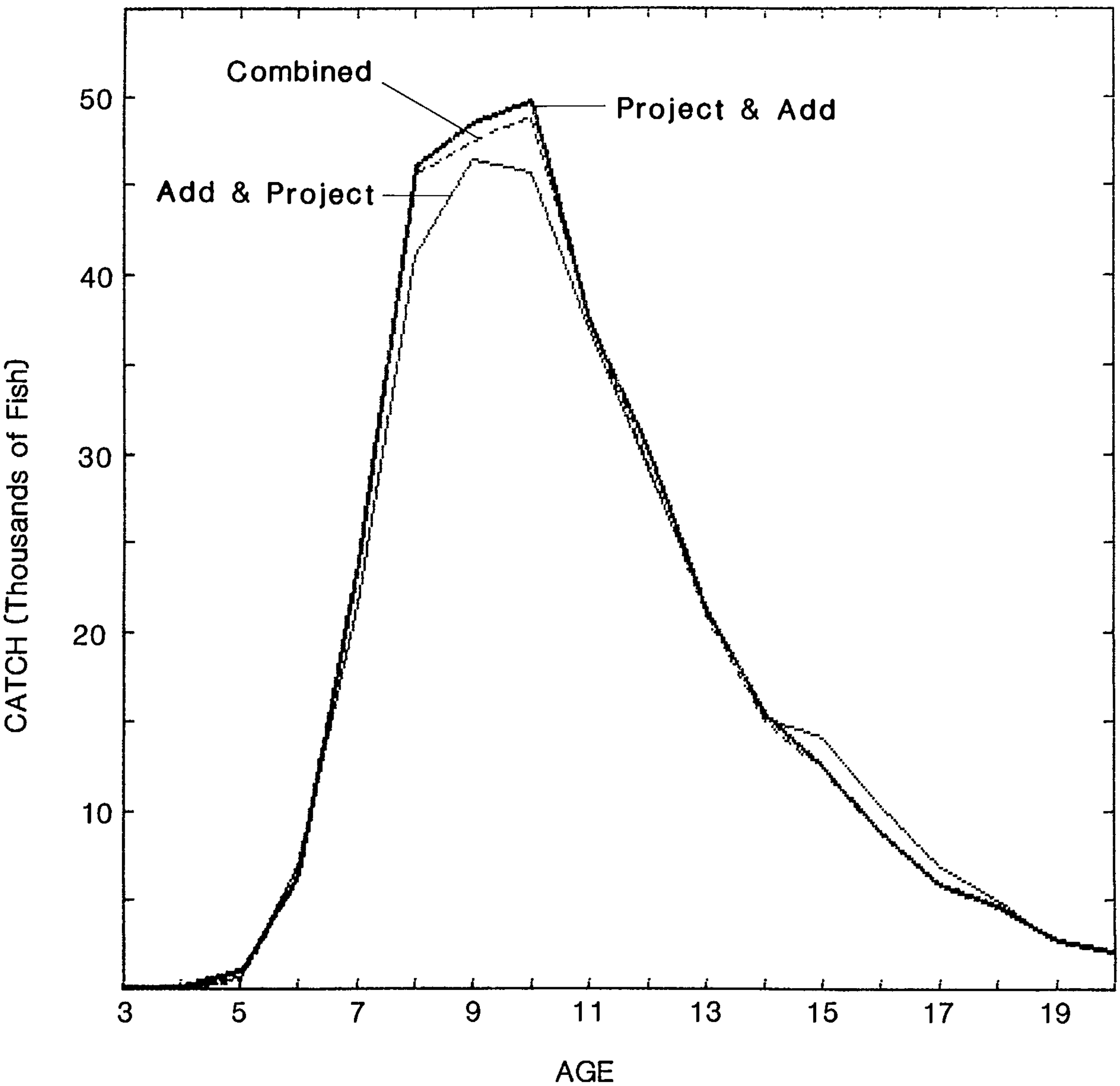

FIG. 3. Estimated catch at age for area 2 in 1980 using three methods of combining data.

C.V.'s between methods are not large. These trends are generally true for other areas and years (Quinn et al. 1983). Estimates of average weight at age have the same order of precision as estimates of catch at age.

These results suggest that it makes little practical difference which method is used to estimate age composition. Most of the catch across months and regions is sampled adequately, and although the samples are not taken in exact proportion to landings, the discrepancies are not large. Theoretical considerations favor the project-and-add method, because it produces unbiased estimates without substantial increase in variability as compared to the other two methods. However, it is desirable to specify minimum sample size requirements to ensure control of variability, which is the subject of the next section. Because average weight may increase during the season and because age and length distributions may de different between strata, age composition discrepancies may occur in combining data with the combined method or the add-and-project method. The project-and-add method provides a safeguard against these problems.

Sample Size Requirements

Average weight of the commercial catch is predicted from all otoliths collected from port sampling. Several

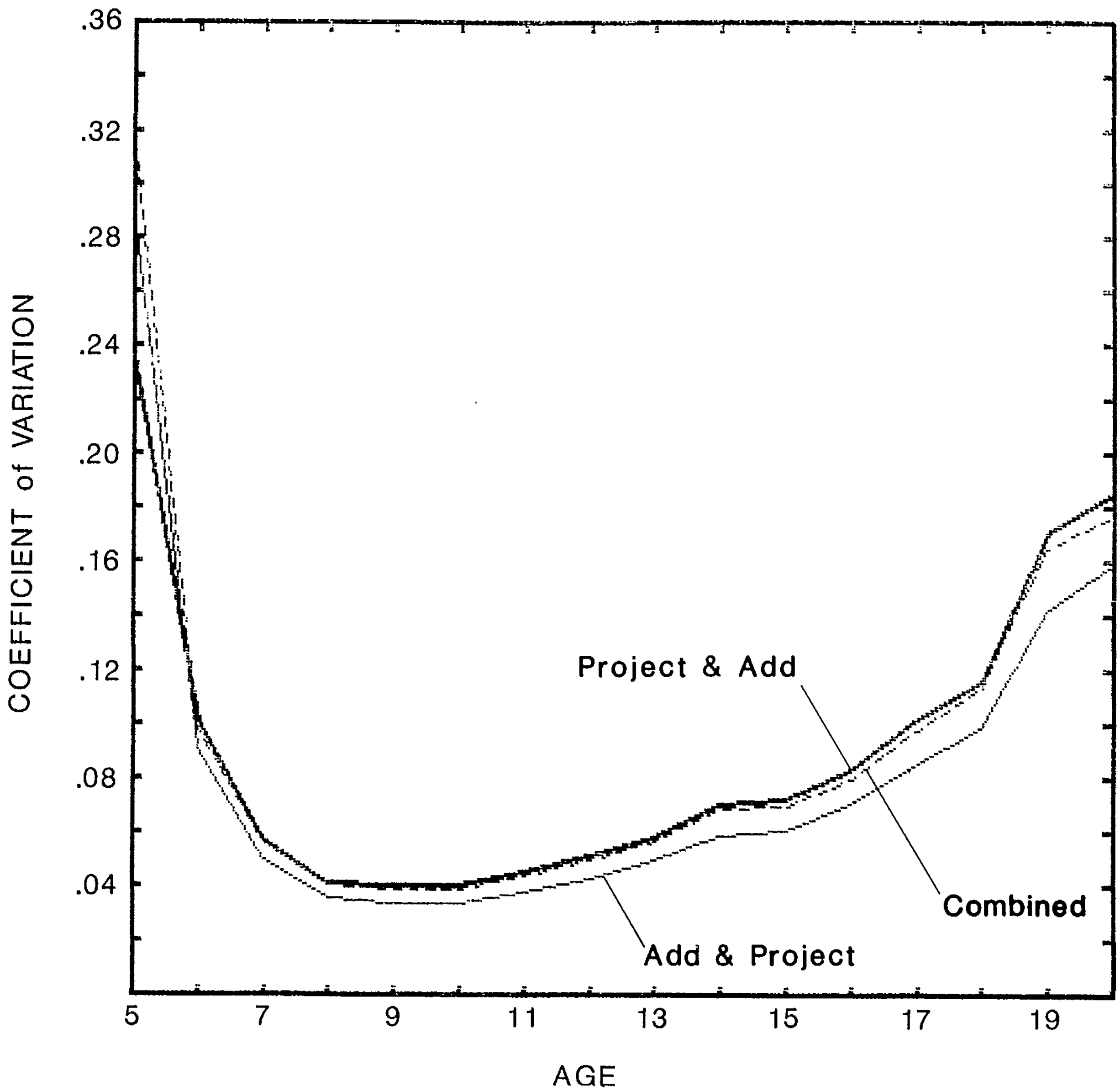

FIG. 4. Coefficients of variation of catch at age for area 2 in 1980 using three methods of combining data.

thousand otoliths are collected each year, which means that the C.V. of estimated average weight is generally small. For all month–region strata between 1975 and 1980, estimates of average weight and C.V. were calculated, and C.V. is plotted versus number of otoliths (L_i) in Fig. 5. A few sample sizes greater than 3000 otoliths were not plotted and their C.V.'s were under 1%. Precision increases as sample size increases. The C.V. is under 5% when over 200 otoliths are collected, which is true of most strata. However, the variance component for predicting weight is not included, so that the C.V.'s are underestimates of true C.V.'s.

To assess precision of catch at age estimates, estimates $\hat{C}_{ik}$ and C.V.($\hat{C}_{ik}$) were calculated for all strata between 1975 and 1980. The age with the lowest percentage of the catch above 5% was isolated for each stratum and its C.V. is plotted versus the number of otoliths aged (A_i) in Fig. 6. The lower limit of 5% is used as a benchmark of important ages in the catch because C.V. goes to infinity as the percentage goes to zero. The C.V. declines sharply as the aging sample size increases. The variability in C.V. stabilizes at 250 otoliths aged, which sets C.V. to under 25%. When more than 600 otoliths are aged, C.V. is generally under 17%. These results suggest that a minimum

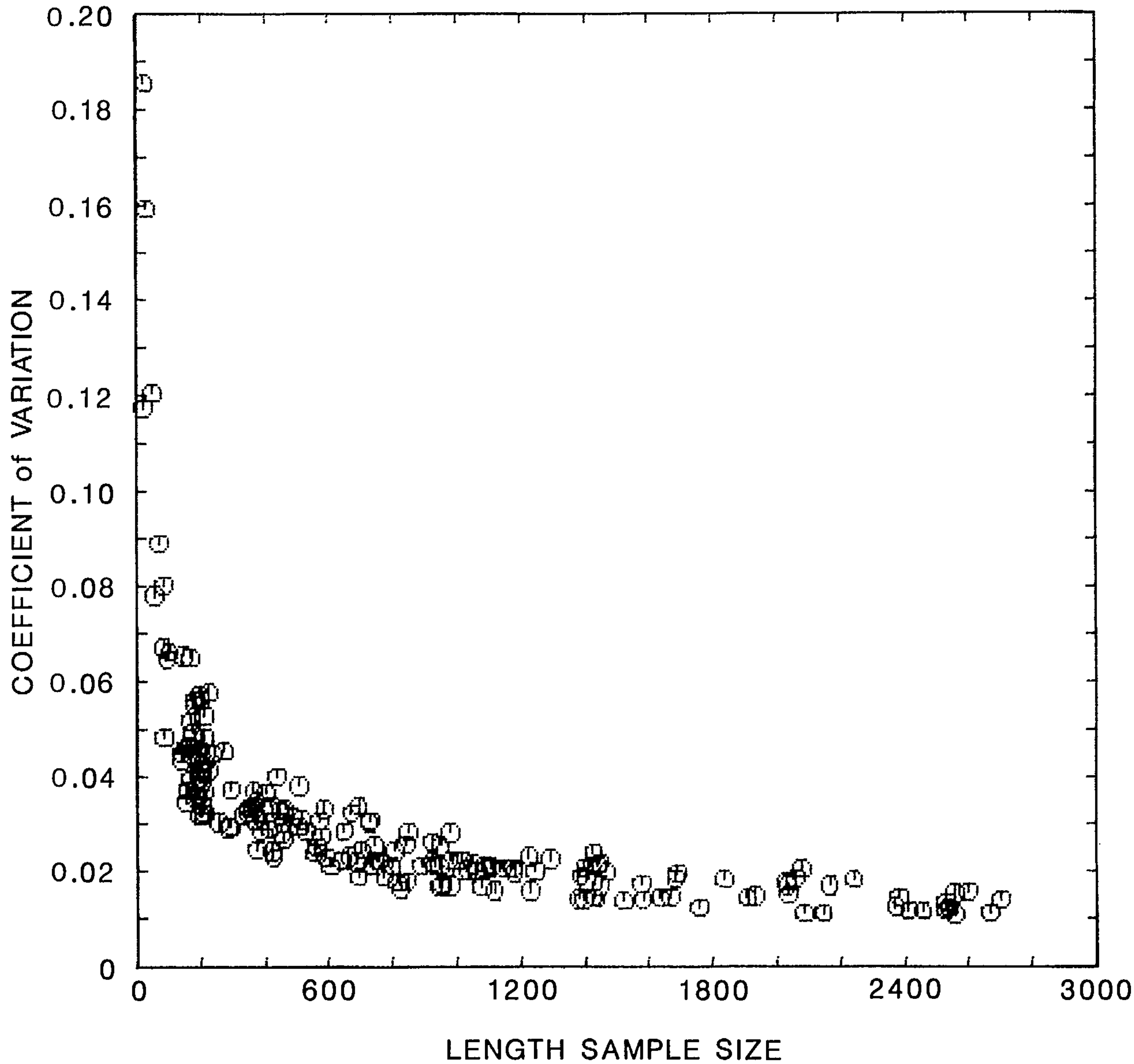

FIG. 5. Coefficients of variation of average weight versus length sample size for month-region strata, 1975–80.

of 250 otoliths is needed to define age composition of the catch in a stratum.

There are formulae for determining the size of the subsample of otoliths to be aged to achieve a specified level of precision given a fixed sample size of otoliths. One formula is based on the assumption that the age subsample is taken proportionally to the length sample, which is true for the IPHC aging system. From Kutkuhn (1963), the C.V.^{2} of the estimated proportion θ_{ik} of age k fish in stratum i from (6) can be rewritten

$$\text{(22)} \qquad \text{C.V.}^2(\hat{\theta}_{ik}) = (W_{ik}/A_i + B_{ik}/L_i)/\hat{\theta}^2_{ik}$$

where W_{ik} and B_{ik} are within- and between-length category variances, respectively. For a specified C.V. the required age sample size by solving (22) for A_i is

$$A_i = W_{ik}/(\hat{\theta}^2_{ik}\text{C.V.}^2 - B_{ik}/L_i).$$

The larger the length sample is, the smaller need be the aging sample, although the relationship is not linear. Using several values for the length sample size, the minimum length sample size which requires complete aging is found. In application to Pacific halibut data, increasing the length sample size above this minimum value does not

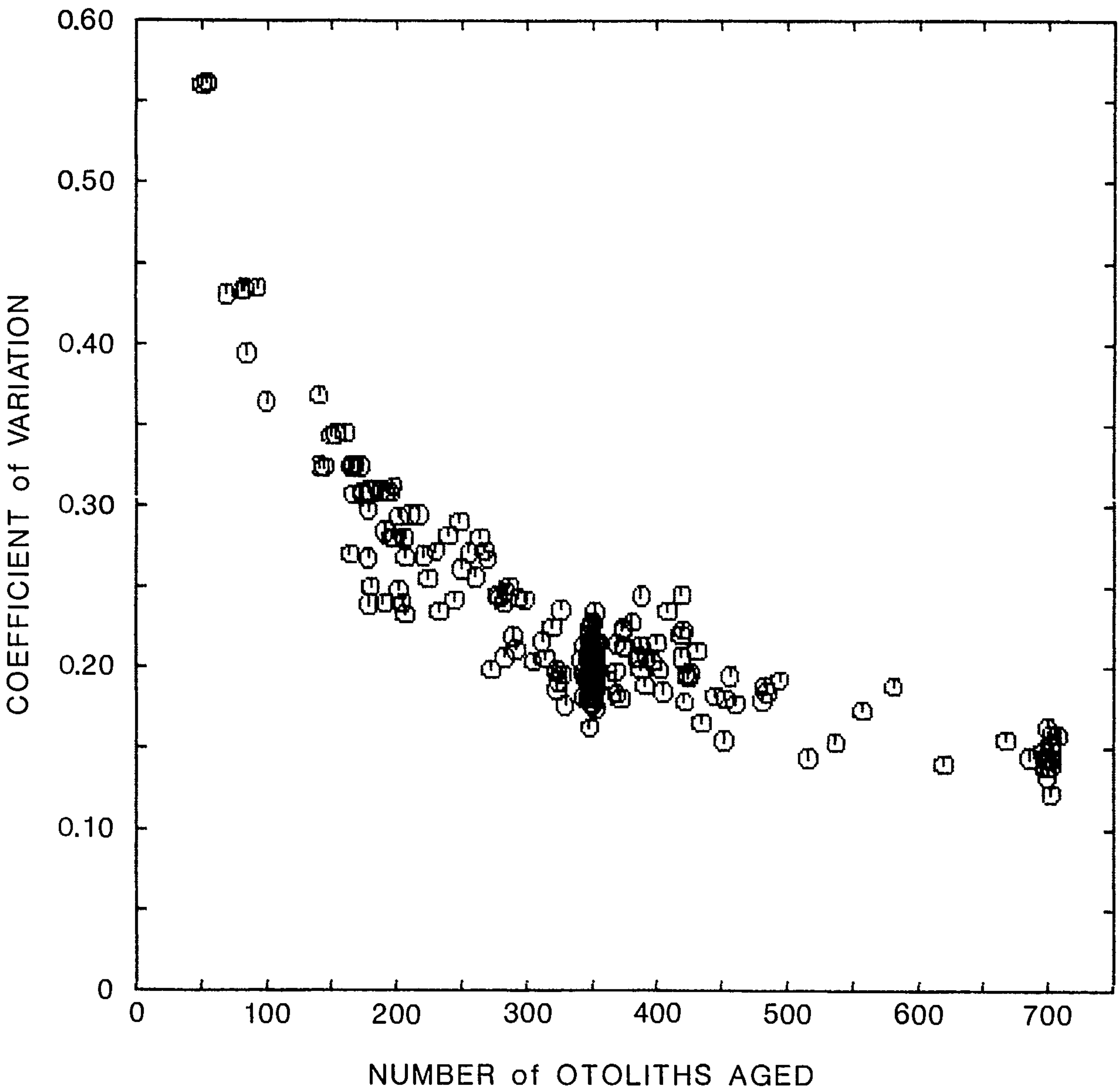

FIG. 6. Coefficients of variation of catch numbers for the age with the lowest percentage of the catch above 5% versus number of otoliths aged for month–region strata, 1975–80.

substantially decrease the subsample size for aging, because B_{ik} is generally negligible.

Four criteria are used to find the sample size necessary to achieve an acceptable level of precision of the age composition estimates:

Criterion 1: Ensure that at least one age achieves a coefficient of variation of 10% or less.

Criterion 2: Ensure that all ages between 8 and 15, inclusive, achieve a coefficient of variation of 20% or less.

Criterion 3: Ensure that all ages that make up at least 0.1% of the catch achieve a coefficient of variation of 50% or less. This criterion ensures that the age composition estimates are significantly different from zero.

Criterion 4: Ensure that each age that makes up at least 5% of the catch achieves a coefficient of variation of 20% or less. This is a modification of Criterion 2 to adjust for differences in age composition.

The levels of precision in the criteria are arbitrary but provide a useful standard for evaluating the sampling program.

The necessary sample sizes to achieve these four criteria are shown in Table 3 for strata sampled in 1980. About 500–600 otoliths are needed to achieve Criterion 1 and about 400–500 are needed to achieve Criterion 4. The sample sizes needed to achieve the other two criteria are quite variable between strata, because the coefficient of variation is unstable for small percentages. The median

TABLE 3. Sample size requirements to achieve four criteria, landings, and actual length and age sample sizes for month-region strata sampled in 1980.

Month	Region[b]	Sample size[a] to achieve: Criterion 1	Criterion 2	Criterion 3	Criterion 4	Landings (thousands of lb)	L_i Length sample	A_i Age sample
4	11	600	1100	3000	500	84	1116	702
4	12	800	2200	—	500	74	814	699
5	3	600	400	1000	500	311	448	448
5	4	500	1500	800	500	1002	1439	698
5	5	500	1300	500	500	2346	1358	696
5	6	600	300	600	500	981	1063	701
5	7	500	600	3000	400	4848	5588	702
5	8	500	800	3100	400	4518	3414	699
7	3	600	600	200	400	208	144	144
7	4	500	600	2000	400	1498	1468	698
7	7	600	400	1400	400	1175	925	701
7	8	500	700	500	400	1393	889	702
8	3	700	700	500	500	189	240	240
8	4	600	600	400	400	979	1443	698
8	11	800	3400	700	500	209	456	456
8	12	900	2300	200	500	50	167	167
9	2	1000	—	200	—	23	54	54
9	3	—	—	—	—	95	26	26
9	4	500	800	400	500	611	1686	702
11	3	500	600	800	400	22	178	178
11	4	600	—	700	500	44	166	166

[a] "—" means that sample size cannot be computed from data.
[b] 2: Vancouver, 3: Charlotte-Outside, 4: Charlotte-Inside, 5: SEAK-Inside, 6: SEAK-Outside, 7: Yakutat, 8: Kodiak, 11: Aleutian, 12: Bering Sea.

value over strata for both of these criteria is 700. Overall, the sample size required for a month-region stratum to achieve these four criteria is 600.

The required sample sizes are compared to the actual length and age sample sizes in Table 3. Month-region strata with large landings have large sample sizes and vice versa. Generally, the sample sizes are sufficient to meet the criteria because in 1980, the number of otoliths aged was increased from 350 to 700 based on sample size requirements from the previous year's data. Some strata had under 250 otoliths available, but these generally had small landings. These strata are pooled with adjacent strata until the 250 otolith limit is obtained; otherwise, estimates from other strata are used. In 1981, the sample size was reduced to 600 otoliths per stratum based on sample size requirements shown in Table 3.

Discussion

IPHC's sampling program is evaluated in two stages. First, the design of the sampling program is reviewed to ensure that sampling is representative of the bulk of the catch. Factors considered at this stage include selection of ports, vessel sampling rate, trip size, trip date, and systematic sampling within trips, details of which were reported earlier.

The second stage is the statistical analysis of age composition data. Data are pooled into month-region strata and approximately unbiased estimates of catch numbers, catch at age, and weight at age are obtained using methods outlined above. The sampling rate selected in the first stage is chosen to have sufficient sample sizes for the length sample and age subsample in each stratum. A sample size of 600 otoliths for aging in each stratum ensures that the coefficient of variation of catch at age for the important ages is under 20%. Project-and-add methodology is used to build estimates for regions and regulatory areas from individual strata. The project-and-add estimators of catch at age are additive across strata and hence unbiased. The precision of the combined-strata estimators is generally much greater than the individual stratum estimators.

The distinctive feature of IPHC's sampling program is the use of otoliths for aging and predicting individual length and weight of aged fish from otolith weight. The accuracy of the predictions most strongly influences estimates of total catch numbers and average weight at age. Periodic evaluation of the accuracy of the predictive relationships is necessary to ensure the accuracy of estimation. Relative age composition estimates are not affected by the predictive relationships, because the predicted length is used only as a stratification variable. Because fish length and otolith weight have a 1-1 correspondence, stratification on either variable produces identical results, except that classes may be defined differently in the extremes of the distributions. However, potential errors in aging can affect relative age composition estimates. Preliminary studies suggest that aging errors are not large for Pacific halibut, although further verification is being conducted.

The age composition and average weight estimates play a prominent role in IPHC's qualitative and quantitative assessment of the halibut population. In particular, cohort analysis and related variants use the catch-age estimates to estimate population numbers and age structure. These estimates and average weight at age estimates are then used to estimate population biomass and annual surplus production. The third stage of IPHC's evaluation of catch-age data is an analysis currently in progress of the sensitivity of the estimates of surplus production to age-structured models and estimates. The completion of this stage will establish a link of quality from initial data collection to final evaluation of population condition.

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Use of Length and Age Data for Estimating the Age Structure of a Collection of Fish

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FOURNIER, D. A. 1983. Use of length and age data for estimating the age structure of a collection of fish, p. 206–208. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

A method is presented for using length-frequency data together with length and age data from a collection of fish to estimate the proportions of fish at age in the collection. The relative merits of aging random and stratified samples are compared. It is concluded that for the situation considered here, stratified sampling is superior.

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Le présent rapport décrit une méthode permettant d'estimer les pourcentages de poissons à un âge donné dans l'échantillon à partir des données sur la fréquence des longueurs combinées aux données relatives à l'âge et à la longueur d'un ensemble de poissons. On compare la valeur relative de la détermination de l'âge des poissons dans des échantillons prélevés au hasard ou stratifiés et l'on conclut que, pour la situation étudiée, l'échantillonnage stratifié est préférable.

Introduction

The attempt to use length-frequency modes to identify distinct age groups in a population dates back to Peterson (1892). Because of the computational difficulties inherent in such analysis, a statistically rigorous solution to the general problem could not be obtained before the advent of modern computers. Hasselblad (1966) described such a method. More recently, MacDonald and Pitcher (1979) and Schnute and Fournier (1980) showed how variations of Hasselblad's methods could be applied to the analysis of fish length-frequency data.

When using the above methods, it is always advisable to age a small sample of the fish when possible to determine the number of age-classes present in the sample or to avoid gross errors such as misaging all the fish by 1 yr.

Since it is advisable to obtain this information in any case, it is reasonable to incorporate it in a statistically rigorous manner into the entire estimation procedure. This practice has several advantages. First, the best use is made of the information contained in all the available data. Second, it is possible to compare the relative merits of different sampling procedures for obtaining the aging data. Two such sampling procedures which could be used are random sampling of the collection and sampling that is stratified by length.

The purpose of this paper is to demonstrate how the information from the sampling procedures can be incorporated into the overall estimation procedure and compare their relative merits in a particular case.

Description of the Model

In a population with M age-classes, let m_i, t_i, and p_i denote respectively the mean length, standard deviation in length, and proportion of the fish in the ith age-class. Suppose that when a fish is measured, its length is determined to lie in one of the N length intervals

$$(x_{j-w/2}, x_{j+w/2}); \qquad j = 1, \ldots, N;$$

where

$$x_j = x_1 + (j-1)w$$

is the midpoint of the ith interval and every interval has width w.

Let q_{ij} be the probability that a fish from age-class i has a length lying in length interval j. In terms of the q_{ij} and the p_i we define several probabilities which will be of use in the following discussion.

$p_i q_{ij}$ is the probability that a fish picked at random belongs to age-class i and has a length lying in length interval j.

$Q_j = \sum_{i=1}^{M} p_i q_{ij}$ is the probability that a fish picked at random has a length lying in length interval j.

$p_i q_{ij}/Q_j$ is the probability that a fish picked at random from those fish whose lengths lie in length interval j will belong to age-class i.

Description of the Sampling Procedure

To collect the data for the model, a total of three different kinds of samples — any one of which may in principle be empty — will be taken from the catch. They are: (1) random sample for which only lengths are taken; (2) random sample for which lengths and ages are taken; and (3) sample stratified by length for which ages are taken.

It is assumed that these three samples are independent of each other. Since the sampling is done from a finite population without replacement, the model assumptions are not strictly satisfied. The deviation from model assumptions are small, however, and should not cause trouble except in one case.

The stratified sample must not be a subsample of the length-frequency sample. However, if the stratified sample used must be a subsample of the length-frequency sample, the likelihood function used in the model could easily be modified to take this into account.

Let f_j be the number of fish from sample (1) whose lengths lie in the jth length interval, r_{ij} be the number of fish from sample (2) belonging to age-class i whose lengths lie in the jth length interval, and s_{ij} be the number of fish in sample (3) picked from length interval j which belong to age-class i.

Description of the Log-Likelihood Function

It follows from the above discussion that the log-likelihood function for the above samples is given by expression (1) which consists of three parts labeled as (1.1), (1.2), and (1.3).

$$(1.1) \qquad \sum_j f_j \log_e(Q_j)$$

$$(1.2) \qquad + \sum_{i,j} r_{ij} \log_e(p_i q_{ij})$$

$$(1.3) \qquad + \sum_{i,j} s_{ij} \log_e(p_i q_{ij}/Q_j)$$

If any sample is empty, the corresponding part of the log-likelihood function is ignored.

Incorporating the Parametric Assumptions

The unrestricted maximum likelihood estimates p_i and q_{ij} for the age structure are found by maximizing expression (1) for the unknown parameters p_i and q_{ij}. There are $M - 1$ p_i's (they must sum to 1) and MN q_{ij}'s or a total of $M - 1 + MN$ parameters in all. It is possible to solve this problem, but the presence of such a large number of parameters requires that the number of fish aged be rather large to obtain useful estimates of the p_i's. Since we are interested in properties of these estimates for small aging samples, this "nonparametric" form of the model will not be considered further; instead we shall introduce three assumptions which will reduce the number of parameters in the model. The assumptions are: (1) for each age-class the lengths are normally distributed around their mean length; (2) the standard deviations t_i are a quadratic function of age-class, so that

$$t_i = a + bi + ci^2$$

where a, b, and c are unknown parameters determining the quadratic relationship; and (3) the mean lengths m_i are themselves normally distributed around an unknown von Bertalanffy curve with standard deviation σ.

Assumption (1) implies that

$$q_{ij}(m, t) = 1/(\sqrt{2\pi}t_i) \int_{x_j - w/2}^{x_j + w/2} \exp(-1/2(x - m_i)^2/t_i^2)\, dx$$

where we have written $q_{ij}(m, t)$ to emphasize that the MN parameters q_{ij} now depend only on the $M + 3$ parameters $m_1, \ldots, m_N, a, b$, and c.

Assumption (2) is included here to illustrate how additional structure can be included into the model. The reader who is uncomfortable with this assumption should be assured that it can easily be modified if desired.

Assumption (3) was first discussed in Foucher and Fournier (1982). It represents a relaxation of the assumption in Schnute and Fournier (1980) where it was assumed that the mean lengths actually lie on an unknown von Bertalanffy curve.

The adoption of assumption (3) has the effect of adding an extra term to the log-likelihood function, expression (1.4) given by:

$$(1.4) \qquad -M \log_e(\sigma) - \sum_{i=1}^{M} [m_i - L_1 - (L_M - L_1)(1 - k^{i-1})/(1 - k^{M-1})]^2/2\sigma^2$$

where $k = \exp(-K)$, K representing the usual quantity in the von Bertalanffy growth curve (von Bertalanffy 1938). This parameterization of the von Bertalanffy curve in terms of L_1, L_M, and k rather than the conventional L, K, and t_0 is discussed in Schnute and Fournier (1980).

Maximizing the Log-Likelihood Function

The log-likelihood function for the problem consists of the terms 1.1–1.4. It depends on the parameters p_i, a, b, c, m_i, L_1, L_M, k, and σ. The parameter σ was not estimated but was set equal to 1. The log-likelihood function was maximized with respect to the other parameters by using a quasi-Newton method, a subroutine FMIN supplied by the computing center of the University of British Columbia.

Description of the Simulated Data

In order to compare the merits of random and stratified sampling, two groups of simulations were performed. Each group consisted of three sets of simulations consisting of 100 simulations of data for length frequencies alone, length frequencies with random sampling for age, and length frequencies with stratified sampling for age. In all cases, the length frequencies were generated by simulating a random

TABLE 1. Summary of results of first and second groups of simulations.

	Group 1						Group 2					
Set 1 No aging information												
estimated proportions	0.21	0.31	0.24	0.13	0.02	0.09	0.17	0.21	0.32	0.15	0.05	0.09
Standard deviation of estimated proportions	0.05	0.04	0.05	0.05	0.03	0.03	0.04	0.07	0.05	0.07	0.04	0.04
Mean of estimated standard deviations	8.12	7.82	7.42	7.00	6.57	6.14	7.19	7.05	7.04	7.04	7.06	7.08
Set 2 Random aging												
estimated proportions	0.20	0.38	0.25	0.07	0.05	0.04	0.20	0.39	0.23	0.07	0.05	0.04
Standard deviation of estimated proportions	0.03	0.04	0.04	0.03	0.04	0.03	0.03	0.06	0.06	0.03	0.02	0.02
Mean of estimated standard deviations	8.48	9.03	8.44	7.67	6.79	5.85	8.60	9.04	8.53	7.87	7.13	6.33
Set 3 Stratified aging												
estimated proportions	0.20	0.39	0.25	0.07	0.06	0.03	0.22	0.41	0.23	0.07	0.05	0.03
Standard deviation of estimated proportions	0.03	0.04	0.04	0.03	0.02	0.01	0.04	0.06	0.06	0.03	0.02	0.01
Mean of estimated standard deviations	8.31	9.24	8.53	7.55	6.43	5.23	8.61	8.73	8.24	7.58	6.90	6.18

sample of 500 fish, and the aging data by simulating the appropriate sample of 25 fish.

The simulated data were generated for a hypothetical population consisting of six age-classes. The mean lengths of the age-classes were 20, 45, 65, 80, 90, and 95 for the first group of simulations, and 20, 46, 62, 80, 87, and 95 for the second group of simulations. In all cases, the standard deviations for the distribution of the lengths around their means were 9, 10, 9, 8, 7, and 6. The proportions of each class present in the sample were 0.20, 0.40, 0.25, 0.07, 0.05, and 0.03.

For both groups of simulations, the mean lengths do not lie exactly on a von Bertalanffy curve, and the standard deviations do not exactly follow a quadratic trend. The mean lengths for the first group deviate only slightly from a von Bertalanffy growth pattern, while those of the second group deviate substantially from a von Bertalanffy growth pattern. This was done to investigate the model's robustness with respect to deviations from these hypotheses.

Conclusion

The results from the first group of simulations are summarized in Table 1.

With no aging data, there is a strong negative bias in the estimate for the proportion corresponding to the second age-class. This appears to be due to the inability of the model to detect the curvature in the trend of the standard deviations.

The estimates for the first two age-classes are very similar for both the random and stratified samples. It is evident, however, that the stratified sampling procedure performs significantly better for the last two age-classes as indicated by the smaller standard deviation of these estimates.

The superiority of the stratified sampling procedure seems to be due to the fact that the random sample picks too many younger fish. For these fish the length separation alone provides good information as to their age. It is necessary to use a stratified sampling procedure to obtain enough information about the length at age of the older fish for which the length separation is poor.

The results for the second group of simulations are also summarized in Table 1. As would be expected, the results are slightly poorer than the corresponding results for the first group as indicated by the larger standard deviations of the parameter estimates. The only qualitative difference is that it is now not clear whether the random sample or the stratified sample of aged fish produces better estimates. It remains clear, however, that aging of some kind produces a marked improvement in the estimates obtained.

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The Sampling Program for Herring and Capelin in Newfoundland

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The sampling performance of the domestic herring and capelin fisheries in the Newfoundland region, 1975–81 is reported, as compared to the recommended NAFO (formerly ICNAF) minimum requirements. Although the type of samples collected from these fisheries did not always correspond to the recommended type, the herring and capelin fisheries appear to be reasonably well sampled, especially when the relatively small and diffuse nature of the fisheries is considered.

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Le présent rapport porte sur le succès de l'échantillonnage des prises canadiennes de hareng et de capelan dans la région de Terre-Neuve de 1975 à 1981, par rapport aux exigences minimales recommandées par l'OPANO (anciennement CIPANO). Quoique le genre d'échantillons recueillis de ces pêches ne corresponde pas toujours au genre recommandé, les pêches du hareng et du capelan semblent être assez bien échantillonnées, surtout quand on considère la nature restreinte et diffuse de ces pêches.

Introduction

There are two major fisheries for pelagic species in the Newfoundland area — the herring and capelin fisheries. Although both fisheries have been in existence for a number of years, it has been only within the last decade that the fish stocks supporting the fisheries have been scientifically assessed and the fisheries formally managed. To properly assess the status of these stocks it is necessary to sample adequately the catches from the fisheries. This paper presents an assessment of the sampling "performance" related to the Canadian herring and capelin fisheries in the Newfoundland region, 1975–81.

Methods

We have assessed the performance of the commercial sampling of the herring and capelin fisheries in the Newfoundland area using the minimum sampling requirements recommended by NAFO (formerly ICNAF) as a baseline; this recommended minimum requirement is one sample of 200 fish for length-frequency analysis per 1000 t of catch per NAFO division per gear type per quarter. Therefore, performance estimates <1 indicate that the minimum requirement was not met, while estimates ≥ 1 indicate that the minimum requirement was met or exceeded. The actual samples taken from both the herring and capelin fisheries have not always corresponded to the minimum of 200 fish suggested by NAFO; however, this is explained in the appropriate species section.

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Results

HERRING

Herring fisheries have been conducted in Newfoundland waters for centuries both for food and bait purposes. The level of annual landings has been highly variable due to the influences of availability of the resource and market conditions. Intensive research into the biology and population dynamics of the Atlantic herring (*Clupea harengus harengus*) in the Newfoundland area by the Department of Fisheries and Oceans, St. John's, coincides with the boom in the Newfoundland herring fishery in the mid-1960s. This boom was created by two key factors: (1) a failure of the British Columbia herring fishery, and (2) the recruitment of two extremely large year-classes into the Gulf of St. Lawrence herring stocks. This led to the development of an intensive meal fishery during the winter along the southwest coast of Newfoundland and during the summer in the southern Gulf of St. Lawrence. To support this fishery a large purse-seine fleet was formed. As the abundance of herring declined, the thrust of the fishery switched from meal to food processing, and a reduction in the overall size of the purse-seine fleet occurred. Concurrent with the decline in the Gulf fishery there was an increased demand for food herring such that during the 1970s, there was a major expansion of herring fisheries along the west and southeast coasts of Newfoundland and finally on the east coast of Newfoundland. With increased demand came increased prices to the fishermen such that rather than being primarily a purse-seine fishery, it encompassed several gear types including ring nets, gill nets, bar seines, traps, etc.

Research on herring generally paralleled the development of the commercial fisheries. The southwest and southeast coasts of Newfoundland were the first to be intensively examined and they were placed under management control in 1973; these regulations also applied to part of the west coast of Newfoundland. However, in 1977, the west coast of Newfoundland management area was created, separate from the southern Gulf of St. Lawrence. The east coast of Newfoundland was first assessed and placed under management in 1976.

In the following analyses the data have been combined into three geographic areas rather than NAFO divisions: (1) west coast (Cape Bauld to Cape Anguille), (2) southeast coast (Cape Race to Pass Island), and (3) east coast (Cape Bauld to Cape Race). While the west coast represents a distinct management area, the southeast coast encompasses two stock areas and the east coast, four stock areas. The fishery along the southwest coast of Newfoundland was based on the southern Gulf of St. Lawrence herring stock and was sampled intensively by the Newfoundland region. This fishery has not been significant since the early 1970s, with the main fishery occurring in the southern Gulf of St. Lawrence where the responsibility for sampling is held by the maritime region. This area therefore has not been included here. For consistency in examining sampling performance, 1975–81 was selected as this period corresponds to the expansion in the fishery along the east and west coasts of Newfoundland.

The Pelagic Section of Fisheries Research Branch, St. John's, has been solely responsible for the collection of herring samples in the Newfoundland area. The nature of herring fisheries in Newfoundland is such that they tend to occur simultaneously in all areas, for example, during the spring on prespawning concentrations. As insufficient research personnel are available to cover all areas, a system of collectors has been developed in conjunction with field sampling. These are generally plant personnel who with the approval of plant managers collect samples from the commercial fishery and store them in a frozen state for pickup at a later date. Besides plant personnel, bait depot operators or fisheries officers act as collectors in particular areas. Deep freezers are provided in areas where no freezing facilities are available. These collectors are instructed as to the proper manner of sample collection and the level of sample collection required.

In all cases, the type of sample collected is a random sample consisting of 50 fish each. The random sample is more suitable to the logistics of the Newfoundland situation than a stratified sampling scheme due to its ease of collection and handling for storage, thereby allowing a more extensive coverage of the commercial fishery than would be otherwise possible.

Southeast Newfoundland — During the last decade catches were highest during the early 1970s and have been in decline since 1973 reaching a low of 700 t in 1981 (Fig. 1). In the 7-yr period since 1975, seventy-two cases of a catch by a gear and quarter have been reported (Table 1). In 49 cases (68%), sampling has been adequate while in the cases of sampling performance less than 1.0, only twice was the catch in excess of 100 t.

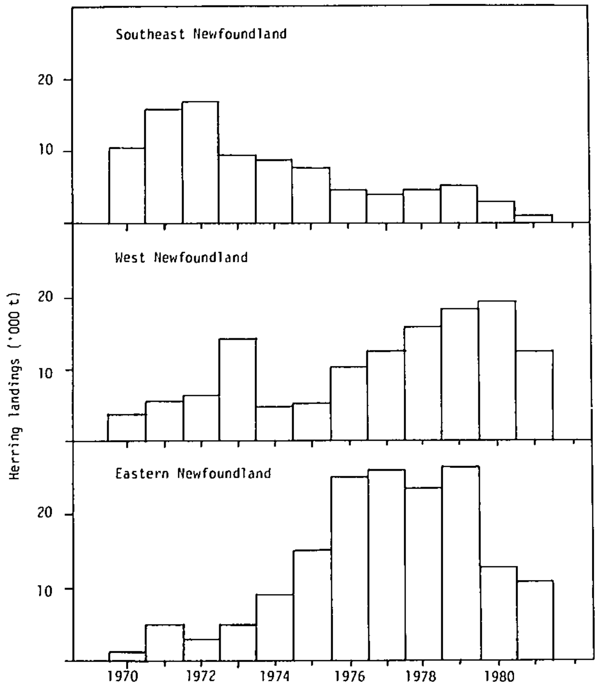

FIG. 1. Newfoundland herring landings for the southeast, west, and eastern coasts of Newfoundland.

West coast of Newfoundland — With the exception of the large catch in 1973, catches in the early 1970s were generally less than 5000 t. Catches increased in the second half of the 1970s increasing from 10 000 t in 1976 to 19 000 t in 1980 and declining to 12 200 t in 1981 (Fig. 1). Catches by gear and quarter since 1975 have been reported for 83 cases (Table 1) of which 42 cases (51%) have had sampling performance greater than 1.0. Of the remaining cases (41) only two occurred in cases when a catch exceeded 100 t.

East coast of Newfoundland — Herring landings along the east coast increased from 1300 t in 1970 to 26 400 t in 1979 (Fig. 1). Due to the decline in abundance and extended quota regulations, catches declined to 12 400 t in 1980 and to 11 000 t in 1981. For these areas there were 101 cases of a catch by gear and quarter since 1975 and of these 71 (71%) were adequately sampled. Of the 30 remaining cases, 16 were represented by catches of less than 100 t. Details of the herring sampling performance by gear and quarter are given in Appendix A.

CAPELIN

For decades there has been a capelin fishery for food, fertilizer, and bait in the Newfoundland area; this fishery prosecuted capelin near the spawning beaches during June and July. Prior to the 1950s, annual nominal catches were estimated to have averaged 20 000–25 000 t (Templeman 1968). These catches declined during the 1950s and 1960s but they have increased in recent years due to market de-

TABLE 1. Summary of sampling performance for herring in the three management areas of Newfoundland, 1975-81. Numbers in parentheses indicate the number of cases with catches below 100 t.

Area	Year	Total no. of cases	No. cases ≥ 1.0	No. cases <1.0
Southeast coast	1975	11	10 (4)	1 (1)
	1976	11	9 (3)	2 (2)
	1977	12	8 (3)	4 (4)
	1978	11	8 (2)	3 (3)
	1979	9	5 (0)	4 (3)
	1980	9	6 (2)	3 (2)
	1981	9	3 (1)	6 (6)
	Total	72	49 (15)	23 (21)
West coast	1975	9	4 (1)	5 (4)
	1976	8	6 (1)	2 (2)
	1977	11	5 (0)	6 (5)
	1978	14	8 (3)	6 (6)
	1979	13	7 (2)	6 (6)
	1980	15	6 (1)	9 (9)
	1981	13	6 (1)	7 (7)
	Total	83	42 (9)	41 (39)
East coast	1975	17	16 (5)	1 (1)
	1976	15	12 (0)	3 (2)
	1977	14	10 (1)	4 (1)
	1978	15	10 (0)	5 (1)
	1979	14	7 (0)	7 (4)
	1980	13	9 (2)	4 (2)
	1981	13	7 (2)	6 (5)
	Total	101	71 (10)	30 (16)

mand in Japan for roe capelin. During the early 1970s, an offshore foreign fishery developed in Div. 2J3KLNO with nominal catches rising sharply, peaking in 1976 at about 370 000 t and declining rapidly. It was during the decline of the offshore fishery in the late 1970s that the inshore Canadian fishery developed. Also during the late 1970s, catches in Div. 4R (all Canadian) increased to take advantage of the Japanese market for roe capelin. Details of the pattern of the nominal catches are given for Div. 2J3K, Div. 3L, Div. 3NO, and Div. 4R in Fig. 2–5, respectively. All Canadian catches were assumed to have occurred in the inshore area of Newfoundland.

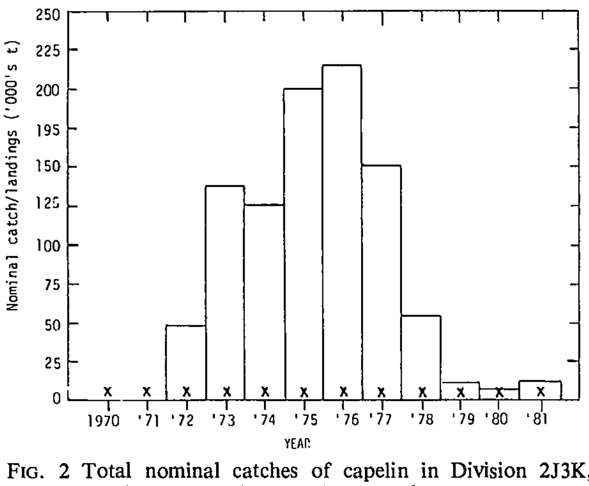

FIG. 2 Total nominal catches of capelin in Division 2J3K, 1970–81. Inshore (Canadian) landings less than 2500 t are symbolized by X.

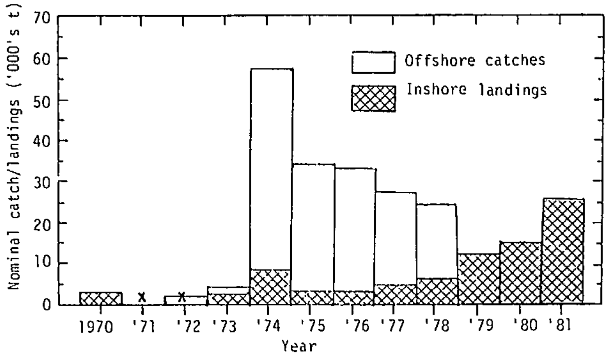

FIG. 3 Total nominal catches of capelin in Div. 3L, 1970–81. Inshore (Canadian) landings of less than 1000 t are symbolized by X.

Generally speaking, the sampling of the offshore commercial catches by foreign vessels was minimal at best. Even with extension of Canadian jurisdiction in January 1977, the sampling did not improve markedly apparently because of an initial start-up period that coincided with a decline of the fishery. The offshore fishery was suspended in the south (Div. 3LNO) in 1979 and in the north (Div. 2J3K) in 1980. There was an experimental fishery in Div. 2J3K in 1980 and 1981, operating in the same manner as the former commercial fishery, and this fishery has been well sampled by the Foreign Observer Program/Foreign Cooperative Research Section.

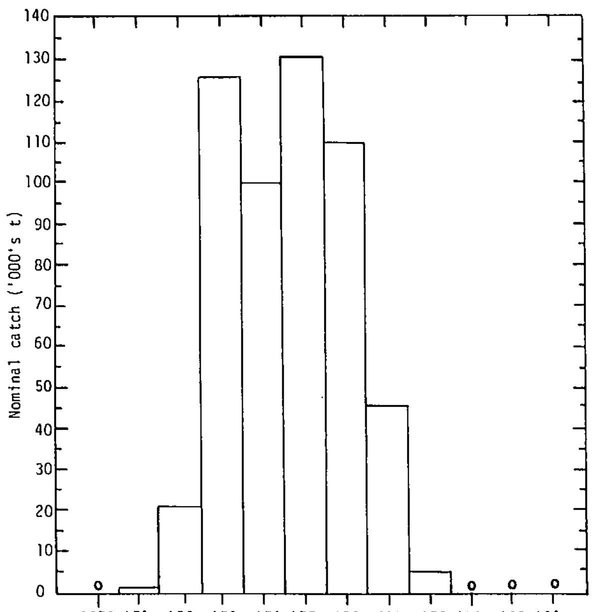

FIG. 4. Nominal catches of capelin in NAFO Div. 3NO, 1970–81.

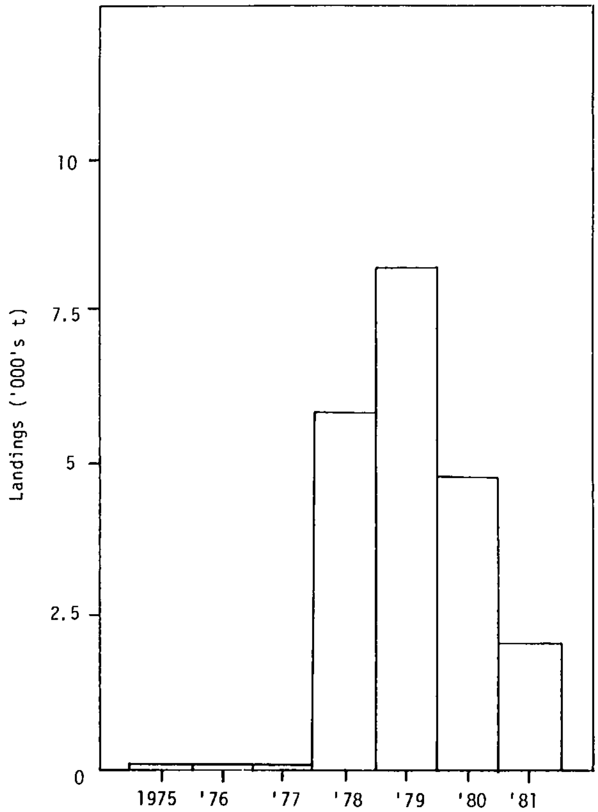

FIG. 5. Landings of capelin in Div. 4R, 1975–81.

This summary addresses only the performance of the sampling of the Canadian catches. As previously noted, the inshore Canadian capelin fishery has developed rapidly since 1977. Most of the fishing activity has occurred in Div. 3L, with smaller catches reported from Div. 3K and Div. 4R. Most of the fishing occurs during June and diminishes rapidly in July. Although this fishing period spans the second and third quarters, we have combined catches and samples into the second quarter results.

The method of collecting the samples is the same as that outlined for herring. Since the fishery is quite short and spread over a wide area and there is insufficient research personnel to cover all areas, collectors in plants usually freeze samples for later pickup.

Prior to 1978, all capelin samples were random samples of 50 fish. From 1978 to the present, all samples are random samples of 200 fish for length frequencies with two otoliths per 0.5 cm per sex collected for aging. For the purposes of this appraisal for capelin, no distinction was made between random and stratified samples.

In Div. 3L and Div. 3K, three gear types are used in the capelin fishery: bar or beach seines, trap nets and ring nets. The large purse-seiners fished this area only in 1978. The sampling performance for Div. 3L exceeded minimum requirements in 15 of 20 cases (75%), while in the other five cases, no samples were collected (Table 2). In Div. 3K, the performance has not been as good, with 39%

TABLE 2. Summary of sampling performance for capelin fisheries in Div. 3L, 3K, and 4R, 1975–81. Numbers in parentheses indicate cases where catches were less than 100 t.

			No. cases	
Area	Year	No. of cases	≥ 1	< 1
Div. 3L	1975	2	1	1
	1976	2	2	0
	1977	3	1	2
	1978	4	3	1
	1979	3	2	1
	1980	3	3	0
	1981	3	3	0
	Total	20	15	5
Div. 3K	1975	2	2 (1)	0
	1976	2	1	1
	1977	2	2	0
	1978	3	1	2 (1)
	1979	3	0 (1)	3
	1980	3	1	2
	1981	3	0	3
	Total	18	7 (2)	11 (1)
Div. 4R	1975	1	0	1 (1)
	1976	1	0	1 (1)
	1977	2	1	1
	1978	2	2 (1)	0
	1979	2	1	1 (1)
	1980	3	1	2 (1)
	1981	3	2	1 (1)
	Total	14	7 (1)	7 (5)

of the cases exceeding minimum requirements and the remainder having no samples collected (Table 2). However, in this case, catches are low (4 out of 18 had catches exceeding 1000 t) both in categories where samples were collected and categories where no samples were collected.

In Div. 4R, the fishery is dominated by large purse-seiners. In this area, minimum NAFO requirements were exceeded 50% of the time; in the remaining instances, no samples were collected (Table 2). However, in the purse-seine fishery, which accounted for more than 89% of the catches, minimum sampling requirements were met.

Details of the capelin sampling performance are given in Appendix A.

Discussion

It should be noted that in this analysis no effort was made to determine the adequacy of the recommended minimum sampling requirements of NAFO and the samples collected for herring and capelin did not always correspond to the type of samples recommended. However, based purely on a numerical comparison, the herring and capelin fisheries are being reasonably well sampled, especially when the relatively small and diffuse nature of the fisheries is considered.

References

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Appendix A

TABLE A1. Details of herring catch and sampling performance by gear type and quarter, southeast Newfoundland (includes Fortune Bay and St. Mary's–Placentia Bay stocks), 1975–81.

		Quarter 1			Quarter 2			Quarter 3			Quarter 4		
Year	Gear	Catch	No. samples	Performance	Catch	No. samples	Performance	Catch	No. samples	Performance	Catch	No. samples	Performance
1975	Purse-seine	3544	36	10.1	925	5	5.4	—	—	—	—	—	—
	Ring net	—	—	—	711	1	1.4	—	—	—	—	—	—
	Gill net	50	2	40.0	1048	36	34.4	6	—	0.0	39	5	128.2
	Bar seine	20	4	200.0	786	14	17.8	—	—	—	54	1	18.5
	Trap	—	—	—	431	2	4.6	—	—	—	—	—	—
	Other	—	—	—	—	—	—	—	—	—	—	—	—
1976	Purse-seine	2165	17	7.9	—	—	—	—	—	—	—	—	—
	Ring net	437	8	18.3	655	26	39.7	—	—	—	—	—	—
	Gill net	5	3	600.0	542	24	44.3	16	—	0.0	9	1	111.1
	Bar seine	143	2	14.0	561	14	25.0	—	—	—	6	—	0.0
	Trap	—	—	—	25	1	40.0	—	—	—	—	—	—
	Other	—	—	—	—	—	—	—	—	—	—	—	—
1977	Purse-seine	928	20	21.6	—	—	—	—	—	—	—	—	—
	Ring net	525	24	45.7	1126	20	17.8	—	—	—	4	—	0.0
	Gill net	45	10	222.2	578	24	41.5	1	—	0.0	7	2	285.7
	Bar seine	33	1	30.3	566	20	35.3	—	—	—	—	—	—
	Trap	—	—	—	32	—	0.0	2	—	0.0	—	—	—
	Other	—	—	—	—	—	—	—	—	—	—	—	—
1978	Purse-seine	187	9	48.1	474	2	4.2	—	—	—	—	—	—
	Ring net	1936	42	21.7	134	20	149.3	—	—	—	65	14	215.4
	Gill net	16	—	0.0	713	23	32.3	16	3	187.5	—	—	—
	Bar seine	86	—	0.0	863	13	15.1	—	—	—	—	—	—
	Trap	—	—	—	36	—	0.0	—	—	—	—	—	—
	Other	—	—	—	—	—	—	—	—	—	—	—	—
1979	Purse-seine	644	8	12.4	—	—	—	—	—	—	—	—	—
	Ring net	2149	64	29.8	312	16	51.3	—	—	—	—	—	—
	Gill net	106	—	0.0	602	18	29.9	5	—	0.0	—	—	—
	Bar seine	23	—	0.0	954	13	13.6	—	—	—	—	—	—
	Trap	—	—	—	10	—	0.0	—	—	—	—	—	—
	Other	—	—	—	—	—	—	—	—	—	—	—	—
1980	Purse-seine	97	4	41.2	182	2	11.0	—	—	—	—	—	—
	Ring net	1383	44	31.8	154	3	19.5	—	—	—	—	—	—
	Gill net	5	2	400.0	771	—	0.0	4	—	0.0	—	—	—
	Bar seine	—	—	—	290	5	17.2	—	—	—	—	—	—
	Trap	—	—	—	42	—	0.0	—	—	—	—	—	—
	Other	—	—	—	—	—	—	—	—	—	—	—	—
1981	Purse-seine	—	—	—	—	—	—	—	—	—	—	—	—
	Ring net	311	6	19.3	44	14	318.2	—	—	—	—	—	—
	Gill net	11	—	0.0	294	8	27.2	1	—	0.0	4	—	0.0
	Bar seine	1	—	0.0	37	—	0.0	—	—	—	—	—	—
	Trap	—	—	—	1	—	0.0	—	—	—	—	—	—
	Other	—	—	—	—	—	—	—	—	—	—	—	—

TABLE A2. Details of herring catch and sampling performance by gear type and quarter, west coast of Newfoundland (Div. 4R), 1975–81.

		Quarter 1			Quarter 2			Quarter 3			Quarter 4		
Year	Gear	Catch	No. samples	Performance	Catch	No. samples	Performance	Catch	No. samples	Performance	Catch	No. samples	Performance
1975	Purse-seine	—	—	—	3495	12	3.4	—	—	—	—	—	—
	Ring net	—	—	—	—	—	—	—	—	—	—	—	—
	Gill net	—	—	—	322	4	12.4	899	2	2.2	272	—	0.0
	Bar seine	—	—	—	2	—	0.0	2	—	0.0	1	—	0.0
	Trap	—	—	—	2	2	1000.0	—	—	—	—	—	—
	Other	—	—	—	—	—	—	—	—	—	1	—	0.0
1976	Purse-seine	—	—	—	8022	27	3.4	—	—	—	184	6	32.6
	Ring net	—	—	—	—	—	—	—	—	—	—	—	—
	Gill net	—	—	—	754	4	5.3	754	6	8.0	334	3	9.0
	Bar seine	—	—	—	2	—	0.0	—	—	—	—	—	—
	Trap	—	—	—	44	—	0.0	15	1	66.7	—	—	—
	Other	—	—	—	—	—	—	—	—	—	—	—	—
1977	Purse-seine	16	—	0.0	7281	43	5.9	—	—	—	2155	6	2.8
	Ring net	—	—	—	—	—	—	—	—	—	12	—	0.0
	Gill net	1	—	0.0	549	3	5.5	1086	21	19.3	1013	12	11.9
	Bar seine	—	—	—	9	—	0.0	4	—	0.0	160	—	0.0
	Trap	—	—	—	—	—	—	—	—	—	—	—	—
	Other	—	—	—	—	—	—	—	—	—	—	—	—
1978	Purse-seine	—	—	—	7289	17	2.3	—	—	—	2636	25	9.5
	Ring net	—	—	—	—	—	—	—	—	—	—	—	—
	Gill net	—	—	—	1350	7	5.2	2657	14	5.2	1525	7	4.6
	Bar seine	—	—	—	27	—	0.0	1	—	0.0	5	—	0.0
	Trap	—	—	—	27	2	74.1	13	—	0.0	—	—	—
	Other	2	—	0.0	22	2	90.9	55	2	36.4	3	—	0.0
1979	Purse-seine	—	—	—	7160	25	3.5	—	—	—	2829	8	2.8
	Ring net	—	—	—	—	—	—	—	—	—	—	—	—
	Gill net	12	—	0.0	4339	17	3.9	2183	16	7.3	1666	7	4.2
	Bar seine	—	—	—	—	—	—	3	—	0.0	—	—	—
	Trap	—	—	—	12	—	0.0	—	—	—	3	—	0.0
	Other	18	—	0.0	85	4	47.1	4	1	250.0	7	—	0.0
1980	Purse-seine	—	—	—	6938	22	3.2	—	—	—	2672	30	11.2
	Ring net	—	—	—	—	—	—	18	—	0.0	—	—	—
	Gill net	13	—	0.0	5145	30	5.8	3343	22	6.6	847	7	8.3
	Bar seine	—	—	—	36	—	0.0	7	—	0.0	—	—	—
	Trap	—	—	—	23	—	0.0	3	—	0.0	—	—	—
	Other	15	—	0.0	45	17	377.8	7	—	0.0	8	—	0.0
1981	Purse-seine	—	—	—	5211	37	7.1	—	—	—	1855	23	12.4
	Ring net	—	—	—	—	—	—	—	—	—	—	—	—
	Gill net	37	—	0.0	2933	33	11.3	1124	13	11.6	903	2	2.2
	Bar seine	—	—	—	1	—	0.0	4	—	0.0	—	—	—
	Trap	—	—	—	13	—	0.0	18	1	55.6	—	—	—
	Other	95	—	0.0	29	—	0.0	—	—	—	4	—	0.0

TABLE A3. Details of herring catch and sampling performance by gear type and quarter, Newfoundland east coast (includes: Notre Dame–White Bay, Bonavista Bay, Trinity Bay and Conception Bay — Southern Shore), 1975–81.

Year	Gear	Quarter 1			Quarter 2			Quarter 3			Quarter 4		
		Catch	No. samples	Performance	Catch	No. samples	Performance	Catch	No. samples	Performance	Catch	No. samples	Performance
1975	Purse-seine	—	—	—	357	4	11.2	1	2	2000.0	4918	31	6.3
	Ring net	6	—	0.0	99	4	40.4	2982	34	11.4	1092	15	13.7
	Gill net	5	5	1000.0	1126	18	16.0	874	12	13.7	1986	15	7.6
	Bar seine	—	—	—	213	14	65.7	480	4	8.3	51	1	19.6
	Trap	—	—	—	308	19	61.7	472	12	25.4	43	3	69.8
	Other	—	—	—	—	—	—	—	—	—	—	—	—
1976	Purse-seine	—	—	—	—	—	—	—	—	—	—	—	—
	Ring net	—	—	—	2236	39	17.4	497	18	36.2	7020	80	11.4
	Gill net	66	—	0.0	1685	33	19.6	390	15	38.5	1518	16	10.5
	Bar seine	2	—	0.0	659	31	47.0	168	—	0.0	343	5	14.6
	Trap	—	—	—	459	17	37.0	277	11	39.7	273	5	18.3
	Other	—	—	—	258	9	34.9	—	—	—	—	—	—
1977	Purse-seine	—	—	—	—	—	—	—	—	—	—	—	—
	Ring net	—	—	—	5535	52	9.4	1475	4	2.7	8640	50	5.8
	Gill net	366	10	27.3	1791	19	10.6	176	—	0.0	1048	—	0.0
	Bar seine	—	—	—	3191	28	8.8	25	—	0.0	2399	14	5.8
	Trap	—	—	—	549	4	7.3	243	8	32.9	60	2	33.3
	Other	—	—	—	236	—	0.0	—	—	—	—	—	—
1978	Purse-seine	—	—	—	—	—	—	—	—	—	—	—	—
	Ring net	304	5	16.5	3208	23	7.2	3491	5	1.4	4756	51	10.7
	Gill net	843	2	2.4	6160	49	8.0	242	—	0.0	1868	5	2.7
	Bar seine	5	—	0.0	1434	18	12.6	144	—	0.0	104	—	0.0
	Trap	—	—	—	430	8	18.6	148	1	6.8	271	—	0.0
	Other	—	—	—	—	—	—	—	—	—	—	—	—
1979	Purse-seine	—	—	—	—	—	—	—	—	—	—	—	—
	Ring net	—	—	—	3496	53	15.2	798	3	3.8	3619	24	6.6
	Gill net	1951	9	4.6	8709	77	8.8	72	—	0.0	2530	1	0.4
	Bar seine	19	—	0.0	4210	30	7.1	8	—	0.0	56	—	0.0
	Trap	—	—	—	380	6	15.8	353	—	0.0	262	—	0.0
	Other	—	—	—	—	—	—	—	—	—	—	—	—
1980	Purse-seine	—	—	—	—	—	—	—	—	—	—	—	—
	Ring net	—	—	—	2016	25	12.4	17	2	117.7	2624	27	10.3
	Gill net	930	2	2.2	3682	20	5.4	249	1	4.0	952	10	10.5
	Bar seine	5	—	0.0	1676	34	20.3	4	—	0.0	116	—	0.0
	Trap	—	—	—	132	—	0.0	10	2	200.0	—	—	—
	Other	—	—	—	—	—	—	—	—	—	—	—	—
1981	Purse-seine	—	—	—	—	—	—	—	—	—	—	—	—
	Ring net	—	—	—	1	—	0.0	43	1	23.3	2420	60	24.8
	Gill net	3	3	1000.0	3147	25	7.9	95	—	0.0	1500	5	3.3
	Bar seine	—	—	—	1012	16	15.8	2	—	0.0	475	11	23.2
	Trap	—	—	—	41	—	0.0	9	—	0.0	116	—	0.0
	Other	—	—	—	—	—	—	—	—	—	—	—	—

TABLE A4. Details of Canadian catch and sampling performance by gear type for capelin taken in Div. 3L, second quarter, 1975–81.

Year	Gear	Catch (t)	No. samples	Performance
1975	Bar seine	1 413	10	7.1
	Trap net	792	0	0
	Ring net			
	Purse-seine			
1976	Bar seine	1 614	2	1.2
	Trap net	953	7	7.3
	Ring net			
	Purse-seine			
1977	Bar seine	2 557	0	0
	Trap net	1 009	6	6.0
	Ring net	1 703	0	0
	Purse-seine			
1978	Bar seine	3 782	6	1.6
	Trap net	1 632	2	1.2
	Ring net	916	0	0
	Purse-seine	1 193	4	3.4
1979	Bar seine	3 469	18	5.2
	Trap net	5 552	14	2.5
	Ring net	3 295	0	0
	Purse-seine			
1980	Bar seine	1 347	6	4.5
	Trap net	5 661	10	1.8
	Ring net	7 439	16	2.2
	Purse-seine			
1981	Bar seine	1 348	17	12.6
	Trap net	7 896	20	2.5
	Ring net	15 249	44	2.9
	Purse-seine			

TABLE A5. Details of Canadian catch and sampling performance by gear type for capelin taken in Div. 3K, second quarter, 1975–81.

Year	Gear	Catch (t)	No. samples	Performance
1975	Bar seine	613	1	1.6
	Trap net	86	1	11.6
	Ring net			
	Purse-seine			
1976	Bar seine	1519	3	2.0
	Trap net	162	0	0
	Ring net			
	Purse-seine			
1977	Bar seine	1892	3	1.6
	Trap net	245	1	4.1
	Ring net			
	Purse-seine			
1978	Bar seine	1948	0	0
	Trap net	447	8	17.9
	Ring net	25	0	0
	Purse-seine			
1979	Bar seine	461	0	0
	Trap net	42	0	0
	Ring net	168	0	0
	Purse-seine			
1980	Bar seine	654	0	0
	Trap net	139	0	0
	Ring net	560	2	3.6
	Purse-seine			
1981	Bar seine	469	0	0
	Trap net	282	0	0
	Ring net	1027	0	0
	Purse-seine			

TABLE A6. Details of Canadian catch and sampling performance by gear type for capelin taken in Div. 4R, second quarter, 1975–81.

Year	Gear	Catch (t)	No. samples	Performance
1975	Bar seine	52	0	0
	Trap net			
	Ring net			
	Purse-seine			
1976	Bar seine	92	0	0
	Trap net			
	Ring net			
	Purse-seine			
1977	Bar seine	105	0	0
	Trap net			
	Ring net			
	Purse-seine	1409	2	1.4
1978	Bar seine	83	2	24.1
	Trap net			
	Ring net			
	Purse-seine	8121	50	6.2
1979	Bar seine	33	0	0
	Trap net			
	Ring net			
	Purse-seine	5705	10	1.8
1980	Bar seine	112	0	0
	Trap net	2	0	0
	Ring net			
	Purse-seine	4661	13	2.8
1981	Bar seine	236	4	17.0
	Trap net			
	Ring net	1	0	0
	Purse-seine	1923	8	4.2

Determination of the Size Composition of the Landed Catch of Haddock from NAFO Division 4X During 1968–81

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O'BOYLE, R., L. CLEARY, AND J. MCMILLAN. 1983. Determination of the size composition of the landed catch of haddock from NAFO Division 4X during 1968–81, p. 217–234. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

The adequacy of the sampling of the landings from the 4X haddock fishery was evaluated for the 1968–81 period. Examination of fleet catch trends and gear composition indicated the presence of six sampling strata which needed to be covered. Identification of these strata was confirmed through analysis of landings age-size data. During the review period, only two of the strata were sampled to any degree. These represented landings from large (tonnage classes 4 and 5) otter trawlers and longliners. It was determined that due to the nature of the fishery, a shift of the current sampling effort to the undersampled strata, i.e. those involving landings from small draggers, would lead to a 50% reduction in the overall landings covered. Within particular strata, variation in the size composition of the landings was high, due to the incidental presence of samples with large numbers of small fish. Removal of these samples increased stratum homogeneity of variance dramatically. To determine the causal factors for these aberrant samples, more background data on the fishing activity are required, which can be obtained through enhancement of existing data collection systems.

O'BOYLE, R., L. CLEARY, AND J. MCMILLAN. 1983. Determination of the size composition of the landed catch of haddock from NAFO Division 4X during 1968–81, p. 217–234. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

On évalue ici la qualité de l'échantillonnage des débarquements, de 1968 à 1981, pour la pêche à l'aiglefin du 4X. L'analyse des tendances des prises pour la flotte et l'examen des engins de pêche utilisés suggèrent que six strates d'échantillonnage doivent être couvertes. Une analyse des données d'âge et de taille obtenues sur les débarquements confirme l'identité de ces strates. Pour la période couverte par cette revue, seulement deux de ces strates ont fait l'objet d'un effort d'échantillonnage notable : ces deux strates correspondent aux débarquements des gros chalutiers à panneaux (classes 4 et 5) et des palangriers. L'étude démontre que, à cause de la nature même de cette pêche, un déplacement de l'effort d'échantillonnage vers les strates sous-échantillonnées, i.e. celles qui couvrent les débarquements des petits chalutiers, mènerait à une diminution de 50% du nombre total des débarquements devant faire l'objet d'échantillonnage. À l'intérieur d'une strate particulière, la variation des débarquements — relativement à leur composition en taille — était grande : cette grande variation est liée à la présence occasionnelle d'échantillons ayant un grand nombre de petits poissons. La suppression de ces échantillons a augmenté de façon significative l'homogénéité de la variance à l'intérieur de chaque strate. Afin de déterminer quelles étaient les causes de ces échantillons aberrants, on doit obtenir des données additionnelles sur les activités de pêche : ces données peuvent être obtenues en améliorant les systèmes existants pour la collecte des données.

Introduction

A large class of mathematical models presently being used in fisheries management requires a knowledge of the age-size structure of a resource's yield. Sequential population analysis procedures such as Virtual Population Analysis (Gulland 1965) and Cohort Analysis (Pope 1972) have been and are being used extensively in fisheries management organizations such as CAFSAC and ICES to determine both historical and current fish population sizes.

Indeed, Rivard and Doubleday (1979) point out that current year estimates of population size using these procedures are almost wholly dependent on the accuracy of the catch-at-age data for that year. This in turn affects the accuracy of projected yield. These projections themselves are normally carried out using exploitation criteria defined by models such as yield per recruit (Ricker 1975) which require good catch age-size data. The use of these types of models in fisheries management is thus critically dependent on the generation of accurate age-size composition of the yield.

The importance of sampling in the stock assessment process has stimulated much research into how best to conduct large-scale sampling programs. Early work by Pope (1956), Gulland (1962), and Mackett (1973) emphasized the need for adequate stratification while later works by Kimura (1977) and Westrheim and Ricker (1978) examined the use of age-length keys in the sampling process. Unfortunately there is a notable lack of studies on the identification of sampling strata and optimization of available sampling effort both within and among strata. For this reason, existing sampling protocols (Beckett 1983) have generally been established through a combination of statistical rigor and operational practicality.

The fishery for haddock in NAFO Division 4X has been sampled since the early 1950s. Coverage of the fleets involved increased substantially during the mid-late 1960s. It was thought worthwhile to review the sampling history of this fishery since 1968. Particular emphasis was placed on the identification of sampling strata and the variability so far observed within each stratum. This knowledge was used to make recommendations on the improvement of sampling coverage, intensity, and data quality.

Description of the Fishery

The first step in the evaluation of a sampling program is a simple description of the fleets involved in the fishery along with their activities over the sampling period. This will allow identification of major sampling strata within which sampling effort can be evaluated.

The Vessels

Prior to the mid-1960s, landings by countries other than Canada represented a substantial portion of the catch (O'Boyle 1981). However since that time, Canadian vessels operating from Nova Scotia ports have been the exclusive exploiters of this stock. These vessels range in size from about 20 gross tons up to 600 gross tons. For convenience, they have been categorized as tonnage class 1 (0–24.9 gross tons), tonnage class 2 (25–49.9 gross tons), tonnage class 3 (50–149.9 gross tons), tonnage class 4 (150–499.9 gross tons), or tonnage class 5 (500 + gross tons) vessels.

Three types of vessels are involved in the fishery. The first is the otter trawler which deploys a trawl either over the stern or side of the vessel while underway. Within this fleet, there are three main groups:

1) tonnage class 1 vessels which restrict their activities to within 15 mi of the coast;
2) tonnage class 2 and 3 vessels which make 1–3-d trips throughout 4X; and
3) tonnage class 4 and 5 vessels owned by the big fishing companies which make 10-d trips in the area but never enter the Bay of Fundy.

The second major fleet to be involved in the fishery is that of the longliners. These vessels rarely range larger than tonnage class 3. They deploy line gear over the side rather than towed gear. At present there is not enough information to determine intrafleet fishing behavioral differences.

The last set of gear employed in the fishery is that of the small coastal fishermen who generally use gill nets, traps, and other miscellaneous fishing apparatuses. As with the longliners, the information on this fleet is not sufficient enough to allow further characterization of subfleet activity.

Fleet Activity During 1968–81

Much of the yield from the resource has been taken by the otter trawler fleet (Table 1). The reported catches by these vessels have also been the main cause for fluctuations in the total landings. Catches by the longliners and miscellaneous gears have remained fairly constant.

Table 1. Reported nominal catches (t round) of haddock from unit areas 4Xm-r for Canadian (Maritimes and Quebec) fishery by gear type.

Year	Otter trawl (Side & stern)	Longline	Miscellaneous gears	Totals
1968	24 128	1 907	1 244	27 279
1969	23 752	2 322	1 339	27 413
1970	11 395	2 867	1 298	15 560
1971	12 001	3 112	954	16 067
1972	7 491	3 967	933	12 391
1973	6 050	5 785	701	12 536
1974	5 572	6 162	509	12 243
1975	10 500	4 943	548	15 991
1976	10 492	4 637	1 165	16 294
1977	14 530	4 035	996	19 561
1978	17 305	6 049	1 946	25 300
1979	18 504	4 348	1 435	24 287
1980	20 095	5 717	2 403	28 215
1981	21 246	6 995	1 915	30 156

Within the otter trawler fleet, the relative contribution to overall yield made by the various tonnage classes has changed over time. Prior to 1973, the tonnage class 4 and 5 vessels reported the majority of the landed cach (Table 2). However, since that time, their overall importance to the fishery has waned to the point that in 1980–81, the majority of the catch of 4X haddock is being reported by tonnage class 2 and 3 otter trawlers. Landings of the tonnage class 1 vessels have also dramatically increased in recent years.

Description of the spatial movement of the various fleets is dependent on compilation of data gleaned from ship's fishing logs. According to the Canadian Fisheries Act, all vessels greater than 25 gross tons are required to complete logs stating where they were fishing and how much they

TABLE 2. Reported nominal catches (t round) of haddock from unit areas 4Xm-r for Canadian otter trawl fishery by tonnage class.

	Tonnage class					
Year	0–24.9	25–49.9	50–149.9	150–499.9	500+	Total
1968	850	3 537	5 904	10 560	3 275	24 126
1969	489	2 037	3 755	9 695	7 776	23 752
1970	196	1 728	2 970	3 666	2 834	1 394
1971	174	1 511	2 604	4 752	2 960	12 001
1972	145	977	1 619	2 807	1 943	7 491
1973	105	786	931	2 565	1 663	6 050
1974	208	1 914	1 827	1 069	554	5 572
1975	316	2 391	3 384	2 414	1 995	10 500
1976	310	1 452	2 586	3 044	3 100	10 492
1977	456	2 196	3 533	3 689	4 656	14 530
1978	930	3 399	4 884	3 860	4 233	17 305
1979	880	3 693	5 297	4 315	4 319	18 504
1980	2 136	4 417	6 102	3 660	3 780	20 095
1981	2 021	6 415	6 163	2 837	3 810	21 246

caught. A complete description on how this information is handled by government data processing groups is given by J. McMillan and R. O'Boyle (Marine Fish Division, Bedford Institute of Oceanography, Dartmouth, N.S., personal communication). It is sufficient here to say that the smallest area of resolution presently available is that of the unit area, of which there are nine in 4X — designated as 4Xl, 4Xm, 4Xn, 4Xo, 4Xp, 4Xq, 4Xr, 4Xs, and 4Xx (Fig. 1). The activities of the tonnage class 1 vessels, since they are not required to carry logs, are known generally but not specifically. Therefore the data given in Table 3a are derived from purchase slip information which, although not as reliable as log derived data, provide a general pattern of fleet activity.

Tonnage class 1 otter trawlers (Table 3a) restrict their major fishing activity to the April–October period in those unit areas bordering the coastline (4Xo, 4Xq, and 4Xr). Much higher catches are reported from the Bay of Fundy than elsewhere. This pattern has not changed dramatically since 1968. As stated above, these vessels only have hold capacity and fuel for 1-d trips. Most of them operate out of ports stretching from the tip of southwest Nova Scotia up into the Bay of Fundy. Reports from fisheries personnel in the area suggest that these vessels also carry trawls with codend meshes smaller than those used by the larger vessel fleets. This has yet to be confirmed.

The tonnage class 2 and 3 vessels (Table 3b) operating out of southwest Nova Scotia ports fish predominantly during February–November. Prior to the closure to fishing of the Brown's Bank spawning grounds in 1970, these vessels would operate in this area during February–May and then slowly shift their activity into the Bay of Fundy where they would fish for the rest of the year. Closure of the spawning grounds led to increased fishing activity in unit area 4Xn, particularly since 1979. The shift of the fishing to the Bay of Fundy still persists. These vessels presently appear to use a range of codend mesh sizes between 115 and 130 mm and fish both close to shore and on the offshore banks.

The tonnage class 4 and 5 otter trawlers (Table 3c) from ports further up the Nova Scotia coast historically expended most of their fishing effort on spawning concentrations of haddock on Brown's Bank during the late winter–early

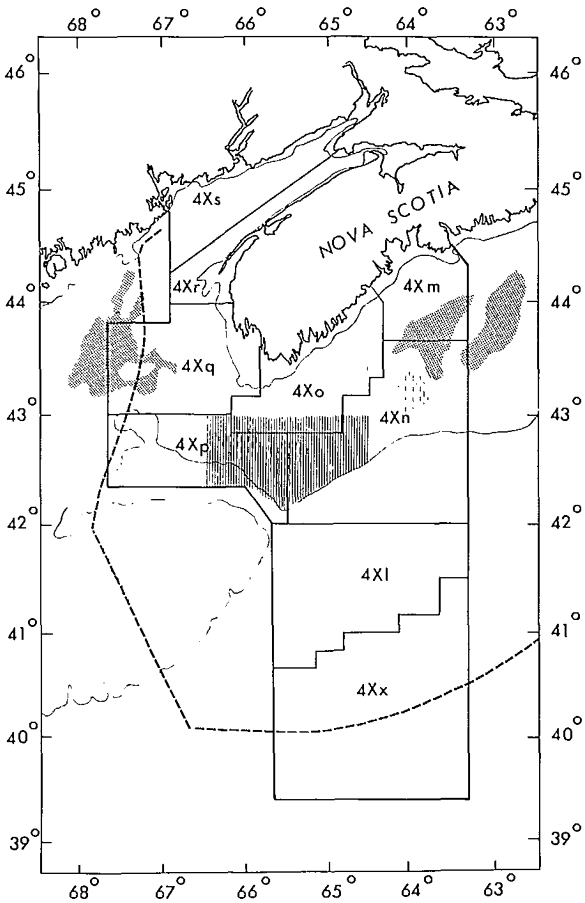

FIG. 1. Canadian fisheries statistical unit areas in NAFO Division 4X. Vertical line shading indicates closed area to groundfishing during March, April, and May of 1970–present. Dash-line shading indicates major banks and stippel shading indicates major basins.

TABLE 3a. Reported nominal catch (t round) of 4X haddock from unit areas m-r, u for Canadian otter trawl fishery (TC 1) by month and year.

Year	Unit area	J	F	M	A	M	J	J	A	S	O	N	D	Total
1968	m	—	—	—	—	—	—	—	—	—	—	—	—	—
	n	—	—	—	—	—	—	—	—	—	—	—	—	—
	o	—	—	—	20	27	24	22	28	22	6	1	—	150
	p	—	—	—	—	—	—	—	—	—	—	—	—	—
	q	—	—	—	—	6	39	12	117	13	2	—	—	189
	r	4	—	2	14	71	197	129	61	30	1	1	1	511
	u	—	—	—	—	—	—	—	—	—	—	—	—	—
1972	m	—	—	—	—	—	—	—	—	—	—	—	—	—
	n	—	—	—	—	—	—	—	—	—	—	—	—	—
	o	—	—	—	—	—	4	—	—	6	—	—	—	10
	p	—	—	—	—	—	—	—	—	—	—	—	—	—
	q	—	—	—	—	—	12	9	19	8	3	—	—	51
	r	3	—	—	1	15	24	8	11	8	1	5	5	81
	u	—	—	—	—	—	—	—	—	—	—	—	—	—
1976	m	—	—	—	—	—	—	—	—	—	—	—	—	—
	n	—	—	—	—	—	—	—	—	—	—	—	—	—
	o	—	—	—	1	2	4	19	12	26	8	—	—	72
	p	—	—	—	—	—	—	—	—	—	—	—	—	—
	q	—	—	—	—	12	17	14	15	44	7	—	—	109
	r	1	—	—	—	26	38	21	8	24	1	7	5	131
	u	—	—	—	—	—	—	—	—	—	—	—	—	—
1977	m	—	—	—	—	—	—	—	—	—	—	—	—	—
	n	—	—	—	—	—	—	—	—	—	—	—	—	—
	o	—	—	—	—	—	—	—	—	—	—	—	—	—
	p	—	—	—	—	—	—	—	—	—	—	—	—	—
	q	—	—	—	—	—	—	—	—	—	—	—	—	—
	r	—	—	—	—	—	—	—	—	—	—	—	—	—
	u	1	—	—	19	35	134	84	74	54	21	35	—	457
1978	m	—	—	—	—	—	1	3	1	9	3	2	—	19
	n	—	—	—	—	—	—	—	—	7	—	—	—	7
	o	5	28	—	23	8	24	39	34	7	23	2	3	196
	p	—	—	—	—	—	13	—	1	—	—	—	—	14
	q	—	—	—	—	22	98	130	120	76	29	1	—	476
	r	9	3	—	—	35	76	28	30	25	9	—	—	215
	u	—	—	—	—	—	—	—	—	—	—	—	—	—
1979	m	—	—	—	2	4	—	—	—	—	—	—	—	6
	n	—	—	—	—	—	5	—	—	1	—	—	—	6
	o	—	—	—	14	16	92	65	67	23	40	8	1	326
	p	—	—	—	—	—	—	—	—	—	—	—	—	—
	q	—	—	—	2	58	123	82	56	52	27	8	—	408
	r	—	—	—	1	16	45	19	23	23	3	2	—	132
	u	—	—	—	—	—	—	—	—	—	—	—	—	—
1980	m	—	—	4	—	—	1	1	—	—	—	—	3	9
	n	—	—	—	21	—	—	—	—	—	—	—	—	21
	o	3	2	26	40	37	115	79	39	35	51	18	20	465
	p	—	—	—	—	—	—	—	—	—	—	—	—	—
	q	—	29	2	35	104	212	257	202	95	61	—	—	997
	r	—	2	2	2	116	236	131	75	61	17	—	—	640
	u	—	—	—	—	—	—	—	—	—	—	—	—	—
1981	m	—	—	—	—	—	—	5	—	—	—	—	—	5
	n	—	—	—	—	—	—	—	—	—	—	—	10	10
	o	29	48	30	27	61	122	120	39	58	34	12	12	592
	p	—	—	—	—	—	—	—	—	—	—	—	—	—
	q	—	—	4	39	168	180	199	169	100	8	—	—	867
	r	1	—	—	16	157	148	88	88	28	18	2	—	546
	u	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 3b. Reported nominal catch (t round) of 4X haddock from unit areas m-r, u for Canadian otter trawl fishery (TC 2 and 3) by month and year.

Year	Unit area	J	F	M	A	M	J	J	A	S	O	N	D	Total
1968	m	—	—	—	—	—	—	—	—	—	—	—	—	—
	n	3	4	5	25	—	7	—	—	—	—	4	—	48
	o	61	35	106	273	217	68	62	28	4	6	6	—	864
	p	4	13	223	948	268	20	33	1	7	27	5	3	1552
	q	32	27	126	137	224	49	68	174	67	39	9	2	954
	r	46	99	43	80	970	1216	993	1134	863	304	186	85	6019
	u	—	—	—	—	1	—	—	—	—	—	—	4	5
1972	m	—	—	—	—	—	—	—	—	—	—	—	—	—
	n	23	15	21	37	28	—	—	—	13	1	—	—	138
	o	3	18	4	6	—	22	9	13	—	—	—	—	75
	p	1	—	—	—	—	335	22	13	—	—	—	—	371
	q	27	5	31	73	108	110	57	33	39	8	2	—	493
	r	21	5	6	17	270	280	268	222	242	142	37	12	1522
	u	—	—	—	—	—	—	—	—	—	—	—	—	—
1976	m	—	—	9	—	3	—	2	4	3	1	—	—	22
	n	—	14	34	5	47	33	50	29	58	28	16	—	314
	o	—	20	51	16	26	38	21	20	82	36	47	6	363
	p	—	40	18	5	6	91	87	60	19	—	3	—	329
	q	—	—	3	19	219	219	126	51	205	107	53	20	1022
	r	—	—	12	15	249	455	597	223	217	127	71	10	1976
	u	5	—	—	—	—	—	—	—	—	—	8	—	13
1977	m	—	—	—	—	—	—	—	—	1	—	—	—	1
	n	—	26	2	80	76	42	71	64	27	—	2	—	390
	o	1	411	92	50	63	24	25	52	40	11	8	—	777
	p	—	44	12	4	—	800	176	261	127	52	13	1	1490
	q	—	—	5	53	121	263	185	165	219	86	15	—	1112
	r	1	—	1	27	161	189	166	243	174	348	111	2	1423
	u	—	22	23	14	26	101	48	31	61	111	87	—	534
1978	m	—	—	—	1	—	—	—	—	—	10	—	—	11
	n	58	61	15	296	282	37	33	9	6	—	—	—	797
	o	65	455	93	224	469	35	26	11	3	6	10	11	1408
	p	51	105	—	51	43	1556	419	304	25	9	15	9	2578
	q	—	3	5	139	272	156	234	268	177	138	36	—	1428
	r	—	5	—	38	171	288	265	274	460	189	102	3	1795
	u	—	34	26	16	46	31	58	20	32	4	1	2	270
1979	m	—	—	—	—	—	2	3	—	—	—	—	—	5
	n	—	5	495	801	150	28	27	93	55	21	11	—	1686
	o	32	20	183	176	83	30	25	48	21	98	81	18	815
	p	8	40	74	120	3	876	339	177	28	99	32	3	1799
	q	—	—	22	46	605	469	335	424	338	294	31	6	2570
	r	—	2	—	39	402	295	186	267	295	176	147	9	1818
	u	—	—	—	29	2	12	53	31	92	84	—	—	303
1980	m	—	—	1	1	1	—	—	—	—	4	1	—	8
	n	8	268	495	1058	476	81	99	55	73	76	12	52	2753
	o	38	138	26	127	103	31	96	108	145	398	135	124	1469
	p	20	167	9	5	6	484	177	93	50	3	—	73	1087
	q	2	11	53	79	495	395	407	406	489	236	70	58	2701
	r	15	7	2	19	346	389	403	418	328	331	77	12	2347
	u	—	—	7	17	3	11	5	2	39	59	15	2	160
1981	m	—	—	—	27	6	—	—	3	1	—	2	2	41
	n	272	775	1177	555	520	143	70	90	60	76	2	4	3744
	o	254	356	83	72	458	143	151	121	104	88	11	12	1853
	p	74	379	5	—	14	898	208	31	9	27	7	7	1659
	q	—	4	8	31	152	251	381	311	821	224	9	9	2201
	r	4	11	6	76	217	271	526	501	465	578	58	19	2732
	u	6	11	23	16	71	25	39	72	71	11	6	—	351

TABLE 3c. Reported nominal catch (t round) of 4X haddock from unit areas m-r, u for Canadian otter trawl fishery (TC 4 and 5) by months and year.

Year	Unit area	J	F	M	A	M	J	J	A	S	O	N	D	Total
1968	m	—	7	—	—	—	5	2	—	—	5	1	8	28
	n	332	790	1039	402	301	47	29	84	177	73	706	118	4098
	o	747	636	132	152	49	9	3	8	3	6	26	6	1777
	p	276	518	1226	1938	1048	808	319	401	218	286	138	163	7339
	q	—	110	107	—	5	26	100	78	37	23	13	46	545
	r	6	—	—	—	3	—	1	—	3	2	17	15	47
	u	—	—	—	—	—	—	—	—	—	—	—	—	—
1972	m	—	—	—	—	—	2	—	—	—	—	—	6	8
	n	178	514	210	171	81	333	28	29	28	49	67	10	1698
	o	344	386	194	57	125	157	23	22	19	44	17	8	1396
	p	108	249	56	—	—	424	142	182	64	40	24	7	1296
	q	—	10	—	20	6	80	150	28	9	8	12	2	325
	r	—	—	—	—	—	14	—	10	—	—	—	—	24
	u	—	—	—	—	—	—	—	—	—	—	—	—	—
1976	m	—	—	—	—	35	16	7	1	—	7	9	5	80
	n	219	752	980	26	626	492	507	147	51	79	21	30	3930
	o	200	148	185	8	43	141	140	67	130	105	224	93	1484
	p	7	25	51	—	54	251	113	13	20	5	1	1	541
	q	—	—	—	6	—	32	40	7	1	—	4	16	106
	r	1	—	—	—	—	—	3	—	—	—	—	—	4
	u	—	—	1	—	—	—	—	—	—	—	—	—	1
1977	m	5	28	29	9	10	17	7	—	—	5	1	17	128
	n	378	970	793	388	363	164	38	91	93	301	427	19	4025
	o	274	474	260	145	201	174	26	127	50	155	436	25	2347
	p	293	204	92	21	—	669	23	32	—	229	154	15	1732
	q	—	—	4	—	3	14	8	3	—	—	9	—	41
	r	—	—	—	—	—	—	—	—	—	—	—	—	—
	u	—	—	31	—	—	—	34	—	—	4	—	—	69
1978	m	—	5	71	8	59	63	2	—	—	—	—	—	208
	n	153	444	389	473	1157	525	279	39	5	—	7	347	3818
	o	398	123	266	43	57	143	108	13	—	—	17	659	1827
	p	152	61	32	—	3	648	361	124	3	2	1	199	1586
	q	22	—	—	14	7	49	12	6	7	—	—	—	117
	r	—	—	—	—	—	—	—	—	—	—	—	—	—
	u	—	—	27	44	72	109	271	—	—	—	—	13	536
1979	m	15	21	28	22	6	—	3	—	3	35	46	77	256
	n	321	427	1734	404	195	12	16	43	191	214	384	791	4732
	o	880	108	53	36	45	4	2	18	83	286	344	799	2658
	p	67	238	101	—	—	51	114	22	42	32	32	94	793
	q	—	—	16	8	—	12	13	—	3	—	—	—	52
	r	—	—	—	—	—	—	—	—	—	—	—	—	—
	u	—	30	41	7	—	3	—	—	—	—	—	63	144
1980	m	5	33	145	—	23	11	1	—	—	—	13	56	287
	n	605	979	635	167	179	98	130	41	41	275	154	425	3729
	o	194	190	43	3	11	8	33	23	89	257	723	648	2222
	p	8	312	103	—	—	68	57	3	33	116	27	405	1132
	q	—	7	—	—	—	1	19	8	—	—	3	—	38
	r	—	—	—	—	—	—	—	—	—	—	—	—	—
	u	—	—	—	—	—	5	—	—	2	22	—	—	29
1978	m	—	27	49	13	17	—	1	—	1	42	26	8	184
	n	198	1128	1435	1142	231	58	—	46	148	67	138	48	4639
	o	99	140	14	3	114	66	5	24	11	16	336	553	1381
	p	25	139	17	1	—	46	—	—	1	4	3	156	392
	q	—	—	—	—	—	—	—	—	1	—	—	—	1
	r	—	—	—	—	—	—	—	—	—	—	—	—	—
	u	—	—	37	—	—	—	—	—	—	—	—	10	47

TABLE 4. Reported nominal catch (t round) of 4X haddock from unit area m-r, u for Canadian longline fishery (all TC's) by months and year.

Year	Unit area	J	F	M	A	M	J	J	A	S	O	N	D	Total
1968	m	—	—	—	—	1	2	11	—	—	1	2	—	17
	n	4	34	80	29	7	4	—	—	2	7	12	10	189
	o	30	24	104	55	96	81	55	48	98	202	77	23	893
	p	—	12	80	129	46	4	5	2	10	4	1	—	294
	q	—	—	—	2	6	2	—	—	3	—	—	—	13
	r	1	—	—	—	31	67	133	124	119	25	—	—	500
	u	—	—	—	—	—	—	—	—	—	—	—	—	—
1972	m	—	—	—	3	3	6	8	8	7	27	20	6	88
	n	6	6	83	85	28	8	23	27	17	25	15	6	329
	o	194	91	89	69	85	158	306	427	607	562	126	133	2847
	p	67	76	3	—	—	26	17	29	8	26	5	—	257
	q	11	17	18	30	71	11	5	20	7	6	2	12	210
	r	1	—	—	2	24	44	43	60	29	22	9	3	237
	u	—	—	—	—	—	—	—	—	—	—	—	—	4
1976	m	4	2	2	5	5	2	7	6	8	9	25	11	86
	n	98	212	92	45	50	43	68	47	72	51	18	29	825
	o	88	207	111	117	115	441	662	462	431	194	119	71	3018
	p	51	274	42	16	8	17	10	4	9	1	—	—	432
	q	—	22	23	31	28	23	29	8	7	—	1	—	172
	r	—	—	—	1	18	42	13	8	4	1	1	—	88
	u	10	—	—	1	—	3	—	2	3	—	—	—	19
1977	m	1	1	7	19	3	—	—	—	—	2	1	5	39
	n	117	145	113	134	40	69	84	24	36	38	28	16	844
	o	52	112	22	10	13	29	20	12	21	43	30	17	381
	p	14	274	19	1	7	49	8	17	17	4	6	—	416
	q	—	—	18	45	32	—	—	—	5	—	—	—	100
	r	—	—	—	—	—	—	—	—	—	—	—	—	—
	u	92	176	36	77	78	233	361	308	308	334	169	85	2257
1978	m	2	13	4	5	2	2	1	7	5	34	35	20	130
	n	118	331	154	119	34	45	23	61	111	96	62	52	1206
	o	229	427	17	63	129	281	489	630	685	246	195	84	3475
	p	97	365	15	—	3	119	30	67	103	42	19	9	869
	q	2	3	1	9	46	23	29	52	93	14	—	—	272
	r	—	—	—	—	7	4	22	32	1	—	—	—	66
	u	—	7	—	—	1	12	7	—	—	—	—	—	27
1979	m	28	2	16	16	12	8	28	21	30	65	60	46	332
	n	105	62	327	69	16	69	33	101	28	64	38	13	925
	o	71	5	44	60	95	327	431	536	514	260	162	79	2584
	p	82	90	3	—	1	22	3	20	14	5	19	3	262
	q	—	—	23	19	31	61	24	20	4	1	—	—	183
	r	—	—	—	3	17	9	11	11	6	1	—	—	58
	u	3	—	—	—	—	—	—	—	—	—	—	—	3
1980	m	21	17	34	44	43	32	19	16	67	98	78	82	551
	n	83	279	80	142	46	74	41	68	72	189	94	216	1384
	o	97	200	47	128	213	345	409	431	466	429	111	114	2990
	p	42	247	9	—	—	20	21	16	17	25	6	—	403
	q	—	14	7	20	39	70	91	8	7	—	—	—	256
	r	—	—	—	1	11	31	37	19	11	4	—	—	114
	u	—	—	—	—	5	—	3	1	3	1	—	6	19
1981	m	25	26	63	14	28	34	42	83	75	235	165	89	879
	n	267	356	159	19	29	21	29	93	75	110	44	57	1259
	o	219	359	139	111	122	261	333	622	433	633	235	94	3561
	p	214	554	52	9	6	16	5	24	15	26	11	5	937
	q	—	—	4	5	15	25	42	17	2	8	—	—	118
	r	—	—	—	—	15	8	30	35	15	6	1	—	110
	u	1	—	1	7	—	14	12	53	39	—	1	—	128

spring. Early in the 1970s, the bank was closed to fishing during March–May as a conservation measure. Also the allocation given to these vessels has declined in recent years in line with departmental policy. Generally these vessels are now allowed to fish both early and late in the year to minimize competition with the smaller vessels. This is a major reason why landings by these vessels are lowest in May–September.

The longline fishery (Table 4) has been operating during most months of the year with peak activity occurring during July–November. The majority of this fishing effort has been expended in unit areas 4Xn and 4Xo. Relatively little longliner activity appears to occur in the Bay of Fundy.

Identification of Sampling Strata

In this section, the patterns described above, as well as known biological characteristics of the haddock population are combined to determine a sampling stratification scheme necessary to ensure adequate coverage of the fleet's landings. For the moment the level of sampling within each stratum is not considered. It will, in general terms, be some function of landings, although there are caveats in this approach, to be described later. In the next section, the historical pattern of sampling is compared to the derived stratification scheme to evaluate the adequacy of sampling coverage.

Based on gear differences alone, sampling levels of otter trawlers, longliners, and miscellaneous gears should be determined separately. Within the otter trawler fleet, two groups are immediately obvious — the tonnage class 1 and tonnage class 4 and 5 vessels. These two groups use dramatically different fishing methods to exploit the stock. The situation with the tonnage class 2 and 3 vessels is more complex. They can fish in areas where both the smallest and largest vessels operate. The tonnage class 3 vessels are slightly more mobile than the tonnage class 2 vessels in this regard. Preliminary evidence shows that this fleet component exploits both small and large fish in the Bay of Fundy but always large fish when on Brown's Bank. Therefore, until further results are available, it is proposed to stratify sampling of these vessels by two areas — 4Xmnop and 4Xqr.

Splitting of the longliner and miscellaneous gear components by either size of vessel or area fished appears unwarranted.

Therefore the 6 sampling strata described are:
1) otter trawl, TC 1
2) otter trawl, TC 2–3 with landings from 4Xmnop
3) otter trawl, TC 2–3 with landings from 4Xqr
4) otter trawl, TC 4–5
5) longline
6) miscellaneous gears.

Strata Coverage

During 1968–81, an average of 48 samples was collected annually (Table 5a). Much of this sampling has been focused on the tonnage class 4 and 5 otter trawlers. For these vessels, the tons landed per sample have averaged 317 (Table 5b) which exceeds considerably the ICNAF/NAFO guidelines of 1000 t per sample (Beckett 1983). Sampling of the longliner fleet has also been good. Coverage of the remaining four strata has, however, been poor, particularly so for the tonnage class 1 vessels.

Another way of looking at sampling coverage is to determine the percentage contribution that the landings from the sampled vessel make towards the total landings of that fleet component. In other words, if a vessel reporting a landing of 50 t is sampled while the entire fleet catch for the time involved was 500 t, then the sampling was representative of 10% of the total landings. Analysis of the 1977–78 otter trawler fleet data, on a monthly basis, indicated that the trip by trip landings of the tonnage class 4 and 5 vessels were very well sampled and samples for the smaller vessels were almost nonexistent (Table 6).

All the above analyses point to an inadequacy of sampling coverage of the landings made by the smaller vessels.

TABLE 5a. Reported nominal catch (t round) of 4X haddock by proposed sampling strata and year. Parentheses indicate number of samples taken by MFD sampling group.

	Otter trawl fleet					
	TC 1	TC 2 & 3			Longliner	Miscellaneous
Year		mnop	qr	TC 4 & 5	fleet	gear
1968	850	2 468 (3)	6 973 (9)	13 835 (36)	1 907	1 244
1969	489	1 828 (6)	3 964 (4)	17 471 (46)	2 322	1 339
1970	196 (1)	2 316 (1)	2 382 (2)	6 500 (22)	2 867	1 298
1971	174 (1)	1 865 (2)	2 250 (3)	7 712 (20)	3 112 (3)	954
1972	145	583 (2)	2 013 (2)	4 750 (22)	3 967 (9)	933 (1)
1973	105	184	1 533 (6)	4 228 (15)	5 785 (9)	701
1974	208 (2)	187	3 554 (6)	1 623 (5)	6 162 (11)	509 (1)
1975	316 (3)	1 919 (7)	3 856 (9)	4 409 (28)	4 943 (8)	548 (1)
1976	310	1 041 (1)	2 997 (3)	6 144 (33)	4 637 (5)	1 165 (3)
1977	456	3 196 (3)	2 533 (3)	8 345 (65)	4 035 (9)	996
1978	930	5 064	3 219	8 093 (48)	6 049 (10)	1 946 (4)
1979	880	4 604 (2)	4 386	8 634 (33)	4 348 (12)	1 435 (2)
1980	2 136	5 473 (10)	5 046 (2)	7 440 (23)	5 717 (17)	2 403 (4)
1981	2 021 (1)	7 647 (23)	4 931 (17)	6 647 (7)	6 995 (25)	1 915 (8)

TABLE 5b. Reported nominal catch (t round) per sample by proposed sampling strata and year.

Year	Otter trawl fleet TC 1	TC 2 & 3 mnop	TC 2 & 3 qr	TC 4 & 5	Longliner fleet	Miscellaneous gear
1968	—	823	775	384	—	—
1969	—	305	991	380	—	—
1970	196	2316	1191	295	—	—
1971	174	933	750	386	1037	—
1972	—	292	1007	216	441	933
1973	—	—	256	282	643	—
1974	104	—	592	325	560	509
1975	105	274	428	157	618	548
1976	—	1041	999	186	927	388
1977	—	1065	844	128	448	—
1978	—	—	—	169	605	487
1979	—	2302	—	262	362	718
1980	—	547	2523	323	336	601
1981	2021	332	290	950	280	239
$\overline{X}$	520	930	887	317	569	553

TABLE 6. Percentage (total weight sampled/total weight landed) of the 1977 and 1978 4X haddock otter trawler landings observed by MFD sampling personnel.

Year	Month	Tonnage class 1	2	3	4	5	Total
1977	J	—	—	—	22	21	21
	F	—	—	4	30	87	47
	M	—	—	—	79	92	78
	A	—	—	—	36	13	17
	M	—	—	—	38	3	11
	J	—	—	—	48	6	11
	J	—	—	—	—	—	—
	A	—	—	—	50	—	10
	S	—	8	16	27	—	14
	O	—	—	—	10	19	8
	N	—	—	—	17	12	11
	D	—	—	—	—	25	16
Total		—	1	2	38	39	23
1978	J	—	—	—	67	15	29
	F	—	—	—	37	57	20
	M	—	—	—	35	31	28
	A	—	—	—	9	—	2
	M	—	—	—	23	28	12
	J	—	—	—	74	12	16
	J	—	—	—	120[a]	53	37
	A	—	—	—	—	—	—
	S	—	—	—	64	—	1
	O	—	—	—	—	—	—
	N	—	—	—	—	—	—
	D	—	—	—	1	—	<1
Total		—	—	—	45	21	15

[a]There appears to be an error in the catch statistics for this month.

Unfortunately, a simple reallocation of sampling effort does not appear possible. Baird and Stevenson (1983) point out that between vessel variation of size composition is greater than within vessel variation. Within the 4X haddock fishery, there are considerably more tonnage class 1, 2, and 3 vessels operating than those in the larger size categories. Thus a shift to sampling of the smaller vessels may result in an overall increase in size composition variation if sampling effort is not increased. This is above and beyond the operational problems involved in sampling hundreds of small boats operating out of as many ports.

An appreciation of the impact of sampling more heavily within the smaller vessel stratum can be realized by examining the 1977–78 otter trawler realized average trip weights-per-sample (Table 7). In these 2 yr, about 26 000 fish were measured and 3700 otoliths read. The average catch per trip for the tonnage class 2 and 3 sampled vessels was 12.1 and 17.8 t, respectively. This compares with 45.9 and 62.9 t per trip for the tonnage class 4 and 5 sampled vessels. On a trip by trip basis, sampling coverage was about 19% for the entire fleet. The figures in Table 8 were generated using the total catch landed for each tonnage class (Table 7), selecting an arbitrary coverage level of 10% and dividing that 10% value by the average catch weight per trip (Table 7) to obtain the probable number of samples required. The numbers measured and aged in Table 8 were calculated using the average values per sample of Table 7. Interestingly, the number of specimens measured and aged remain about the same. Thus the trade-off would be reduced overall coverage, from 19 to 10%, for a more even coverage of the sample strata.

Before examining intrastratum variation, it was considered worthwhile to verify that the stratification scheme proposed earlier had some basis in the size-frequency data.

TABLE 7. Average trip weight for the 1977–78 4X haddock otter trawl samples.

Year		Tonnage class 1	2	3	4	5	Total
1977	Catch (t)[a]	456	2 217	3 543	3 639	4 656	14 561
	Catch/trip (t)	—	12.1	17.8	42.2	58.5	47.2
	Number of samples	—	2	4	33	31	70
	No. measured	—	400	884	7 132	6 700	15 116
	No. aged	—	59	88	1 094	993	2 234
	%coverage[b]	—	1.1	2.0	37.8	38.9	22.7
1978	Catch (t)[a]	931	3 441	4 936	3 860	4 233	17 400
	Catch/trip (t)	—	—	—	49.6	67.3	54.4
	Number of samples	—	—	—	35	13	48
	No. measured	—	—	—	8 413	2 800	11 213
	No. aged	—	—	—	2 097	337	1 434
	% coverage[b]	—	—	—	45.0	20.7	15.0
Mean	Catch/trip (t)	12.1[c]	12.1	17.8	45.9	62.9	50.8
	No. measured sample	200	200	221	124	216	22.5
	No. aged/sample	30	30	22	32	30	31
	% coverage[b]	—	1.1	2.0	41.4	29.8	18.9

[a]Total annual catch for that tonnage class.
[b]Number of trips sampled/total number of trips.
[c]Assumed tonnage class 2 conditions.

Length-frequency data for the otter trawler and longliner fleets fishing in 4Xm-q were compared for the 1975–80 period (Fig. 2). In general, longliners landed considerably larger fish than did otter trawlers. This difference is particularly evident in 1975 when the modes were 47 and 62 cm for the otter trawler and longliner samples, respectively.

The size composition data for the tonnage class 2 and 3 otter trawlers fishing both inside and outside the Bay of Fundy were examined for the 1970–80 period, excluding 1977–79 (Fig. 3) when no data were available. In all years except 1980, the landings from 4Xr contained a substantially higher proportion of fish smaller than those landed from 4Xm-p. Although not shown here, samples from 4Xq compared more closely to those from 4Xr than those from 4Xm-p (O'Boyle et al. 1981). These comparisons were by no means consistent over years. This may be due to differential areal fishing within 4Xq, i.e. nearshore fishing in 4Xq produces small fish while fishing further offshore produces large fish. Unfortunately, available log record data do not provide positional information to fine enough resolution to assist in interpretation of this situation. This problem clearly points to a need for the collection of positional information to a much finer degree of accuracy than is now the case.

These observations indicate that fish smaller then 40 cm total length are concentrating in the Bay of Fundy area. This is in general agreement with previous observations on the fishery (O'Boyle 1981; O'Boyle et al. 1981). Preliminary reports from 1982 field operations indicate that vessels fishing closer to shore use smaller mesh gear.

Unfortunately, there is not enough data to examine the landings of the tonnage class 1 vessels. However, preliminary reports from 1982 field operations indicate that these vessels are catching fish comparable in size to those being caught by tonnage class 2 and 3 vessels operating in the Bay of Fundy. Thus there may be no need to have a separate stratum for this fleet component.

TABLE 8. Sampling intensity required to maintain a 10% even (across all tonnage classes) coverage of the 1977 and 1978 4X haddock otter trawler fisheries, assuming catch conditions outlined in Table 7.

Year		Tonnage class 1	2	3	4	5	Total
1977	Catch (t)	456	2 217	3 543	3 689	4 656	14 561
	Total catch sampled (t)	46	222	354	369	466	2 456
	Number of samples	4	18	20	8	7	57
	No. measured	748	3 600	4 420	992	1 512	11 272
	No. aged	120	540	440	256	210	1 566
1978	Catch (t)	931	3 441	4 936	3 860	4 233	17 400
	Total catch sampled (t)	93	344	494	386	423	1 740
	Number of samples	8	28	28	8	7	79
	No. measured	1 600	5 600	6 188	3 472	1 512	18 372
	No. aged	240	840	616	256	210	2 162

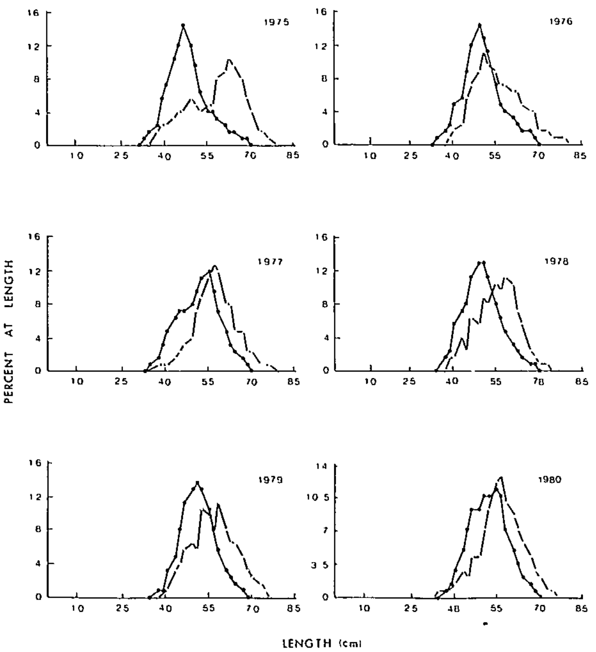

FIG. 2. Length-frequency compositions (percent) for the 1975–80 4X haddock longliner and otter trawl landings samples collected in 4Xm-q. Plot with closed circles indicates otter trawlers and plot with open circles indicates longliners.

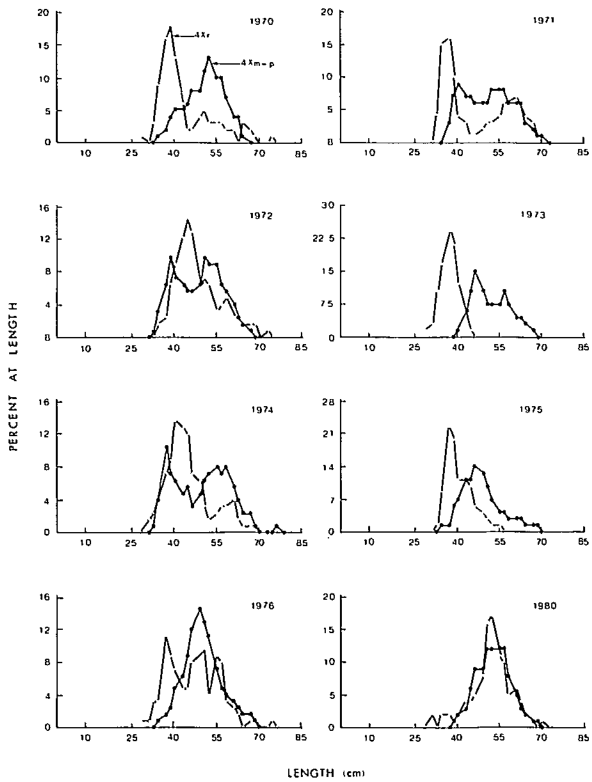

FIG. 3. Length-frequency compositions (percent) for 1970–80 4X haddock otter trawl (TC 2-3) samples collected in 4Xm-q and 4Xr. Plot with open circles is always 4Xr.

In summary, analysis of the historical data set supports the stratification scheme proposed in the previous section. The in-depth study conducted during the 1982 fishing season once analyzed will provide valuable information on strata boundaries and may lead to changes in the proposed stratification scheme.

SIZE COMPARISONS WITHIN STRATA

The most extensive data set for the 1968–81 period is that of the tonnage class 4 and 5 trawlers operating in 4Xm-p during 1977 and 1978. Sampling in February and March 1977 was particularly good, with 10 and 11 samples being collected, respectively. This data set was examined in detail to describe the level of variation present within the defined strata.

The method used was that developed by Smith and Maguire (1983). Full details on the method are given in that document. The method was first applied to the 10 length-frequency samples of the February otter trawler (tonnage class 5) fishery. Of the 45 comparisons, 25 were found to be significantly different at the 5% level by the paired comparisons test in Smith and Maguire (1983). The results are expressed in Table 9 as the number of significant comparisons for a particular sample and length group. For sample number 31, out of nine possible comparisons with the other samples, six (67%) were found to be significantly different in the 40.5-cm group and seven (78%) in the 42.5-cm group. Using this technique, it is readily apparent that many of the significant comparisons in the data set are due to one sample, number 31. When this sample is removed and the analysis repeated, the number of significant differences drops dramatically (Table 9). Figure 4 shows the individual length-frequency curves for these samples. Sample number 31 has a size distribution substantially skewed towards the smaller lengths.

The reason for this is not immediately apparent. K. Zwanenburg (Marine Fish Division, Bedford Institute of Oceanography, Dartmouth, N.S., personal communication) recorded an instance where a sample was considerably different in size composition from those collected from other vessels in the same area. It transpired that the vessel had been fishing near shore just before coming in to port and the port technician had fortuitously sampled the particular part of the hold containing the most recent catch. It is impossible to state here without more data whether or not this occurred in the 1977 data. Analysis of the ship's log records would be useful in this regard.

Analyses of the February tonnage class 4 and March tonnage class 5 data sets resulted in comparable conclusions (Tables 10, 11). In both cases, one sample was found to be comprised of substantial numbers of small fish (sample number 102 in the March tonnage class 5 samples and sample number 38 in the February tonnage class 4 samples).

The March tonnage class 4 samples were generally very similar to each other (Table 11) and no one sample could be seen to be causing high variance in the comparisons.

TABLE 9. Enumeration of number of significant chi-square comparisons by length group (cm) for samples of landings by the February 1977 tonnage class 5 otter trawl fishery operating in 4Xm-p.

A. NUMBER OF SIGNIFICANT COMPARISONS.

1) With sample 31.

Sample number

1)	31	33	46	67	35	47	48	65	66	68
32.5	0	0	0	0	0	0	0	0	0	0
34.5	0	0	0	0	0	0	0	0	0	0
36.5	9	1	1	1	1	1	1	1	1	1
38.5	9	1	1	1	1	1	1	1	1	1
40.5	6	0	1	1	1	1	1	0	0	1
42.5	7	1	1	1	2	1	1	0	1	1
44.5	2	1	0	0	2	0	0	0	0	1
46.5	0	0	0	0	0	0	0	0	0	0
48.5	1	0	0	2	2	2	3	0	0	0
50.5	0	1	1	1	1	6	2	1	1	0
52.5	2	0	4	0	1	3	1	1	0	2
54.5	4	1	0	0	1	1	0	0	0	1
56.5	3	1	0	0	2	1	1	0	0	0
58.5	4	3	3	0	1	3	3	0	3	0
60.5	2	1	1	0	5	1	0	1	0	1
62.5	3	0	1	0	0	0	0	1	0	1
64.5	2	0	0	1	0	0	1	0	0	0
66.5	0	0	0	0	0	0	0	0	0	0
68.5	0	0	0	0	0	0	0	0	0	0
70.5	0	0	0	0	0	0	0	0	0	0
72.5	0	0	0	0	0	0	0	0	0	0
74.5	0	0	0	0	0	0	0	0	0	0
76.5	0	0	0	0	0	0	0	0	0	0

2) Without sample 31.

Sample number

2)	33	46	67	35	47	48	65	66	68
34.5	0	0	0	0	0	0	0	0	0
36.5	0	0	0	0	0	0	0	0	0
38.5	0	0	0	0	0	0	0	0	0
40.5	0	0	0	0	0	0	0	0	0
42.5	0	0	0	1	0	0	0	1	0
44.5	1	0	0	1	0	0	0	0	0
46.5	0	0	0	0	0	0	0	0	0
48.5	0	0	2	2	2	2	0	0	0
50.5	1	1	1	1	6	2	1	1	0
52.5	0	4	0	1	2	1	1	0	1
54.5	0	0	0	0	0	0	0	0	0
56.5	0	0	0	1	1	0	0	0	0
58.5	3	2	0	0	3	2	0	2	0
60.5	1	0	0	4	1	0	1	0	1
62.5	0	0	0	0	0	0	0	0	0
64.5	0	0	0	0	0	0	0	0	0
66.5	0	0	0	0	0	0	0	0	0
68.5	0	0	0	0	0	0	0	0	0
70.5	0	0	0	0	0	0	0	0	0
72.5	0	0	0	0	0	0	0	0	0
74.5	0	0	0	0	0	0	0	0	0
76.5	0	0	0	0	0	0	0	0	0

B. PERCENTAGE OF SIGNIFICANT COMPARISONS.

1) With sample 31.

Sample number

	31	33	46	67	35	47	48	65	66	68
32.5	0	0	0	0	0	0	0	0	0	0
34.5	0	0	0	0	0	0	0	0	0	0
36.5	100	12	12	12	12	12	12	12	12	12
38.5	100	12	12	12	12	12	12	12	12	12
40.5	67	0	12	12	12	12	12	0	0	12
42.5	78	12	12	12	23	12	12	0	12	12
44.5	23	12	0	0	23	0	0	0	0	12
46.5	0	0	0	0	0	0	0	0	0	0
48.5	12	0	0	23	23	23	34	0	0	0
50.5	0	12	12	12	12	67	23	12	12	0
52.5	23	0	45	0	12	34	12	12	0	23
54.5	45	12	0	0	12	12	0	0	0	12
56.5	34	12	0	0	23	12	12	0	0	0
58.5	45	34	34	0	12	34	34	0	34	0
60.5	23	12	12	0	56	12	0	12	0	12
62.5	34	0	12	0	0	0	0	12	0	12
64.5	23	0	0	12	0	0	12	0	0	0
66.5	0	0	0	0	0	0	0	0	0	0
68.5	0	0	0	0	0	0	0	0	0	0
70.5	0	0	0	0	0	0	0	0	0	0
72.5	0	0	0	0	0	0	0	0	0	0
74.5	0	0	0	0	0	0	0	0	0	0
76.5	0	0	0	0	0	0	0	0	0	0

2) Without sample 31.

Sample number

	33	46	67	35	47	48	65	66	68
34.5	0	0	0	0	0	0	0	0	0
36.5	0	0	0	0	0	0	0	0	0
38.5	0	0	0	0	0	0	0	0	0
40.5	0	0	0	0	0	0	0	0	0
42.5	0	0	0	12	0	0	0	12	0
44.5	12	0	0	12	0	0	0	0	0
46.5	0	0	0	0	0	0	0	0	0
48.5	0	0	25	25	25	25	0	0	0
50.5	12	12	12	12	75	25	12	12	0
52.5	0	50	0	12	25	12	12	0	12
54.5	0	0	0	0	0	0	0	0	0
56.5	0	0	0	12	12	0	0	0	0
58.5	37	25	0	0	37	25	0	25	0
60.5	12	0	0	50	12	0	12	0	12
62.5	0	0	0	0	0	0	0	0	0
64.5	0	0	0	0	0	0	0	0	0
66.5	0	0	0	0	0	0	0	0	0
68.5	0	0	0	0	0	0	0	0	0
70.5	0	0	0	0	0	0	0	0	0
72.5	0	0	0	0	0	0	0	0	0
74.5	0	0	0	0	0	0	0	0	0
76.5	0	0	0	0	0	0	0	0	0

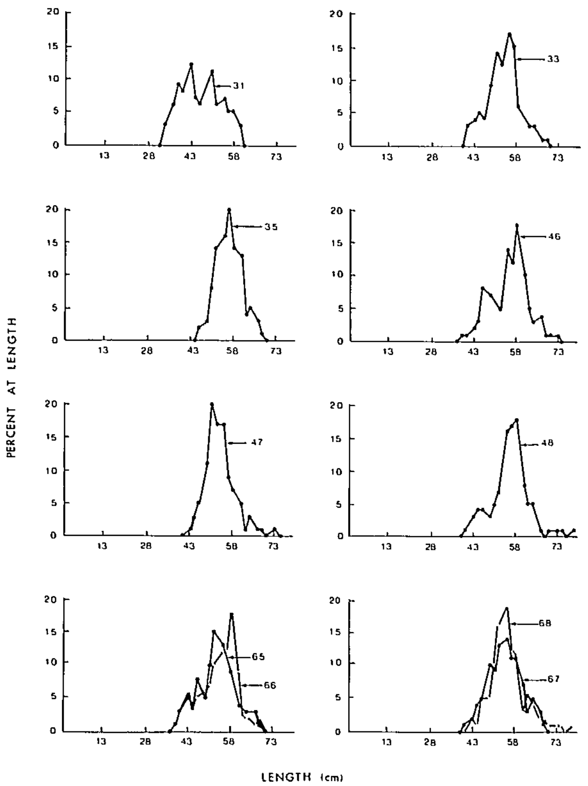

FIG. 4. Percentage at length plotted for the ten samples taken in February of 1977 (gear-OTB-2 TC 5). The corresponding number is the sample number.

These results are encouraging. With the exception of specific samples, there was a fair degree of homogeneity within strata. Techniques are presently being developed to quantify the level of variation and thus allow establishment of ideal sampling levels. For the moment, however, the above technique is useful in determining data set outliers.

It was felt instructive to extend this analysis to cover an entire year's data set.

For the tonnage class 4 samples, both samples 18 and 38 are substantially different from anything else present in the data set (Table 12). The same is true for sample 177 (May), 228(June), and 458(September). In the tonnage class 5 data set (Table 13), sample numbers 31 (February), 102 (March), and 508 (October) have high numbers of significant comparisons. In all cases, these differences were due to substantial numbers of fish present in the lower end of the length frequency.

These findings are similar to those of Dickie (1964). He found that a major component of between sample variance was contributed by one or two samples in a data series. The heterogeneity reflected the fact that fishing takes place on separate concentrations of fish with different biological characteristics. The analysis was carried further in Dickie and Paloheimo (1965) in which the authors stated that heterogeneity in the distribution of fish was so high as to preclude establishment of any reliable sampling program. The present authors recognize the high variability, most of which may be due to spatial differences. However, broad patterns are discernible and the definition of sampling strata possible. Within these, variations can be reduced by establishment of recording systems that can assist in the explanation of "aberrant" samples.

PRESENT CONSTRUCTION OF THE CATCH AT AGE

The previous section pointed out that there can be a fair amount of variation in the size composition samples of a commercial fleet's yield. One would think that this variation obfuscates the identification of year-classes in the fishery. The intriguing thing is that the resultant catch at age matrix does show clear patterns in year-class strength which the fisherman will tell you are there and agree with groundfish research vessel results (O'Boyle 1981).

At present, the catch-at-age matrix is being constructed through application of samples to the catch using the stratification scheme presented above. Until sampling improves, tonnage class 1 catches will be lumped with those of tonnage classes 2 and 3 for the appropriate area. As well, miscellaneous gear catches will be lumped with those of longliners.

Within each stratum, one age-length key is constructed for each quarter and applied to the respective combined length frequency to provide an age composition per weight of landed catch.

This procedure will be used until more powerful statistical tools become available. McGlade and Smith (1983) have introduced the method of defining strata using Principle Component Analysis. As well, G. N. White III (Marine Fish Division, Bedford Institute of Oceanography, Dartmouth, N.S., personal communication) feels that Jackknife and Bootstrap methods (Smith 1980) may be useful in quantifying within stratum variance. Thus, very shortly, an array of procedures will become available which will allow both sample design modifications and construction of catch-at-age matrices based on statistical as well as practical grounds.

Summary and Recommendations

Rivard and Doubleday (1979) determined, using sensitivity analysis, that the accuracy of the current year's catch at age has considerable influence on the population at age estimates generated by cohort analysis for that year. It is thus of some importance that representative sampling of the commercial landings be conducted. Due to the complexities of commercial fishing operations, it then becomes all important to define the various fleet components and sample each adequately.

In the case of the 4X haddock fishery, sampling over the 1968–81 period has been primarily directed at the landings of the tonnage class 4 and 5 otter trawlers. Historically, landings from this fleet sector did indeed dominate the catch. More recently, however, landings from the tonnage class 1–3 vessels have dramatically increased. These two fleet components tend to fish in different areas at different

TABLE 10. Enumeration of number of significant chi-square comparisons by length group — for samples of landings by the March 1977 tonnage class 5 otter trawl fishery operating in 4Xm-p.

A. NUMBER OF SIGNIFICANT COMPARISONS.

	Sample number										
	123	79	104	69	70	107	105	101	134	102	153
32.5	0	0	0	0	0	0	0	0	0	0	0
34.5	0	0	0	0	0	0	0	0	0	0	0
36.5	0	0	0	0	0	0	0	0	0	0	0
38.5	1	1	0	1	1	1	1	0	1	8	1
40.5	1	2	1	2	2	1	1	5	2	10	1
42.5	1	1	1	3	3	3	3	4	1	9	1
44.5	4	4	0	4	4	3	1	3	2	6	1
46.5	1	0	0	2	0	2	0	0	2	3	0
48.5	0	0	0	0	0	0	0	0	0	0	0
50.5	2	1	9	1	1	1	2	1	1	1	2
52.5	3	1	3	3	1	0	4	4	4	5	0
54.5	1	1	1	2	1	1	1	2	3	9	2
56.5	0	1	1	1	0	0	0	1	1	5	0
58.5	2	2	2	0	0	0	0	0	0	2	0
60.5	4	0	1	4	1	4	2	2	0	2	0
62.5	0	1	1	7	0	1	1	1	1	2	1
64.5	5	2	0	4	0	2	1	2	1	2	0
66.5	0	0	0	0	0	0	0	0	0	0	0
68.5	2	0	0	0	0	1	0	0	1	0	0
70.5	0	0	0	0	0	0	0	0	0	0	0
72.5	0	0	0	0	0	0	0	0	0	0	0
74.5	0	0	0	0	0	0	0	0	0	0	0
76.5	0	0	0	0	0	0	0	0	0	0	0

B. PERCENTAGE OF SIGNIFICANT COMPARISONS.

	Sample number										
	123	79	104	69	70	107	105	101	134	102	153
32.5	0	0	0	0	0	0	0	0	0	0	0
34.5	0	0	0	0	0	0	0	0	0	0	0
36.5	0	0	0	0	0	0	0	0	0	0	0
38.5	10	10	0	10	10	10	10	0	10	80	10
40.5	10	20	10	20	20	10	10	50	20	100	10
42.5	10	10	10	30	30	30	30	40	10	90	10
44.5	40	40	0	40	40	30	10	30	20	60	10
46.5	10	0	0	20	0	20	0	0	20	30	0
48.5	0	0	0	0	0	0	0	0	0	0	0
50.5	20	10	90	10	10	10	20	10	10	10	20
52.5	30	10	30	30	10	0	40	40	40	50	0
54.5	10	10	10	20	10	10	10	20	30	90	20
56.5	0	10	10	10	0	0	0	10	10	50	0
58.5	20	20	20	0	0	0	0	0	0	20	0
60.5	40	0	10	40	10	40	20	20	0	20	0
62.5	0	10	10	70	0	10	10	10	10	20	10
64.5	50	20	0	40	0	20	10	20	0	20	0
66.5	0	0	0	0	0	0	0	0	0	0	0
68.5	20	0	0	0	0	10	0	0	10	0	0
70.5	0	0	0	0	0	0	0	0	0	0	0
72.5	0	0	0	0	0	0	0	0	0	0	0
74.5	0	0	0	0	0	0	0	0	0	0	0
76.5	0	0	0	0	0	0	0	0	0		0

TABLE 11. Enumeration of number of significant chi-square comparisons by length group (cm) for samples of landings by the February and March 1977 tonnage class 4 otter trawl fishery operating in 4Xm-p.

A. NUMBER OF SIGNIFICANT COMPARISONS.

February	Sample number							March	Sample number						
	34	18	32	38	39	61	19		62	91	78	144	122	135	120
34.5	0	0	0	0	0	0	0	34.5	0	0	0	0	0	0	0
36.5	1	1	1	6	1	1	1	36.5	0	0	0	0	0	0	0
38.5	1	2	1	6	1	1	2	38.5	0	0	0	0	0	0	0
40.5	1	4	1	5	2	1	2	40.5	0	0	1	1	0	0	0
42.5	1	4	2	2	0	1	0	42.5	0	0	0	2	1	0	1
44.5	0	2	0	2	0	2	2	44.5	0	0	0	0	0	0	0
46.5	0	1	0	0	0	1	0	46.5	0	0	0	0	0	0	0
48.5	0	0	0	1	0	1	0	48.5	0	0	0	0	0	0	0
50.5	0	0	0	0	0	0	0	50.5	0	0	0	0	0	0	0
52.5	0	0	0	1	0	1	0	52.5	1	1	3	4	1	1	1
54.5	1	1	2	5	1	1	1	54.5	0	0	0	0	0	0	0
56.5	1	1	1	6	1	1	1	56.5	0	0	0	0	0	0	0
58.5	1	0	1	3	0	0	1	58.5	0	0	0	0	0	0	0
60.5	0	2	0	1	0	1	0	60.5	0	0	0	0	0	0	0
62.5	0	3	1	1	0	1	0	62.5	0	0	0	0	0	0	0
64.5	0	0	0	0	0	0	0	64.5	0	0	0	0	0	0	0
66.5	1	6	1	1	1	1	1	66.5	0	0	0	0	0	0	0
68.4	0	4	1	1	0	1	1	68.4	0	0	0	0	0	0	0
70.5	0	0	0	0	0	0	0	68.5	0	0	0	0	0	0	0
72.5	0	0	0	0	0	0	0	72.5	0	0	0	0	0	0	0
74.5	0	0	0	0	0	0	0								

B. PERCENTAGE OF SIGNIFICANT COMPARISONS.

February	Sample number							March	Sample number						
	34	18	32	38	39	61	19		62	91	78	144	122	135	120
34.5	0	0	0	0	0	0	0	34.5	0	0	0	0	0	0	0
36.5	17	17	17	100	17	17	17	36.5	0	0	0	0	0	0	0
38.5	17	34	17	100	17	17	34	38.5	0	0	0	0	0	0	0
40.5	17	67	17	84	34	17	34	40.5	0	0	17	17	0	0	0
42.5	17	67	17	17	0	17	0	42.5	0	0	0	34	17	0	17
44.5	0	34	0	34	0	34	34	44.5	0	0	0	0	0	0	0
46.5	0	17	0	0	0	17	0	46.5	0	0	0	0	0	0	0
48.5	0	0	0	17	0	17	0	48.5	0	0	0	0	0	0	0
50.5	0	0	0	0	0	0	0	50.5	0	0	0	0	0	0	0
52.5	0	0	0	17	0	17	0	52.5	17	17	50	67	17	17	17
54.5	17	17	34	84	17	17	17	54.5	0	0	0	0	0	0	0
56.5	17	17	17	100	17	17	17	56.5	0	0	0	0	0	0	0
58.5	17	0	17	50	0	0	17	58.5	0	0	0	0	0	0	0
60.5	0	34	0	17	0	17	0	60.5	0	0	0	0	0	0	0
62.5	0	50	17	17	0	17	0	62.5	0	0	0	0	0	0	0
64.5	0	0	0	0	0	0	0	64.5	0	0	0	0	0	0	0
66.5	17	100	17	17	17	17	17	66.5	0	0	0	0	0	0	0
68.5	0	67	17	17	0	17	17	68.5	0	0	0	0	0	0	0
70.5	0	0	0	0	0	0	0	70.5	0	0	0	0	0	0	0
72.5	0	0	0	0	0	0	0	72.5	0	0	0	0	0	0	0
74.5	0	0	0	0	0	0	0								

TABLE 12. Enumeration of number of significant chi-square comparisons by length group (cm) for samples of landings by the 1977 tonnage class 4 otter trawl fishery operating in 4Xm-p.

	Jan.		Feb.							Mar.							Apr.			May		June					Aug.		Sept.	Oct.	Nov.	
Sample no.	9	12	19	34	18	32	38	39	61	62	91	78	144	122	135	120	154	165	166	177	176	236	227	250	228	199	354	353	458	509	541	542
9	-	4	1	-	7	1	4	1	2	3	-	-	4	1	3	1	1	3	2	1	-	-	-	-	1	-	-	1	6	-	-	1
12	-	-	-	2	1	2	8	-	2	-	-	-	-	1	1	2	-	1	-	5	-	3	2	6	6	-	4	3	22	7	1	5
19	-	-	-	-	4	-	7	-	-	-	-	-	1	-	1	-	-	-	-	3	-	2	1	4	2	-	2	1	9	4	-	2
34	-	-	-	-	1	1	5	-	-	-	-	-	1	-	1	-	1	1	3	3	-	1	-	1	5	-	-	1	6	1	-	1
18	-	-	-	-	-	5	11	1	7	3	3	5	5	4	4	7	1	1	5	9	1	7	4	8	10	3	7	7	15	9	4	6
32	-	-	-	-	-	-	5	-	-	2	-	-	4	-	1	-	1	1	-	2	1	-	-	1	2	-	-	1	6	1	1	2
38	-	-	-	-	-	-	-	5	7	9	5	5	6	5	6	6	7	8	6	1	5	2	6	3	1	6	4	4	3	2	5	3
39	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	1	-	2	6	-	-	8	1	-		-
61	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	3	-	-	-	-	3	-	-	-	8	2	2	1
62	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	4	-	2	2	4	6	-	2	4	9	4	1	3
91	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	2	-	-	-	-	4	-	-	-	8	2	1	3
78	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	1	1	1	-	-	-	1	2	-	-	-	6	1	-	1
144	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2	1	1	1	5	-	3	2	4	7	1	4	4	10	6	3	4
122	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	3	-	-	-	1	3	-	1	1	7	1	1	1
135	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	3	-	2	-	1	3	-	1	1	7	3	1	3
120	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	3	-	-	-	-	4	-	-	1	7	-	-	-
154	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	1	1	4	6	-	-	2	11	4	1	2
165	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	6	1	3	2	5	9	1	2	2	9	5	2	4
166	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	2	1	4	6	1	2	1	6	4	2	2
177	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	1	1	-	-	4	2	-	5	-	3	-
176	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	4	-	-	-	10	-	-	-
236	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-	7	-	-	-
227	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-	-	7	2	-	2
250	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-	6	-	2	1
228	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	2	1	3	-	3	-
199	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	2	-	2
354	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-	1
353	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-	-
458	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	7	3
509	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
541	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
542	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 13. Enumeration of number of significant chi-square comparisons by length group (cm) for samples of landings by the 1977 tonnage class 5 otter trawl fishery operating in 4Xm-p.

	Jan.			Feb.										Mar.										Apr.	May	June	Oct.		Nov.	Dec.
Sample no.	3	6	8	31	33	46	67	35	47	48	65	66	68	123	79	104	69	70	107	105	101	134	102	153	164	184	251	508	496	545	568
3	—	—	1	3	2	2	2	4	4	1	—	1	1	2	3	—	2	3	1	2	1	4	2	2	5	2	1	9	2	6	1
6	—	—	—	2	—	1	—	3	1	—	—	—	—	—	—	—	3	2	—	1	—	1	4	1	2	—	—	6	—	6	—
8	—	—	—	2	—	1	—	3	1	1	—	1	—	—	—	1	1	2	1	1	3	3	2	2	1	1	1	8	1	2	—
31	—	—	—	—	4	6	5	9	5	7	3	3	8	8	4	4	10	7	2	4	3	6	—	3	1	—	4	2	4	4	2
33	—	—	—	—	—	1	—	2	—	2	—	1	—	2	—	—	2	—	—	—	—	—	5	—	1	1	—	8	—	5	—
46	—	—	—	—	—	—	—	1	2	—	1	—	1	—	1	—	1	2	3	2	2	2	8	3	4	4	2	9	3	7	—
67	—	—	—	—	—	—	—	1	—	1	—	—	—	—	1	—	1	—	1	—	—	—	7	—	2	3	1	8	—	3	—
35	—	—	—	—	—	—	—	—	4	—	1	1	1	1	4	1	1	1	5	1	4	1	10	1	7	6	5	11	6	10	5
47	—	—	—	—	—	—	—	—	—	4	1	2	—	1	—	1	1	—	—	—	1	—	7	—	2	2	3	9	—	6	1
48	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	1	2	2	1	2	9	1	3	5	2	10	5	7	2
65	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	—	2	—	—	8	1	6	—
66	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	2	2	2	2	1	1	7	1	3	2	1	8	2	7	—
68	—	—	—	—	—	—	—	—	—	—	—	—	—	1	2	1	1	—	1	—	2	—	8	—	5	4	2	9	1	8	2
123	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	2	4	4	—	9	1	5	6	4	9	5	7	3
79	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	3	1	—	—	1	—	5	—	1	1	—	6	—	6	1
104	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	2	2	1	6	1	4	3	2	7	2	8	—
69	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	3	7	3	9	2	6	7	5	12	5	7	5
70	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	3	—	5	—	4	5	3	10	8	6	4
107	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	3	—	2	—	—	4	—	3	2
105	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	6	—	3	2	2	8	—	5	1
101	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	5	—	2	—	1	6	—	6	—
134	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	—	5	4	4	9	1	7	3
102	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	5	—	3	—	5	1	3
153	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	3	3	10	1	6	2
164	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	2	5	1	3	2
184	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	4	2	2	—
251	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	—	2	—
508	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	1	5
496	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	—
545	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
568	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

times of the year. Consequently, continuation of sampling of the tonnage classes 4 and 5 to the same degree as was done previously could lead to substantial biases in the determined catch age composition. However, it is also recognized that enhanced sampling of the catches by the tonnage class 1–3 vessels could mean substantial increases in both field and laboratory work.

Within the samples for the tonnage classes 4 and 5 vessels, high variability was observed. Much of this appeared to be due to the causal presence of samples containing large numbers of fish at the lower end of the length frequency. There are a number of possible reasons for this. First is the area fished. If the vessel had fished close to shore, such a distribution might be expected. Also, trawl codend mesh size is a factor. The small vessels fishing in 4Xr use codend meshes less than 120 mm and catch substantially smaller fish than those using 130 mm. Another factor is the onboard processing practices. In the large "company" ships, these should be fairly standard. However, the degree of culling aboard smaller vessels may vary substantially. Finally, onshore sampling may not be representative of the vessel's catch (Belzile 1978).

The first three items can at least be partially addressed by enhancing the existing data gathering systems. Port samplers could ask the vessel's skipper about gear characteristics, catch processing, areas of capture, etc., to obtain background information useful in interpretation of the sampling data. As well, the log book information should be standardly computerized and linked with the sample data base. J. M. McGlade (Marine Fish Division, Bedford Institute of Oceanography, Dartmouth, N.S., personal communication) carried out this process manually and showed quite dramatically how useful such a link could be.

The last item, that of representative sampling of a particular vessel's landings, requires more information on how the vessel stores its catch. Some categorization of this process would aid the statisticians in determining the best method of sampling. Thus, port samplers could have more specific instructions on sampling, tailored more closely to the storage method employed by the vessel.

The construction of the catch-at-age matrix is presently being carried out using the stratification scheme outlined in this document. The enhancement of this method will have to await the development of statistical methods necessary for the comparison of age-length keys. Along with these procedures will hopefully come variance estimates that will allow decisionmaking on the required level of sampling effort.

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Principal Component Methods for Exploratory Data Analysis of Commercial Length-Frequency Data

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McGlade, J. M., and S. J. Smith. 1983. Principal component methods for exploratory data analysis of commercial length-frequency data, p. 235–239. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Length-frequency data from 26 unculled samples of pollock (*Pollachius virens* L.) in the 1981 fishery were examined with a principal component analysis. A visual analysis of the plot of the first and second prinicipal component scores for each sample showed that the associated mean lengths were distributed in an anticlockwise pattern, from small (51.71 cm) to large (74.18 cm). This pattern could not be simply explained by the temporal succession of samples. Rather, anomalies in the associated temporal patterns could be attributed to the influx of juvenile pollock to offshore aggregations of adult fish, as inferred from the age composition of the fish in each sample. This observation concurs with the known biology of the species. The implications of this event are that any assumption of randomness in the reconstruction of ages in the catch is violated. It was concluded that principal component analysis is an invaluable exploratory tool that can be used to identify spatial and temporal patterns amongst length-frequency data.

McGlade, J. M., and S. J. Smith. 1983. Principal component methods for exploratory data analysis of commercial length-frequency data, p. 235–239. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

On applique ici l'analyse des composantes principales à des données sur les fréquences de longueurs, représentant 26 échantillons de goberges (*Pollachius virens* L.) pêchées en 1981. L'inspection visuelle d'un graphique dont les axes représentent les première et deuxième composantes principales révèle que les échantillons ont tendance à se ranger par ordre croissant par rapport à la longueur moyenne, se répartissant du plus petit (51,71 cm) au plus grand (74,18 cm) dans le sens contraire des aiguilles d'une montre. Cet arrangement ne peut s'expliquer simplement par la succession temporelle des échantillons. Plutôt, des anomalies dans l'ordonnance temporelle peuvent être imputées à un influx de goberges juvéniles dans les concentrations hauturières de goberges adultes, tel que suggéré par la composition en âge des poissons dans chaque échantillon. Cette observation concorde avec notre connaissance de la biologie de cette espèce et suggère que l'hypothèse de distribution aléatoire, qui est sous-jacente à la reconstruction des ages présents dans la prise, n'est pas réalisée. On conclut que l'analyse des composantes principales est un outil exploratoire inestimable, pouvant être utilisé pour identifier les ordonnances spatiales et temporelles présentes dans les données sur les fréquences de longueurs.

Introduction

The analytical models currently used to assess many of the fish stocks in the northwestern Atlantic have as their underpinning, data in the form of length frequencies. In the Marine Fish Division, port technicians collect these data from samples of the annual commercial fish catch. These samples are obtained throughout the fishing season and are putatively representative of catches taken by the various fishing gears in all sectors of the fishery (Smith and Maguire 1983). The fish in each sample are measured for fork length and a subsample has its otoliths removed for subsequent age determination.

At the end of the year, the length frequencies and associated age data are combined and used to estimate the age structure of the catch. The process by which this estimate is constructed implicitly assumes two things: (1) that the length-frequency data are correct; and (2) that each sample is a random sample from the same population.[1] Apart from the checks made for obvious errors when the data are entered into the computer, there is at present no system in the Marine Fish Division that can be used to verify these assumptions. For stocks[2] where large numbers of samples are collected, visual examination of each length frequency can be a time-consuming task. It would be useful therefore to have a technique or techniques to explore efficiently large numbers of length-frequency samples for patterns and irregularities.

[1]The term population is used to describe the data universe rather than a group of randomly mating individuals.

[2]Defined in terms of uniformity of a management regime rather than a biological entity.

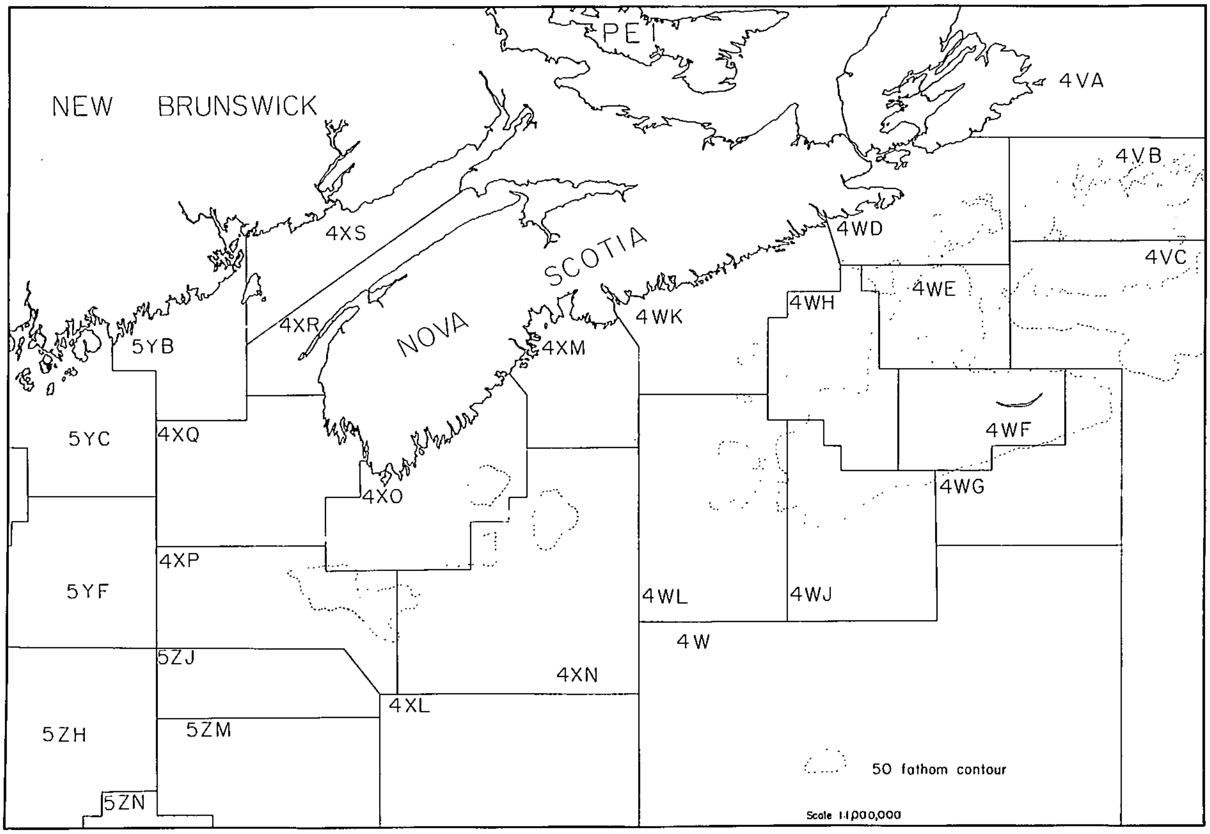

FIG. 1. Map of NAFO fishing areas on the Scotian Shelf and Georges Bank.

In this paper we investigate the multivariate method of principal component analysis as a tool for exploration of length-frequency data. Principal component analysis has often been used to provide a more parsimonious description of the dependence structure of multivariate data (Morrison 1976). Rao (1964) has also shown that this technique can be used to scrutinize the data for outliers and identify groups or clusters of similar observations.

For the application presented here, 26 length-frequency samples collected from the pollock (*Pollachius virens* L.) fishery in 1981 for NAFO (Northwest Atlantic Fisheries Organization) Divisions 4VWX (Scotian Shelf) and NAFO Subarea 5 (northern Georges Bank) were used. Each length-frequency sample was envisaged to be an observation from a p-character (variable) system (Sneath and Sokal 1973), where each character was defined as one of the 3-cm groups used in reporting pollock length-frequency data. Hence the variables for each sample were the frequencies in each 3-cm group.

Materials and Methods

Unculled samples of pollock, taken in 1981, were collated and separated into mixed and single catch locations. Only single location samples were used (Table 1; Fig. 1); these were checked against the original log records and purchase slips, to verify all entries. Each 3-cm entry was considered to be a separate character; a total of 24 character codes were thus assigned for the entire data set.

The data were analyzed by BMDP4M (Biomedical Computer Programs P-Series) (Frane and Jennrich 1977) to obtain the principal components. Principal component analysis (PCA) is a multivariate technique in which sets of linear combinations of the variables are extracted which explain progressively smaller portions of the total sample variance. An extensive data set can thus be reduced to a small number of variables which will encapsulate and summarize the information content of the original data. The components can be interpreted geometrically as the variates corresponding to the principal axes of the scatter of observations in space (Morrison 1976). Thus, a plot of the sample coordinates on the axes of the first and second components was used to interpret the pattern of associations amongst length-frequency vectors. Each observation was successively labeled by fishing area, quarter of the year, and mean length and age of fish in the sample.

Results

A total of 26, single location, length frequencies were used in the analysis. The majority of these samples came from divisions 4X and 5Ze (Table 1). In several instances,

TABLE 1. Sample number, fishing area, date of sample, and sample statistics for commercial samples of pollock taken in 1981.

Sample no.	Fishing area		Date of sample and quarter	No. of fish sampled	Mean length (cm)	Range of lengths (cm)	Mean age	Range of ages	Age-classes (>15% of sample) (%)
1	Pollock Shoals	4XQ	25.03.81 1	252	67.27	49–97	6.19	3–12	6(42)
2	Pollock Shoals	4XQ	4.03.81 1	205	65.09	49–91	5.47	3–8	5(25) 6(37)
3	Roseway Bank	4XQ	23.02.81 1	251	68.56	55–103	6.79	4–11	6(42) 7(28)
4	SW Browns Bank	4XP	15.01.81 1	308	72.82	40–103	7.17	3–13	6(22) 7(42)
5	Pollock Shoals	4XQ	27.03.81 1	280	63.07	37–88	5.36	2–10	5(34) 6(23)
6		4XN	03.04.81 2	220	56.52	40–76	5.67	2–7	5(39) 7(40)
7	Pollock Shoals	4XQ	18.06.81 2	297	56.47	40–79	4.30	2–8	3(28) 5(55)
8	The Cowpen	4WH	30.06.81 2	220	64.49	37–97	6.13	2–12	6(41) 7(34)
9	W. Emerald Bank	4WL	15.06.81 2	207	55.61	46–85	4.84	2–7	3(29) 6(25)
10	Yankee Bank	4XS	05.06.81 2	200	74.18	46–103	7.10	5–11	7(40) 8(24)
11	W. Emerald Bank	4WL	05.06.81 2	237	61.75	49–88	5.68	3–9	6(35) 7(28)
12	W. Emerald Bank	4WL	19.05.81 2	204	58.40	43–76	5.71	2–7	5(25) 6(34) 7(28)
13	The Cowpen	4WH	13.05.81 2	192	69.47	58–103	6.83	5–9	6(28) 7(17) 8(25)
14	W. German Bank	4XQ	30.04.81 2	271	64.70	43–94	5.64	3–10	5(26) 6(27)
15	Pollock Shoals	4XQ	02.04.81 2	210	62.41	46–82	6.08	3–8	5(40) 6(22)
16	W. German Bank	4XQ	09.04.81 2	208	61.48	46–79	5.59	3–7	5(24) 6(40)
17	W. German Bank	4XQ	13.04.81 2	219	71.53	49–97	6.65	3–12	6(25) 7(32) 8(21)
18	W. German Bank	4XQ	23.06.81 2	217	55.79	40–79	4.56	2–7	3(31) 5(27) 6(27)
19	W. German Bank	4XQ	26.06.81 2	252	51.71	40–94	3.72	2–8	3(60)
20		4XM	17.06.81 2	200	61.64	52–82	6.00	3–9	6(65) 7(20)
21	Pollock Shoals	4XQ	07.08.81 3	230	55.27	43–76	4.44	2–7	3(24) 4(25) 5(31)
22	Pollock Shoals	4XQ	06.08.81 3	216	70.80	46–100	6.36	3–12	5(20) 6(27)
23	Pollock Shoals	4XQ	10.08.81 3	206	72.91	49–100	7.10	3–13	6(25) 7(28)
24	Pollock Shoals	4XQ	31.08.81 3	205	56.76	43–73	4.18	2–7	3(40) 5(25)
25	Georges Bank	5ZeJ	10.11.81 4	184	71.09	46–106	5.98	2–13	5(28) 6(28)
26	Western Gully	4WJ	01.12.81 4	228	71.74	55–100	6.89	3–10	6(33) 8(23)

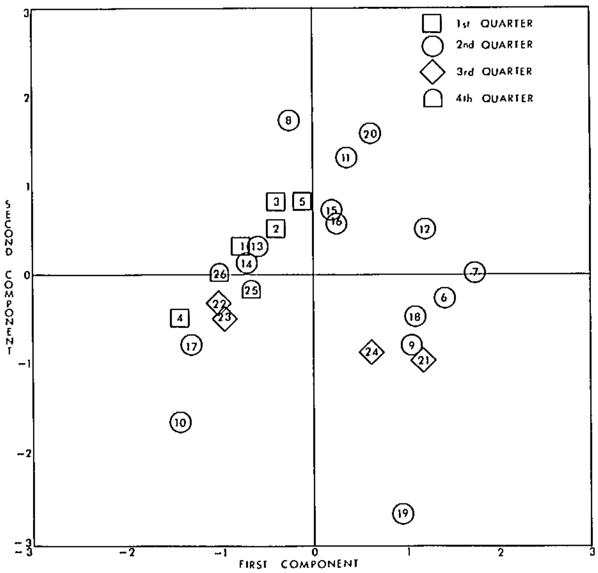

FIG. 2. Plot of sample coordinates by first and second components. Points labeled by sample number and quarter of the year (Table 1).

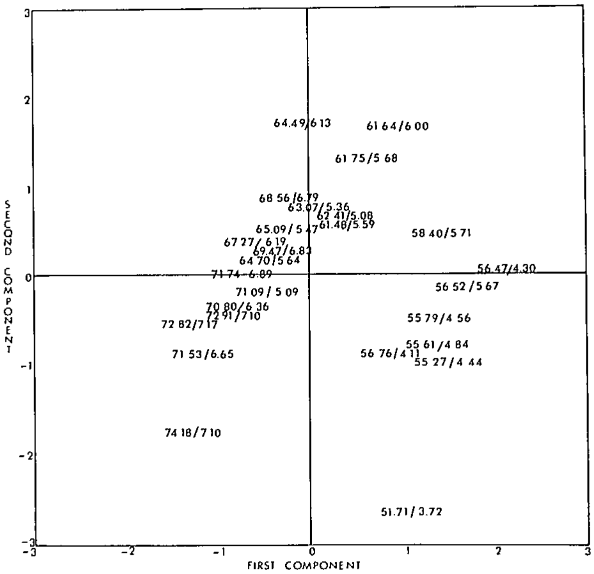

FIG. 3. Plot of sample coordinates by first and second components. Points labeled by mean length (cm)/mean age of sample.

a single vessel, with catches from the same fishing ground, was repeatedly sampled throughout a quarter. Thus parts of the data set provided an effective source for comparisons to be made.

The results of the PCA show that 76% of the total variance is explained by the first two principal components.[3] No obvious trends can be observed in the plot of the first (abscissa) and second (ordinate) prinicipal components when the samples are labeled by quarter (Fig. 2) or fishing area.

The variables used in the PCA were defined by size-classes; thus if any spatial or temporal patterns exist, they should be size related, as the principal components represent linear combinations of these variables. In Fig. 3, the samples are labeled by their mean length and age, and there is clearly an anticlockwise trend from the smallest mean length and age, in the lower right-hand quadrant, to the greatest mean length and age, in the lower left-hand quadrant. This pattern explains in part, the apparent heterogeneity amongst samples labeled by quarter of the year.

To explore the ramifications of this patterning, samples in the second quarter (April–June) were examined. Of the 15 samples, seven were collected in Division 4XQ, while the remainder were taken from divisions 4XN, 4W, and 5ZE. Moreover, six of the seven samples taken from Division 4XQ were from the same vessel off the same fishing ground; thus direct comparisons between samples are clearly valid.

The positions of the seven samples from Division 4XQ on a plot of the first and second principal components are shown (Fig. 4); each point is labeled by the temporal succession of capture within each month, and by its associated mean length and age. The samples collected in April (A) increase in mean length and age over the course of the month, whilst those in June (J) decrease. This apparent anomaly can in part be explained by the mean age of each sample, which decreases in June and increases in April (Fig. 4). However, this observation must be qualified, because two points (A1 and J1) represent catches from Pollock Shoals in Division 4XQ, whilst the rest come from German Bank. In both instances, the mean age of the samples from Pollock Shoals indicate that the fish from this area are either larger at age compared to German Bank and/or that there are large numbers of younger fish in the area. This is particularly clear in the case of samples A1 and A2 which were taken by the same vessel within 5 d of each other, on the two fishing grounds.

The age composition of the samples provides a key to this anomaly (Table 1). In the case of A1 and A2, the catches are predominated by fish of ages 5 and 6, respectively: in the case of J1 and J2, the catches are predominated by fish of ages 3/5 and 5/7, respectively. Moreover the preponderance of one or two age-classes in any one catch, plus radical shifts in age composition support the hypothesis of age-specific schooling in pollock.

Discussion

The results of this analysis clearly indicate that the method of principal components is a powerful exploratory analysis tool for length-frequency data. It allows the variance structure to be examined, such that the components explaining the largest proportion can be identified.

[3]Both the relative frequencies and absolute frequencies were analyzed in this manner. The results were identical for our study although large variations in sample size may be better dealt with by using relative frequencies only.

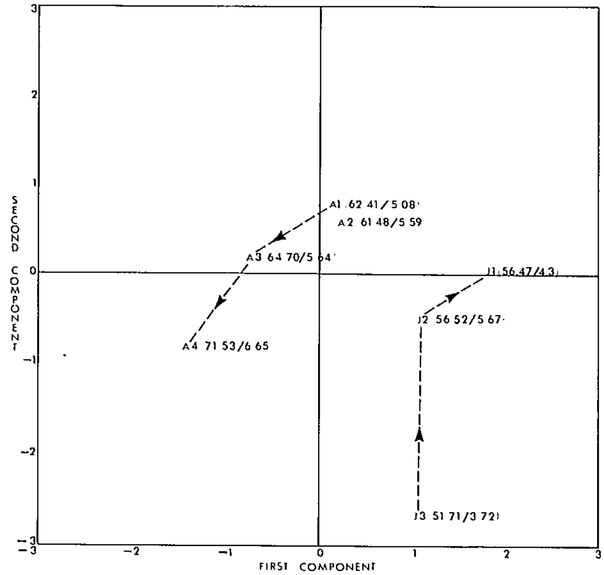

FIG. 4. Plot of sample coordinates by first and second components for samples taken in April (A) and June (J) in area 4XQ. Points labeled by sequence in which they were taken, plus associated mean length (cm)/mean age. Arrowed line indicates direction of increasing mean length.

Moreover, a plot of the most informative components, in this case the first and second, can be visually assessed, especially if the points are labeled by an appropriate set of characteristics. In this example, spatial and temporal patterning were obtained indirectly by looking at the mean length and mean age of the fish in each sample. The heterogeneity amongst samples taken in the same month (viz. April 4XQ) could in part be explained by growth. In June, however, the average size decrease is indicative of an influx of younger fish into the fishery during the latter part of the month. This is entirely consistent with the known biology of the species which suggests an offshore migration of juveniles during the summer months (Steele 1963). These results concur with those cited previously in an analysis of mackerel, cod, and silver hake (Doubleday 1976).

This behavior has serious ramifications for estimating the age structure of the catch and that of the population. If one assumes that the individual samples provide reasonable estimates of the structure of the catches from which they were taken, then it appears that a size-related temporal-spatial pattern exists, which clearly complicates a direct estimate of the structure of the entire catch. That is, if age groups are not randomly assorted in space and time, some are more likely to be caught than others according to when and where the fishery is prosecuted. Thus one needs to know the distribution of fish and the intensity and time of fishing in each area to account for the availability of fish when estimating the age structure of the catch. Further, the samples on hand may not adequately estimate the catches from those time periods and areas of the fishery not sampled. The question of how these patterns could affect the assessment of pollock stocks is beyond the scope of this paper, and will be considered elsewhere. The main point made here, is that the method of principal components is very effective in recognizing the existence of spatial and temporal patterns in length-frequency samples and hence age structure of the catch.

Acknowledgments

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Commercial Catch Sampling: A Review of its Usage in the Management of Contagiously Distributed Subtidal Mollusc Species

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JAMIESON, G. S. 1983. Commercial catch sampling: a review of its usage in the management of contagiously distributed subtidal mollusc species, p. 240–247. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates /L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

The quality and usage in management of commercial catch sampling data are discussed for three major Canadian subtidal mollusc fisheries: sea scallop, abalone, and geoduc. Atlantic sea scallop catch data have been collected since 1970, but the frequent inability to identify the precise fishing location of a subsample and the lack of a statistically rigorous sampling design impedes data usage. In British Columbia, both abalone and geoduc fisheries are relatively recent, and little catch sampling has occurred. The potential, value, and usage of commercial catch data in all three fisheries are discussed, and it is suggested that with present programs, commercial catch sampling of these species should be of low priority.

JAMIESON, G. S. 1983. Commercial catch sampling: a review of its usage in the management of contagiously distributed subtidal mollusc species, p. 240–247. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/ L'echantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Le présent rapport examine la qualité et l'utilisation gestionnelle des données d'échantillonnage recueillies sur les prises commerciales de trois pêches importantes de mollusques habitant les zones infratidales des eaux canadiennes, soit le pétoncle, l'ormeau et le geoduck. On recueille depuis 1970 des données sur les prises de pétoncle de l'Atlantique, mais l'incapacité fréquente d'identifier l'endroit précis de la pêche d'un sous-échantillon et l'absence d'un modèle d'échantillonnage bien étayé du point de vue statistique en empêchent l'utilisation. En Colombie-Britannique, la pêche de l'ormeau et du geoduck est récente et a fait l'objet de peu d'échantillonnage. L'ouvrage étudie la valeur potentielle et l'utilisation des données sur les prises commerciales de ces trois pêches, et conclut que, dans le cadre des programmes actuels, l'échantillonnage des prises commerciales de ces espèces devrait avoir une faible priorité.

Introduction

The degree to which commercial catch size-frequency data is employed in the development of optimal fisheries management strategies is largely a function of two factors: the quality and nature of the data that can be obtained, and the priority given to obtaining commercial catch data as opposed to carrying out basic research on species biology or population dynamics. This paper reviews the collection, quality, and use of commercial catch data in the major benthic mollusc fisheries from the east and west coasts of Canada.

Fisheries can be broadly grouped into two types: (1) deep-water or offshore fisheries, which involve large vessels fishing from a limited number of ports; and (2) shallow water or inshore fisheries, which involve small vessels, often fishing from a large number of ports. Invertebrate fisheries such as snow crab (*Chionoecetes opilio*), shrimp (*Pandalus borealis*), and offshore lobsters (*Homarus americanus*) and sea scallops (*Placopecten magellanicus*) are type (1) fisheries, while inshore lobsters, Northumberland Strait sea scallops, abalone (*Haliotis kamatschatkana*), most clams, and Irish moss (*Chondrus crispus*) are type (2) fisheries. Squid, because of their mobility, may be either type of fishery. Because type (1) fisheries are usually capital-intensive and high profile, and can be more readily subsampled by fewer personnel, the recent tendency with limited federal resources has been to emphasize commercial catch sampling in these fisheries. Recent support from the Nova Scotia government has allowed extensive commercial catch sampling of some Nova Scotian type (2) fisheries, but this may not be a long-term commitment.

Invertebrates as a group have widely different, often poorly understood biologies, and in many fisheries high priority has been applied recently to the characterization of species' life history phenomena and the determination of species' distributions. Without such knowledge, the interpretation of commercial catch size-frequency data is difficult, and its subsequent usage in management is of questionable value.

Species Mobility and Distribution

Although most sedentary mollusc species are capable of movement, their range of dispersal as adults is generally limited, varying from a few metres for clams, to a few kilometres for scallops and abalone. After settlement,

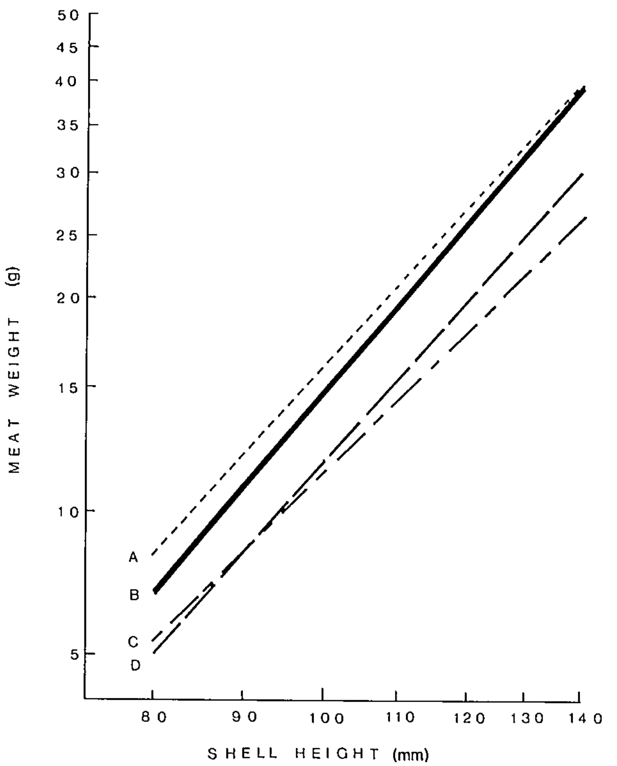

FIG. 1. Shell height:meat weight relationships for scallops from (A) Georges Bank; (B) Bay of Fundy; (C) German Bank; and (D) Browns Bank.

many benthic molluscs cannot readily optimize the environmental conditions which they experience, and so the ocean climate experienced by these species is primarily characterized by geographical location. Thus, scallops on the Scotian Shelf experience less optimal conditions for growth in contrast to those from Georges Bank (Jamieson et al. 1981a), only 80 km away, as shown by different meat yield and growth rates (Fig. 1, 2).

Mollusc population parameters including growth rate, age of sexual maturity, asymptotic size, and natural mortality are influenced by site-specific environmental factors. Abiotic factors, such as substrate type, current velocity, and temperature often change significantly over short geographical distances, making it essential for the accurate interpretation of commercial mollusc catch data to document the precise fishing location of the catch sample data being analyzed. If age is inferred from weight or size data, a number of appropriate regressions for data transformation may be required to characterize a region's mollusc age structure. However, since environmental variation exists over the ranges of all exploited species present, do analytical processes used for mollusc catch data adequately accommodate this variability, and how does such variability influence the use and value of commercial mollusc catch data in general?

DEFINITION OF MANAGEMENT UNIT

Many species only occur in commercial quantities in a few geographical locations. Thus, for example, while sea scallops occur from the Strait of Belle Isle south to Cape Hatteras (Posgay 1957), continuous commercial fisheries exist in Canadian waters only on Georges Bank; off Digby, Nova Scotia, in the Bay of Fundy; in the Northumberland Strait, and in Port au Port Bay, Newfoundland. Sporadic fisheries occur on the Scotian Shelf and St. Pierre Bank. Each "stock" is either exploited by a different fleet of vessels or is sufficiently isolated by geography or bathymetry to permit management as a distinct biological unit.

With inshore species, socioeconomic factors may result in further division of a biological management unit. Land

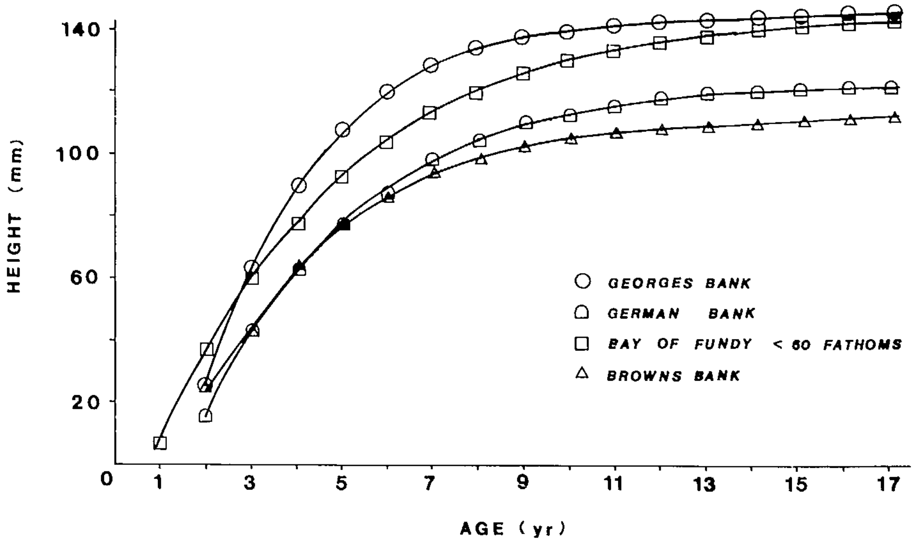

FIG. 2. Von Bertalanffy growth curves for offshore scallop stocks.

reference is convenient, and management subunits may be provinces, statistical districts (e.g. abalone, geoduc), or districts established for other fisheries. An example of the latter is the usage of lobster districts to establish management units for Northumberland Strait scallops. Seasonal closures may also separate a continuous fishing ground into management subunits, as occurs with Bay of Fundy scallops off Digby, Nova Scotia. In this instance, during May to September inclusive, no scallop fishing is allowed within 6 mi (9.7 km) of shore in an effort to preserve scallops for near-port exploitation in the harsher fishing climate of the winter months.

Treatment of Environmental Variability

While in the broad sense the use of management subunits may reduce biological parameter variance for a population, microenvironmental differences causing considerable population variability may still be a major concern. Parameters such as growth rate and yield will vary even within a subunit as a result of both abiotic and/or biotic (e.g. species density, interspecific competition) effects. The resulting variance may mask real differences in population parameters which might be expected from such factors as season or subunit location. This is demonstrated with scallop yield at size at varying distances from shore off Digby, Nova Scotia. Yield is inversely correlated with distance from shore (Jamieson et al. 1981b), and while the biological explanation for this is unclear, and when data analysis does not reflect this fact, overall population age structure can easily be estimated inaccurately (Table 1). Commercial fishing vessels in the Bay of Fundy frequently fish at varying distances from shore during the same fishing day, and since the scallop meats fished at each location are not kept separate, average "inshore" and "offshore" regressions are presently used to age scallops from individual meat weights. The presence of a seasonal area closure makes this distinction practical, but

TABLE 1. Analysis of height-frequency data from the Bay of Fundy off Digby, Nova Scotia, to demonstrate the effect of both distance from shore and presently used aging regressions in age-frequency analysis.

		A. Age analysis									B. Age frequencies		
		Meat wt (g) at distance (km) from shore			Age[b] (yr) weighted for distance (km) from shore				Age[b] (yr) with no weighting for distance (km) from shore			Estimated no. at age	
Height (mm)	Frequency	3.9^1	9.7^a	19.3^a	3.9	9.7^2	9.7^3	19.3	9.7^2	9.7^3 & 19.3	Age (yr)	Weighted for distance from shore	No weighting for distance from shore
												9.7^2 km from shore	
59.7	1	3.00	2.67	2.07	2.9	2.8	3.6	3.3	2.9	3.8	2	1	1
65.5	15	4.00	3.56	2.76	3.3	3.1	4.1	3.7	3.3	4.3	3	2798	1076
70.4	236	5.00	4.45	3.45	3.6	3.4	4.5	4.1	3.6	4.8	4	6935	7690
7.47	825	6.00	5.34	4.14	3.9	3.7	5.0	4.4	3.9	5.3	5	1731	2337
78.5	1722	7.00	6.23	4.83	4.1	3.9	5.4	4.7	4.1	5.7	6	267	528
82.0	2375	8.00	7.12	5.52	4.4	4.2	5.8	5.1	4.4	6.2	7	67	138
85.1	2102	9.00	7.96	6.21	4.6	4.4	6.2	5.4	4.6	6.7	8	15	44
88.1	1491	10.00	8.90	6.90	4.9	4.6	6.7	5.7	4.9	7.2			
												9.7^3 km from shore	
90.8	967	11.00	9.79	7.59	5.1	4.8	7.1	6.0	5.1	7.7	3	1	1
93.4	666	12.00	10.68	8.28	5.4	5.0	7.6	6.3	5.4	8.3	4	251	251
95.9	413	13.00	11.57	8.97	5.6	5.3	7.1	6.7	5.6	8.9	5	4922	2547
98.2	291	14.00	12.46	9.66	5.9	5.5	8.6	7.0	5.9	9.6	6	3573	4477
100.4	209	15.00	13.35	10.35	6.1	5.7	9.1	7.4	6.1	10.4	7	1633	2458
102.5	152	16.00	14.24	11.04	6.3	5.9	9.8	7.8	6.3	11.2	8	704	1079
104.5	96	17.00	15.13	11.73	6.6	6.1	10.5	8.1	6.6	12.3	9	361	291
106.5	71	18.00	16.02	12.42	6.8	6.3	11.3	8.6	6.8	13.6			
												19.3 km from shore	
108.3	62	19.00	16.91	13.11	7.1	6.6	12.2	9.0	7.1	15.4	3	16	1
110.2	38	20.00	17.80	13.80	7.4	6.8	13.3	9.5	7.4	18.5	4	2783	251
111.9	25	21.00	18.69	14.49	7.6	7.0	14.8	10.0	7.6	—	5	5968	2547
113.6	13	22.00	19.58	15.18	7.9	7.3	17.0	10.5	7.9	—	6	2046	4477
115.2	16	23.00	20.47	15.87	8.2	7.5	21.3	11.1	8.2	—	7	652	2458
116.8	13	24.00	21.36	16.56	8.5	7.7	—	11.8	8.5	—	8	167	1079
118.4	15	25.00	22.25	17.25	8.8	8.0	—	12.6	8.8	—	9	100	291

[a]Weight = $weight^1 * [(18.50 - (0.34 * distance (km)))/17.18]$ (Jamieson et al. 1981b).

[b]Derived from the parameters in Table 5B: 3.9 and 9.7^2 km: inside summer closure zone parometers; 9.7^3 and 19.3 km: outside summer closure zone parameters.

present techniques for determining population age structure in this fishery are still not optimal. A major problem remains the abrupt difference in average subunit growth rates at the 6-mi (9.7-km) closure line, which transects highly productive scallop ground.

Calculation of population parameters for management units or subunits generally fails to weight for inherent biological variability. It is usually assumed that areas of highest species CPUE will be sampled most heavily. While the resulting bias will overestimate the magnitude of average population parameter values, management strategy would still be conservative for the most productive ground, i.e. that area which predominantly supports the fishery. This is probably a reasonable assumption if the locations of high abundance or yield for a species were always the same and were positively biased in sampling. However, these conditions seldom apply. The locations of pelagic larval settlement are determined by unknown factors and appear to be randomized within a broad geographical area. Limited species' mobility often confines later life stages to these areas. Furthermore, data samples are generally obtained from randomly located stations in stratified resource surveys. When estimates of a contagiously distributed population's average yield and growth are calculated from samples collected randomly over a variety of microhabitats, as with scallops (Haynes 1966; Jamieson 1979; Jamieson et al. 1981a; Posgay 1962), then the bias may be to underestimate considerably the exploited population's average characteristics. An unknown number of samples might come from areas that were not optimal for survival or growth. This could result in unwarranted management restriction of a fishery which in fact was centered for economic reasons in areas of high species yield, or growth. These locations are frequently difficult to identify and sample before exploitation is complete.

Fishery Characteristics

The value and usage of commercial catch data are influenced by the specific nature of a fishery. Three major Canadian mollusc fisheries are discussed in detail to demonstrate this effect.

The Offshore Scallop Fishery

Description — Scallops are unique among Canadian invertebrate fisheries in that the catch is both sorted and processed at sea; only the scallop's adductor muscle (meat) is landed. A daily log of fishing location, catch, and expended effort is kept by fishermen, but because of a meat count regulation, the catches from different fishing locations are often mixed. Once shucked, scallop meat is held in tubs in seawater until a sufficient quantity has accumulated to warrant its being placed in 18.2-kg (40-lb) cotton bags that are then iced until the vessel's return to port. Specific fishing locations generally yield only one scallop age-class in abundance, and little culling occurs. Because the meat count regulation requires that the average number of meats in randomly selected 500-g subsamples from the bags not exceed a specific value (presently 44 meats/500 g), blending of meat sizes from different fishing locations before bagging is common. The bags are color-coded with thread to designate what third of the trip (maximum: 12 d duration, dock to dock) they were filled in. Vessels often mix scallop meats from the Scotian Shelf and Georges Bank in the same bag.

Contact with freshwater ice during holding may increase meat weight at landing by as much as 17% (Caddy and Radley-Walters 1972). However, in recent studies (unpublished) that document more precisely the weight change during holding, variance in water content between controls was significant, presumably due to different ambient salinities at capture; subsequent analysis has become complex and is not yet complete.

Fishery data collection — Offshore scallops are largely landed in four Nova Scotia ports (Table 2): Lunenburg, Riverport, Yarmouth, and Saulnierville. Prior to 1979, no personnel were assigned specifically to collect commercial mollusc fishery catch data. Since 1979, a port sampler has been stationed in both Halifax and Yarmouth to coordinate sampling of all invertebrate species; most recent commercial fishery data have been collected by summer students under federal supervision but employed by the Nova Scotia Department of Development (Provincial Employment Program). Landings by month for 1972–81 (Table 3) indicate considerable annual bias in sampling. Seasonally, average landings from April to October inclusive have been proportionately undersampled, whereas landings in January and December have been over-

TABLE 2. Atlantic Coast (excluding Gulf of St. Lawrence) scallop landings by statistical district for the years 1978 and 1979.

Statistical district	Main ports	Scallop landings t (round) 1978	1979
04	Big Bras d'Or	—	1
06	Alder Point	1	34
07	Louisbourg, Glace Bay	122	148
09	St. Peters	—	4
19	Ecum & Secum Bridge, Port Dufferin	10	13
26	Lunenburg, Riverport	68 047	57 314
28	Liverpool, Port Mouton	9 329	5 859
29	Lockeport	346	—
31	Shelburne	18	61
33	Pubnico	120	—
34	Yarmouth	8 203	4 829
36	Saulnierville	13 816	11 040
37	Centreville, Westport	996	475
38	Digby	5 011	5 876
39	Victoria Beach, Parker's Cove	186	184
40	Black Rock	—	1
44	Advocate	1	1
50	Grand Manan	84	205
51	Campobello Island	—	16
52	Back Bay	14	28
Total		106 304	86 309

TABLE 3. Distributions (%) of commercial scallop fishery samples (S) and landings[a] (L) by month for 1972–81 inclusive, and the percentages of the total catch sampled.

	1972		1973		1974		1975		1976		1977		1978		1979		1980		1981		Average (SD)	
Month	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L
January	0	1	5	1	0	1	0	1	4	0	5	0	4	1	0	1	0	0	0	1	1.8 (2.4)	0.7 (0.5)
February	0	2	0	1	0	3	3	2	2	2	9	3	5	6	0	0	1	4	1	4	2.1 (2.9)	2.7 (1.7)
March	0	6	17	7	0	3	4	3	5	5	9	4	6	4	6	9	0	2	4	5	5.1 (5.2)	4.8 (2.1)
April	3	10	17	12	8	7	10	6	12	15	10	11	3	11	5	12	3	14	0	6	7.1 (5.2)	10.4 (3.2)
May	3	14	11	13	18	15	11	12	17	13	9	3	11	13	19	17	17	15	18	20	13.4 (5.2)	13.5 (4.4)
June	0	16	8	15	5	13	9	18	14	14	11	13	11	15	24	13	24	15	24	20	13.0 (8.5)	15.2 (2.3)
July	2	12	5	13	17	15	8	14	6	13	15	11	4	8	20	12	25	13	16	12	11.8 (7.8)	12.3 (1.9)
August	21	12	4	9	6	14	9	12	4	9	8	12	9	13	11	10	13	11	17	10	10.2 (5.5)	11.2 (1.7)
September	30	9	7	9	5	7	11	11	9	12	5	10	6	10	6	9	7	10	6	9	9.2 (7.5)	9.6 (1.4)
October	1	6	10	9	3	9	17	8	10	7	7	8	8	10	6	8	3	8	4	5	8.1 (4.0)	7.8 (1.5)
November	2	9	10	6	13	7	8	6	11	7	5	9	23	6	3	7	4	4	6	5	8.5 (6.2)	6.6 (1.6)
December	38	3	6	5	25	7	10	6	6	3	9	5	11	3	0	3	2	3	3	2	11.0 (11.8)	4.0 (1.6)
Wt sampled (t)	0.043		0.102		0.072		0.099		0.110		0.095		0.133		0.704		1.603		1.221			
Commercial landing (t)[a]	4161		4228		6138		7414		10384		13176		12216		9638		6694		8013			
% sampled	0.0010		0.0024		0.0012		0.0013		0.0011		0.0007		0.0011		0.0073		0.0239		0.0152		0.0055 (0.0079)	
Avg. count /500 g	45.2		44.9		38.5		42.7		31.4		34.3		26.4		29.4		38.1		44.9			

[a]Landings for all fishing locations (from log records).

sampled. The harsher winter climate can restrict the number of locations that can be readily fished, and hence catch proportions from different grounds may show considerable seasonal variation. Season significantly affects meat yield from animals of the same shell size from the same region (Haynes 1966). Catch sampling has also been biased by port, and although the entire offshore fleet fishes primarily the same general resource, the average size of scallop exploited is smaller for Lunenburg and Riverport vessels (= Lunenburg fleet) than for Yarmouth and Saulnierville vessels (= Yarmouth fleet) (Table 4). Why this difference exists is not clear, as shucking small scallops is more tedious and difficult per unit of meat obtained. Both fleets are harvesting scallops on average below the size giving maximal Y/R. For Georges Bank scallops, this meat weight is 35 g (=7.8 yr-old animals) (Brown et al. 1972).

Port sampling procedures since 1979 have required that three 500-g samples be obtained randomly from each third of a sampled vessel's trip. During the summer, almost every scallop vessel is sampled in the Lunenburg fleet, although if more than 5–6 vessels land at once, some may be missed. With the Yarmouth fleet, regular sampling is more difficult, as fishermen occasionally land at odd hours (e.g. late at night), without advance notice. During the winter months, sampling occurs whenever possible, often when bad weather forces a number of vessels to come in together. Trips are often broken (i.e. of shortened duration) and so fewer samples may be obtained per vessel trip.

TABLE 4. Average scallop meat weight and sample size by month and fleet for the year 1979. The Yarmouth fleet includes Yarmouth and Saulnierville vessels, whereas the Lunenburg fleet includes Lunenburg, Riverport, and Liverpool vessels.

	Lunenburg fleet		Yarmouth fleet	
Month	Avg. wt (g)	No. meats	Avg. wt (g)	No. meats
January	—	0	—	0
February	—	0	—	0
March	14.55	2441	—	0
April	16.23	1742	23.26	449
May	14.61	7763	31.65	186
June	15.06	8115	22.65	1699
July	17.72	4939	23.99	3231
August	17.77	3626	23.40	1088
September	13.35	1668	17.71	553
October	12.20	1006	18.04	1588
November	15.20	591	17.51	497
December	—	0	—	0
Annual	15.52	31891	22.06	9291

TABLE 5. Meat weight-shell height regressions *(A)* and Von Bertalanffy growth parameters *(B)* for sea scallops by management units.

A: Meat weight *(W)* – shell height *(H)* regressions

Management unit	Regression	Source
Georges Bank		
October	$\ln W = -10.2516 + 2.785 \ln H$	Haynes (1966)
November–March	$\ln W = -11.7472 + 3.131 \ln H$	Haynes (1966)
April–September	$\ln W = -10.9926 + 2.995 \ln H$	Haynes (1966)
All months	$\ln W = -10.8421 + 2.949 \ln H$	Haynes (1966)
Scotian Shelf		
Browns Bank	$\ln W = -13.35 + 3.41 \ln H$	Jamieson et al. (1981a)
German Bank	$\ln W = -11.48 + 2.99 \ln H$	Jamieson et al. (1981a)
Bay of Fundy (off Digby, N.S.)		
Inside summer closure zone (9.7 km from shore)	$\ln W = -12.367 + 3.236 \ln H$	Jamieson et al. (1981b)
Outside summer closure zone (9.7 km from shore)	$\ln W = -11.299 + 2.925 \ln H$	Jamieson et al. (1981b)
Northumberland Strait		
All regions	$\ln W = -10.72 + 2.919 \ln H$	Jamieson et al. (1981c)

B: Von Bertalanffy growth parameters

Management unit	*W* (g)	*H* (mm)	*K*	t_0 (yr)	Source
Georges Bank	46.66	145.36	0.38	1.5	Brown et al. (1972)
Scotian Shelf					
Browns Bank	14.04	108.80	0.36	1.6	Jamieson et al. (1981a)
German Bank	19.06	124.60	0.28	1.6	Jamieson et al. (1981a)
Bay of Fundy (off Digby, N.S.)					
Inside summer closure zone	42.33	145.44	0.22	0.5	Jamieson et al. (1981b)
Outside summer closure zone	21.01	134.89	0.23	0.6	Jamieson et al. (1981b)
Northumberland Strait					
Eastern region	32.73	127.97	0.19	-1.1	Jamieson (1979)
Central region	23.64	114.82	0.28	-0.2	Jamieson (1979)
Western region	32.56	127.78	0.22	-0.5	Jamieson (1979)
All regions	32.12	126.17	0.21	-0.4	Jamieson (1979)

Prior to 1979, trip and bag sampling bias were greater, samples were fewer in number and were collected irregularly during the season. Samples to be measured were bought; in return for weighing the meats individually as a personal service, the sampler was allowed to keep the meats. There was thus a tendency to sample only the freshest scallop meats, i.e. those animals most recently fished. Less effort was made to sample randomly.

Catch data analysis — Because only the adductor muscle of scallops is landed, meat weight-age regressions are required to determine commercial exploitation at age. The meat weight-shell height regressions presently in use for Georges Bank (Table 5) were determined from 1957 to 1962 scallop data (Haynes 1966), in which Georges Bank was subdivided into four areas (northern edge, Great South Channel, eastern part, and southeast part). Significant differences in yield between seasons were reported, but not between sexes or areas. However, present analyses do not weight data for seasonal effects. Von Bertalanffy growth parameters (Brown et al. 1972) are used to extrapolate scallop meat weight or shell height to age (Table 5).

Potential sources of error in the extrapolation of offshore scallop meat weights to age are:

1) meats are of unknown geographic origin, and hence the wrong regression is utilized;
2) meats may not be entire or complete because of poor processing technique; shell height and age are underestimated;
3) meat weight may have increased during holding because of freshwater uptake from melting ice; shell height and age are overestimated;
4) incorrect extrapolation to age or shell height because of use of inappropriate seasonal or location regressions; transition between seasons or management subunits is not knife edge (e.g. Table 1).

The effects of such errors are likely to be minimized with the younger age-classes because of the relatively large differences between average age-class meat weights. However, as age increases and annual growth increments decline, the magnitude of error increases (e.g. Table 1).

Management and catch data usage — Landings by the offshore scallop fleet are regulated by fleet size restriction and vessel quotas for both trip and 4-mo. period. Biological recommendations have received little weight in establishing landing restrictions. Yield per recruit analyses (Brown et al. 1972; Jamieson et al. 1981b) suggests optimal ages of first exploitation, and this has been converted to meat yield and number of meats per unit weight (i.e. meat count). Present meat count regulations for Georges Bank are well above the optimal value.

In the absence of quota management, there is no direct management need to know total biomass or annual catch at age. Rather, fishery catch data are anticipated to be most useful in determining how a resource of estimated abundance at age should be exploited optimally through blending of meats of different sizes. While efforts are presently underway to develop methods to do this analytically, commercial catch data at age will indicate current levels of performance. Understanding how a resource is exploited will allow better evaluation of the impact of alternate or modified management measures such as lower meat counts on landings. It is this unknown economic impact that has prevented in part a decrease in regulated meat count to more optimum levels. Sufficient resource survey and commercial catch data may now be available to accomplish this evaluation and so the priority given to the collection of new commercial catch data at this time should be reassessed.

The Abalone and Geoduc Fisheries

Description — Abalone and geoducs first became exploited in quantity in the mid-1970s when markets for both species were developed in Japan. Abalone landings increased dramatically from an annual average of 50 t (1973–75) to 410 t (1977–78), but recent regulations have restricted this fishery to about 90 t (Breen 1980). Magnitude of geoduc landings has increased more gradually to the 1981 level of 2084 t in the south coast and 375 t in the north coast. Both species are exploited by divers, with animals retained whole until onshore processing.

Abalone are either frozen or kept alive until landing, depending upon how frequently the vessel returns to port. Geoducs are difficult to hold alive and because of their large size and the vessels involved, freezing at sea is impractical. Maximum holding duration for live abalone is about 1 wk. To maintain an acceptable product quality, geoducs are usually landed daily. In both species, landings are made at the nearest port with convenient access for the buyers. Abalone are rapidly shipped to Japan once they are landed; hence, commercial catch sampling is most convenient while the vessels are at sea. In contrast, most geoducs are processed in one of four Canadian plants, and geoducs are most easily sampled at these locations.

Fishery catch sampling — Landings from the commercial abalone fishery have never been sampled; all size-frequency data for select populations have come from resource surveys.

Seven geoduc samples from commercial landings were obtained for the first time in 1981. Whole weight and shell length were measured, and the shells were numbered and retained for subsequent age analysis. Samples averaged 229 animals (SD = 93) and were fished from sites primarily around Vancouver Island.

Catch data analysis — With so little data collected, routine procedures have yet to be established for data analysis. Abalone cannot be aged accurately by counting annual shell rings, and no other satisfactory technique has been developed for individual aging. Rather, analytical approaches are being investigated (e.g. Schnute and Fournier 1980) to identify age-classes from population length-frequency data. In contract, geoduc shells can be aged by counting internal growth lines in acetate peels of cross sections of the shell (Shaul and Goodwin 1982). Geoduc growth does not appear to fit most conventional growth models in that there is no apparent asymptotic size; growth appears to be composed of two stanzas, 0–10 yr of age and >10 yr of age. This species is very long-lived, with average exploited age for a population frequently of 30–50 yr and some individuals in excess of 100 yr old.

Management and catch data usage — Both abalone and geoduc fisheries are regulated by licence restrictions and catch quotas for each statistical district. Fishing log records are required to be completed, and there is a minimum legal size (shell length of 100 mm) for abalone. Realistic management quotas require that knowledge of the size of the exploitable resource and commercial removal at age be available. Annual resource surveys are not carried out in either fishery, and present quotas are derived in part from rough estimates through resource surveys of the virgin biomass and theoretical models of stock-recruitment relationships (Breen 1980; P. Breen, personal communication). Considerable harvesting in both fisheries is being carried out in previously unfished areas.

While commercial size-frequency data might be used to determine growth and exploitation rates, the fact that culling occurs underwater by commercial divers prevents any information of prerecruit abundance from being obtained. Nevertheless, catch data for the recruited stock may be valuable, especially in the geoduc fishery where average exploited age is great. Since only one site is usually fished in a day, age frequencies may provide a record of relative year-class abundance variability in the past, and annual growth increments, as with tree rings, may provide an indication of past ocean climate events that significantly affected growth. It is anticipated that regional sampling of commercial catch data in the geoduc fishery will increase in the near future to characterize region-specific age frequencies, although routine annual sampling of a specific stock may not be supported.

Discussion

Commercial catch at age data has been used little in the past in routine evaluations of mollusc population characteristics and in the refinement of management recommendations. Many mollusc species, particularly intertidal ones, support largely recreational fisheries that have been both of low management priority in comparison to commercial fisheries and relatively difficult to sample effectively. Among commercial, sedentary, subtidal mollusc fisheries, those for abalone and geoduc have only been established recently, and initial research emphasis in these fisheries has been largely directed towards resource surveys and the characterization of growth and yield rates. Sea scallops, which have been exploited offshore for three decades, have the most extensive commercial catch data base among Canadian mollusc fisheries, but even here data quality in some years has been poor. Caddy and Jamieson (1977) have used commercial catch data in cohort analysis in an effort to determine exploitation rate at age, but such analyses have little significance with present management approaches. Thus the priority for future extensive collection of commercial sea scallop catch data should be low.

This should not imply that commercial catch data have no potential role in the management of sedentary mollusc fisheries. Rather, new, innovative approaches to the analysis and use of such data are needed. The mixing of individuals from different geographic locations exploited by a fishery, and the fishing of specific locations at certain times, pose difficulties in the broad interpretation of observations. Nevertheless, limited resources may make commercial catch sampling a relatively cost-effective method to study some aspects of population dynamics and exploitation strategies. If analytical procedures become more refined, the ultimate value of a statistically designed, commercial catch data base for specific sites may be high.

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Planning and Organization

Planification et organisation

Standards Used for the Sampling of Commercial Catch Under ICNAF/NAFO

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BECKETT, J. S. 1983. Standards used for the sampling of commercial catch under ICNAF/NAFO, p. 251–254. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

The development is reviewed of the ICNAF, and subsequently NAFO, minimum sampling standard that "the ICNAF sampling requirement should be specified at one sample per 1,000 tons of fish caught for each division, quarter of year, and gear. As an approximate guideline, such samples should consist of 200 fish from the entire length range for length composition and one fish per centimeter length group for age composition." This minimum has been recognized as minimal, and sampling of individual stocks has been carried out at much higher levels, but no new general standard has been developed.

BECKETT, J. S. 1983. Standards used for the sampling of commercial catch under ICNAF/NAFO, p. 251–254. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Le présent rapport porte sur l'élaboration des normes minimales d'échantillonnage de l'OPANO, anciennement le CIPANO, voulant que les exigences d'échantillonnage devraient être établies à un échantillon par 1 000 tonnes de poissons capturés pour chaque division, trimestre, et type d'engin. À titre de ligne directrice approximative, ces échantillons devraient consister en 200 poissons répartis sur toutes les classes de longueur pour la composition par longueur et un poisson par groupe de longueur (intervalle de 1 centimètre) pour la composition par âge. Cette norme est reconnue comme minimale et l'échantillonnage des stocks individuels a été effectué à des niveaux plus élevés. Cependant aucune nouvelle norme générale n'a encore été élaborée.

Introduction

The importance of sampling commercial catches was recognized very early in the deliberations of the International Commission for the Northwest Atlantic Fisheries (ICNAF). As early as 1953, the passage following:

> "In order to recognize the effect of fishing, it is necessary to record the lengths of the fish in adequate samples of catches, showing fish discarded and fish retained. This is considered essential for all the fisheries for the important species by *all* the participating countries throughout the Convention Area. The total range of fish caught can be sampled only at sea by specially trained observers. The sea sampling of the sizes retained should be supplemented by samplings of landings ashore."

was included in *A fishery research program for the northwest Atlantic*, that was adopted by the Commission in that year (Anon. 1953, p. 23).

At its 5th Annual Meeting, the Commission agreed (Anon. 1955, p. 13) that a meeting of the Committee on Research and Statistics should be held in Biarritz, France, in March 1956, to, amongst other tasks, specify the absolutely essential information necessary for predicting the effects of fishing and compare and resolve differences in field and laboratory techniques. This meeting produced an important synthesis of current practice and made a number of recommendations for standardizing and improving sampling activity (Anon. 1958, p. 117).

Each year rather pious statements were recorded in the Proceedings of the ICNAF Commission Meetings requesting improvement by member countries of their sampling programs. The same situation existed in other areas and, in commenting on a resolution taken in the Northeast Atlantic Fisheries Commission in 1971, the Liaison Committee (the forerunner of the Advisory Committee for Fisheries Management) of the International Council for the Exploration of the Seas, drew particular attention to deficiencies in biological sampling programs (Anon. 1972a). This commentary was used by ICNAF's Standing Committee on Research and Statistics (STACRES) at its May 1972 meeting to underline to the Commission their own concerns (Anon. 1972b, p. 7). In the following year, the Commisssion accepted the recommendation of STACRES (Anon. 1973, p. 44–46) that a special Working Group be established to consider improvements in the ICNAF data base, including "a detailed study of the sampling methods used by member countries for estimating age-length compositions of catches . . . . ." The Working Group met initially in Rome in January 1974, and, amongst its conclusions (Anon. 1974, p. 51) was an agreement that "there was a need to establish guidelines for all kinds of biological sampling and, where possible, to develop standard methodology for sampling length and age distributions and other biological characteristics of the stocks."

Sampling Coverage Requirements

The work of this Working Group was not completed by the time of the Annual Meeting of STACRES in June 1974, but a review of proposed minimum and desirable levels of sampling led to the adoption of a recommendation "that an ICNAF sampling requirement should be specified at one sample per 1,000 tons of fish caught for each division, quarter of year, and gear. As an approximate guideline, such samples should consist of 200 fish from the entire length range for length composition and one fish per centimetre length group for age composition" (Anon. 1974, p. 70–71).

STACRES, through its Subcommittee on Statistics and Sampling, coordinated studies of variances associated with sampling (Anon. 1975, p. 131) but the minimum standard remained unchanged despite considerable debate in subsequent years. A minor early clarification to the standard referred to the need for age samples by sex where this was recorded separately. An ad hoc Working Group of STACRES on Standardization of Reporting Procedures for Sampling Data met in Bergen in November 1978 and noted, in a review of the current sampling situation, that some fisheries were not being sampled at the minimum level while others were being sampled at a much higher rate. Furthermore, coastal states were requiring higher standards of commercial sampling from countries fishing in their fisheries zones, e.g. USA requirement of one sample per 1000 t of catch per month per 30′ x 30′ unit area, and Canadian requirements of a minimum of 10 samples per stock per year, whether subject to a directed fishery or not.

Additionally, coastal states were placing observers on the vessels of other countries in the zones of extended jurisdiction, with these observers also sampling catches (Anon. 1979, p. 21).

Thus, while it has long been widely recognized that the existing minimum sampling requirements are indeed minimum, and much greater coverage should be, and has been, achieved for many fisheries, no new general standard has been adopted. Indeed, the standard was adopted unchanged by the Northwest Atlantic Fisheries Organization (NAFO), when this body took over from ICNAF in 1979–80.

Coordination of Techniques and Reporting Format

A great deal of attention has been paid to coordinating and standardizing both sampling techniques and the reporting formats. Both the Biarritz meeting and the Bergen meeting already referenced made very important contributions in these areas. A complete summary of the ICNAF/NAFO Sampling Program may be found in Anon. (1981, p. 7–13). Some aspects are discussed further below.

Sources of Sampling Requirements

The ICNAF/NAFO sampling program has included stipulations that samples must be drawn from catches by commercial vessels if they are to be applied against nominal catches. Where samples are taken from landings, then sampling of discards has been particularly encouraged, and where samples are taken from research vessel catches, it has been required that they be so identified, even if taken in a manner comparable to commercial fishing activity. It has been recommended that measurements be on "round fresh" fish, in order to avoid bias due to length variation during storage.

Age Sampling

The body parts used most frequently for aging studies are the otoliths, with scales the next most common. There have been a number of cases where the results obtained from these two sources are in disagreement, and comparative studies were needed to reconcile them. The aging material normally used is given in Table 1.

Such material can be collected on a random basis or on a stratified basis. The latter is much more effective than random sampling for compilation of age-length keys used in assessments because, by selecting a certain number of fish from specified length intervals, the entire length range of the catch is covered, and it reduces the number of individuals that need be sampled to adequately cover the catch.

Length Reporting Standards

The length measurements required to be reported to ICNAF/NAFO and the form for reporting them have evolved with time, with the most recent revision being carried out in 1974, and minor changes being made since then. The lengths and size groupings to be reported, and whether the data should be separated by sex are summarized in Table 1. The actual measurements taken in the field may be on a finer scale than these requirements and subsequently combined. These more detailed measurements may be used for individual studies, and their collection is illustrated by current practice of scientists of the Canadian Department of Fisheries and Oceans (Table 1). The current definitions of the various lengths (Anon. 1981) are as follows:

Fork length — from the tip of the snout to the apex of the V forming the fork of the tail, for species with forked tails.

Total length — from the tip of the snout to the tip of the longest lobe of the tail when the lobe is extended posteriorly in line with the body. This is sometimes referred to as greatest total length. For fishes with nonforked tails, only total length is appropriate.

Other (to be specified) — for example, mantle length for squids, upper valve greatest diameter for scallops, carapace lengths for shrimps, etc.

while the method of recording may be as follows:

Nearest centimetre (rounded) — measurements are

TABLE 1. NAFO reporting requirements and current Canadian practice.

Species	Length	Length group	Sexes separate	Aging material	Current practice by Canadian scientists at sea
Atlantic cod (*Gadus morhua*)	fork length	3 cm	No	otoliths	nearest cm
Pollock (= Saithe) (*Pollachius virens*)	fork length	3 cm	No	otoliths	nearest cm
Cusk (*Brosme brosme*)	total length	3 cm	No	otoliths	nearest cm
White hake (*Urophycis tenius*)	total length	3 cm	No	otoliths	nearest cm
Wolffishes (*Anarhichas* sp.)	total length	3 cm	No	—	nearest cm
Roundnose grenadier (*Macrourus rupestris*)	pre-anal length	1/2 cm	No	otoliths	nearest 1/2 cm
Haddock (*Melanogrammus aeglefinus*)	fork length	2 cm	No	otoliths	nearest cm
Greenland cod (*Gadus ogac*)	total length	2 cm	No	—	nearest cm
Red hake (*Urophycis chuss*)	total length	2 cm	No	otoliths	nearest cm
American Plaice (*Hippoglossoides platessoides*)	total length	2 cm	Yes	otoliths	nearest cm
Witch flounder (*Glyptocephalus cynoglossus*)	total length	2 cm	Yes	otoliths	nearest cm
Yellowtail flounder (*Limanda ferruginea*)	total length	2 cm	Yes	otoliths	nearest cm
Greenland halibut (*Reinhardtius hippoglossoides*)	total length	2 cm	Yes	otoliths	nearest cm
Winter flounder (*Pseudopleuronectes americanus*)	total length	2 cm	Yes	otoliths	nearest cm
Redfish (*Sebastes* sp.)	fork length	1 cm	Yes	otoliths	nearest cm
Silver hake (*Merluccius bilinearis*)	fork length	1 cm	Yes	otoliths	nearest cm
Atlantic herring (*Clupea harengus*)	total length	1 cm	No	otoliths	nearest cm or nearest 1/2 cm or nearest 10 mm group
Atlantic mackerel (*Scomber scombrus*)	fork length	1 cm	No	otoliths	nearest cm or nearest 1/2 cm
Alewife (*Alosa pseudoharengus*)	total length	1 cm	No	scales	nearest cm or nearest 1/2 cm
Atlantic argentine (*Argentina silus*)	total length	1 cm	No	otoliths	nearest cm or nearest 1/2 cm
Squids (*Illex* and *Loligo*)	mantle length	1/2 cm	No	length[a]	nearest 1/2 cm sexed
Capelin (*Mallotus villosus*)	total length	1/2 cm	Yes	otoliths	nearest 1/2 cm
Sea scallops (*Placopecten magellanicus*)	shell height	1/2 cm	No	length	nearest 1/2 cm
Northern deepwater prawn (*Pandalus borealis*)	carapace length	1 mm	Yes	length	nearest 1 mm or nearest 0.5 mm below also nearest mm rounded down. sexed. nearest 0.1 mm by 0.3 mm grouping sexed
Atlantic salmon (*Salmo salar*)	fork length	1 cm	Yes	scales	nearest mm
Atlantic lobster (*Homarus americanus*)	carapace length	1 cm	No	length	nearest mm rounded down. sexed nearest 0.1 mm by 0.3 mm grouping sexed
Snow crab (*Chionoecetes opilio*)	carapace width	1 cm	No		nearest mm

Other species not listed above should initially be reported by 1-cm length groups.

[a] Statoliths being examined.

recorded to the nearest centimetre (i.e., fish in the length range 29.5-30.4 cm are actually recorded as 30 cm).

Centimetre below (truncated) — measurements are recorded to the centimetre below (i.e. fish in the length range 30.0-30.9 cm are recorded as 30 cm).

Other (to be specified) — for example, capelin are to be measured in half-centimetre units, and should be recorded to the nearest half centimetre below.

Reporting Format

The actual format for reporting has also evolved with time. Currently, NAFO receives individual rather than aggregated sample data for inclusion in the data base. Examples of the reporting forms may be found in Anon. (1981).

Other Agencies

The ICNAF/NAFO sampling requirements do not cover those species in the Northwest Atlantic that are under the mandate of the International Commission for the Conservation of Atlantic Tunas. The body has established requirements for the sampling of tunas, billfishes, and sharks. The standard length is fork length (upper jaw, except lower jaw for billfish) by 1-cm below grouping up to 40 cm fork length and by 2-cm below grouping thereafter. The recommended national sampling level is 500 fish monthly for each gear type/unit area (unit depends on fishery).

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The Atlantic Observer Programs — A Discussion of Sampling from Commercial Catches at Sea

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A brief history of the observer programs in the Atlantic region, a summary and analysis of sampling effort, and program benefits are presented. Since 1977 when technicians were first sent to sea as observers of commercial operations, the program had grown to where, in 1981 about 12 500 fishing days were covered. Nearly 2 million lengths were collected from a large and very complex fishery for use in stock assessments. Set by set sample extraction, the strategy used at sea by observers resulted in more representative catch at age data. Sampling efficiency (expressed as samples per 1000 t) for overall commercial activity has certainly increased with the introduction of the observer programs. The problems raised by sample removal in the commercial environment and the duality of the observer's role are discussed and solutions to these problems presented. Along with its many other functions, the programs present a cost effective way to obtain much needed commercial data.

KULKA, D. W., AND D. WALDRON. 1983. The Atlantic observer programs — a discussion of sampling from commercial catches at sea, p. 255–262. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Le présent rapport fournit un bref historique des programmes d'observateurs et leurs avantages dans la région de l'Atlantique ainsi qu'un résumé et une analyse de l'effort d'échantillonnage. De ses débuts en 1977, quand les premiers techniciens ont été envoyés en mer pour observer les opérations commerciales, le programme s'est amplifié jusqu'à en venir à couvrir 12 500 jours de pêche en 1981. Près de deux millions de données sur la longueur, utilisées pour les évaluations des stocks, ont été recueillies au cours de cette pêche importante et très complexe. La stratégie utilisée en mer par les observateurs, soit le prélèvement d'échantillons après chaque mouillage, a généré des données plus caractéristiques sur la composition en âge des prises. L'efficacité de l'échantillonnage (nombre d'échantillons par 1000 t) pour les activités commerciales globales s'est améliorée par suite de la mise en oeuvre des programmes d'observateurs. L'article couvre les problèmes soulevés par le prélèvement d'échantillons dans un contexte commercial et la dualité du rôle de l'observateur, et présente également des solutions. En plus de ses nombreuses autres fonctions, le programme constitue un moyen rentable d'obtenir des données très utiles sur la pêche commerciale.

Introduction

The concept of placing fisheries observers aboard foreign trawlers off the coast of Canada to collect data was conceived in 1976 during a meeting of the International Commission for the Northwest Atlantic Fisheries (ICNAF). The program's prime objective was to evaluate the impact of small mesh fisheries on the Scotian Shelf; however, it was not until 1977 that specific bilateral agreements were struck with countries taking part in the fisheries, particularly, the USSR and Cuba. This experimental program resulted in several papers based on the data collected. The usefulness of these documents demonstrated a need for such a project to continue in future years. Not only was the program a source of information for assessing silver hake and squid resources, it also provided a means to evaluate current gear and mesh regulations in a quantitative manner. Plans were formulated in the fall of 1977 to incorporate and apply the concepts of data collection and vessel monitoring to the French fleet scheduled to fish in the Gulf of St. Lawrence in early 1978. Because the program was initiated under very pressing time constraints, the overall success of this early program was questionable; it did lay, however, the groundwork for what was to follow. This initial experience aided in the eventual creation of a full-scale, ongoing scheme.

Establishment of a joint Biological and Enforcement Observer Program took place in the spring of 1978. The basic aim was to provide the department with a tool to assist in both the assessment and management of the fishery within the extended zone of fisheries jurisdiction. The program was to provide a source of reliable data for all offshore commercial species and to act as an effective method of monitoring the compliance of foreign and domestic fleets to current regulations.

In 1980, an expansion of foreign fleet coverage and an extension to domestic offshore vessels took place. In the same year, the program was converted into a third party company contract system to replace the individual personal services contracts previously used. The effects of these major changes will be discussed.

Until 1981, these operations were administered by the Newfoundland and Scotia-Fundy components of the Department of Fisheries and Oceans, the former responsible for coverage in the Northwest Atlantic Fisheries (NAFO) for subareas 0, 2, and 3, the latter responsible for NAFO subarea 4, with overlapping coverage between regions for the Gulf of St. Lawrence. In 1981, the Gulf Region Observer Program was introduced with jurisdiction in the Gulf including NAFO subareas 4R, S, T, and 3Pn on the domestic and the French fleet. The three programs, in conjunction with the existing shore sampling systems, now represent a very comprehensive commercial fisheries data acquisition system.

The object of this paper is to elucidate the scope of the program, describe its various functions, present a historical perspective of the biological portion of the activity since 1979 (the first full year of operation), define the fundamental objectives, and discuss benefits to the various users and operational shortcomings and their solutions. Particular areas to be focused on are: the success of techniques developed to obtain and process quality data in a commercial environment, the implications of personnel having a dual role (sampling and enforcement) as it pertains to the validity of data collected, and the effect of a fluctuating administrative structure. Also included is a general description of the collection and processing system.

Materials and Methods

The observer is responsible not only for the collection of biological samples but also for recording catch-effort, enforcement, and a variety of other data. This paper deals only with the sampling function. The attainment of representative samples from commercial catches is a particularly difficult process as populations and their parameters are unevenly distributed and ever changing entities. Fish populations exhibit annual and other cycles, but with many anomalies. These biological patterns alone would affect attempts to sample catches, but the job of the observer is further confounded by the nature of the workplace. The observer must work alone on a constantly moving platform where the primary aim of the ship's crew is to catch and process fish as quickly as possible. Each vessel presents a unique set of logistical problems to be overcome in order to obtain valid samples; hence, flexibility is the operative concept.

To ensure that the observer is able to carry out the data acquisition duties in a competent manner, a comprehensive training course must be completed before the first deployment. The training includes multispecies sampling technique sessions in the laboratory, at fish plants, and finally at sea. Each stresses the theory of random sampling and outlines the barriers encountered in attaining such samples in the commercial environment. All techniques taught are laid down in manuals and/or instruction pamphlets. In these documents, each species and category is dealt with in detail so that observers have a written reference to deal with any problems encountered at sea. Further instruction is given at the briefing session just prior to a trip, along with specific sample requirements for that particular fishery. At this time, new techniques can also be taught if there are any special data needs. A sampling strategy is then devised using reports from past trips. Finally, the government and the contracted company utilize monitoring techniques and a disciplinary system to improve the work of their employees. Such feedback acts as a monitor and results in a continual upgrading of the data generated from the program.

When at sea, the observer must first assess the vessel layout and processing system to determine the best sampling plan. In consultation with the vessel's captain or processing foreman, a sampling position is selected where fish can be randomly removed from the catch with minimum interference to production. Since culling by the crew can be quite a subtle procedure, the whole sampling operation must be planned carefully by the observer to eliminate effects that can lead to sampling bias.

To date, the observer programs have concentrated on vessels employing the otter trawl, gillnet, or longline gears. These vessels use a basic processing design regardless of vessel type. Situated in the vicinity where the gear is retrieved, is a series of holding pens and/or a hole that accesses the below-deck processing operation. Once the net is retrieved after the fishing operation, it is emptied either into the pens or directly down the chute to a larger pen or hold.

Sampling small catches from deck pens is done by visually sectioning the pen and sampling all the fish in one section. Sampling large catches (>4 t) from deck pens can be rather difficult. The system of partitioning and sampling all the fish in one section is not practical. If the fish are to be processed below decks, the observer is encouraged to sample from that area. However, if processing occurs on the deck, the observer is confronted with the logistic operation of collecting samples. Under those circumstances, sampling can be achieved by subsampling during the processing operation by taking fish at the beginning, middle, and end of the production period.

A randomizing technique is used in the selection of the sampling units or baskets, usually about 5–8 to avoid removing fish from a small, possibly nonrepresentative subsection of the catch. This is important because individuals of a population can be segregated or stratified by size or sex. Since only about 20% of all sets coming on board are sampled, those chosen must reflect time and area fished because there can be radical differences in size and ratio of sex between areas and time of day. Certainly, the sampler's judgment plays a large part in the appropriateness of data obtained from commercial operations at sea. The result is a more representative combined sample for a given time period and stock.

To make the one person operation at sea more efficient, a number of techniques or types of equipment were considered. Such devices as keyboards or punch sheets used in the laboratory for recording data did not present any advantage to the commercial sampler and were not practical at sea. Also, voice recorders were used to record data but again they did not save time and were often unreliable. Most observers prefer to record the data directly on computer tally sheets or on white plastic strips attached to the sampling board. This latter device eliminates the need to handle paper at the sampling station. Alternatively, waterproof forms have been successfully used.

From time to time, limited access to fish, very poor working conditions (as encountered on small side trawlers in the winter), and very small catches severely limit the size and number of samples that can be taken. These situations are encountered most often within the Canadian fleet. No practical solutions exist and this can lead to a certain amount of undersampling. Fortunately such difficult situations occur relatively infrequently.

Typically, sampling can be applied to the landings (usually culled animals), the catches, or the discards. The opportunity to sample discards and unculled catches is the major advantage to sea sampling. At shore-based plants, only landings could be sampled. Frequencies obtained from unculled catches are obviously the most useful form of length data in that they represent the total removals. When discarding or reduction occurs, the shore sampling would bias the estimate of the frequency distribution. If it is not possible to obtain samples of the catch, then samples of discards should be taken.

Landings are, in general, the target of most sampling programs for the following reasons: (1) access to unculled catches is often a problem, and (2) the amounts of discards are very difficult to estimate accurately. This last problem leads to only rough estimates of removals at length. The ideal situation on Canadian vessels (or for that matter in any commercial operation where discarding takes place) is to take catch samples, accurately determine both the landed and discard weight, add these two values to a total catch weight, and adjust the frequencies to this result. If amounts of discards and their lengths were known, then the landing samples taken at the plant could also be adjusted in a similar manner. This procedure is not possible in practice, particularly where there is substantial discarding, because it is impractical for one observer to estimate precisely the amount of fish that is being dumped. the procedure used now is to sample landed fish (after discarding) and ignore the resulting bias. The observer, however, is able to take samples of discarded fish when requested to accompany the best estimate of discards. In this way, the manager has an approximate idea of the size of the problem.

The selection of fisheries or specific vessels to be sampled for removals at length is based on the overall requirements of the program, not just scientific needs. The observer deployment strategy has been determined from the following three factors (in ascending order of importance): (1) the acquisition of catch, effort, and operational data, (2) attainment of representative scientific samples from the offshore sector, and (3) collection of other specific biological and technological data. Deploying observers to cover departmental needs (given a mandate and money for about 20% domestic and about 80% foreign coverage) is largely a random process with the general aim of obtaining roughly equal coverage per stock except in special cases where the need for more operational data are greater. The strategy generally satisfies basic sampling needs because of the relative randomness that vessels within a fleet are selected for observation.

To illustrate this point, commercial statistics for the three full years of operation were compiled using foreign catch statistics supplied by FLASH (Foreign Licensing and Surveillance Hierarchical Information System) or the NAFO Statistical Bulletin, and domestic statistics collected by the Department of Fisheries and Oceans. Relative sampling efficiencies were calculated by taking the number of samples extracted for each fishery divided by the corresponding catch, and multiplying by 1000. The value rounded to the nearest whole number represents the NAFO standard of number of samples per 1000 t of fish caught. Any values less than 1 would represent an undersampled stratum. In certain instances, observed catch exceeded reported catch. In such cases, the observed catch was used to carry out the sampling efficiency calculations.

Results

Table 1 is a condensed historical summary of sampling performance which combines the effort of the two Atlantic Observer Programs (Newfoundland and Scotia–Fundy). Detailed sampling statistics from which this condensed version was derived can be found in D. W. Kulka (Department of Fisheries and Oceans, Research and Resource Services, St. John's, Nfld.) and D. W. Waldron (Department of Fisheries and Oceans, Marine Fish Division, Bedford Institute of Oceanography, Dartmouth, N.S. 1982, unpublished data). It is these detailed tables stratified by country, species, NAFO division, gear and quarter that form the basis for discussion of sampling efficiency. The strategy used when collecting data was to sample by division and by month, in order to produce a relatively even coverage over the stocks. This is the general format of the detailed tables although in certain cases the data have been combined by stock to reduce the volume. Not included are the small amounts of data collected in 1981 by the newly formed Gulf Region Program or limited data collected in 1978 by the other two regions. For the years 1979–81, Table 1 lists the relative sampling performance by country, species, and quarter.

For this paper, a relative efficiency level of less than 1 is considered inadequate, although as discussed later one sample per 1000 t may not yield a satisfactory data set.

TABLE 1. Quarterly sampling efficiency and percentage observed catches, 1979–81.

		1979 Efficiency					1980 Efficiency					1981 Efficiency				
Country	Species	1	2	3	4	% observed	1	2	3	4	% observed	1	2	3	4	% observed
Bulgaria	Cod	—	—	—	—	—	—	—	0	—	200	—	—	—	—	—
	Haddock	—	111	29	—	0	—	—	—	—	—	—	—	—	—	—
	Redfish	—	0	—	—	0	—	—	—	—	3	—	—	—	—	—
	Silver Hake	—	13	23	—	73	—	82	27	—	44	—	—	—	—	—
	Illex	—	57	10	—	56	—	—	40	—	43	—	—	—	—	—
	Capelin	—	—	0	0	0	—	—	—	—	—	—	—	—	—	—
Canada	Cod	<1	<1	<1	2	6	5	3	<1	1	10	17	6	9	4	36
	Haddock	<1	<1	<1	<1	1	5	1	0	4	10	13	7	0	10	24
	Redfish	<1	<1	1	1	1	10	3	2	7	6	29	9	3	11	21
	Pollock	1	<1	0	1	1	3	0	0	1	7	3	4	3	3	13
	Silver Hake	—	—	—	—	—	—	17	23	—	59	—	—	—	—	—
	Illex	—	—	—	—	—	—	—	0	—	78	—	—	—	—	—
	Am. Plaice	0	<1	<1	2	1	5	4	4	3	8	38	120	109	10	109
	Witch	0	0	14	2	0	9	4	51	9	9	24	68	0	18	19
	Yellowtail	0	2	0	1	7	5	1	1	1	1	1000	26	57	103	44
	Turbot	0	2	0	2	0	3	1	—	19	9	83	289	0	—	123
	Shrimp	—	—	119	—	33	0	902	200	648	125	0	>1000	843	992	209
Cuba	Cod	34	0	100	0	82	77	71	255	—	97	—	83	176	0	53
	Haddock	—	91	333	—	0	—	>1000	>1000	—	140	—	333	>1000	—	78
	Redfish	78	<1	<1	3	0	—	141	—	—	13	—	—	—	—	0
	Pollock	—	0	0	0	0	—	32	>1000	—	109	—	0	—	—	98
	Silver Hake	—	34	34	15	43	—	125	90	—	94	—	136	228	—	125
	Illex	—	0	19	62	40	—	610	37	—	70	—	280	346	—	816
	Argentine	—	—	100	—	0	—	0	667	—	150	—	—	—	—	—
	Capelin	—	—	0	0	109	—	—	—	—	—	—	—	—	—	—
Denmark	Shrimp	0	0	396	173	0	0	<1	25	35	2	—	—	—	—	—
Faroe Islands	Shrimp	—	209	150	227	42	—	—	—	—	—	—	—	—	—	—
	Porbeagle	—	—	0	87	2	—	0	—	—	14	133	150	—	0	70
	Cod	—	—	—	—	—	—	—	—	—	0	—	24	116	38	50
	Turbot	—	—	—	—	—	—	—	—	—	0	0	—	—	—	—
France	Cod	10	23	0	0	31	25	23	1	0	54	14	18	0	0	60
	Haddock	71	175	0	0	1	48	20	333	0	2	—	—	—	—	—
	Redfish	69	78	0	0	18	250	23	10	0	5	378	0	0	0	26
	Illex	—	—	19	—	99	—	—	69	—	106	—	—	0	0	100
	Shrimp	—	—	0	0	0	—	—	957	—	99	—	—	—	—	—
	Pollock	87	0	—	—	0	29	34	—	—	12	—	—	—	—	—
	Herring	—	>1000	—	—	0	—	—	—	—	—	—	—	—	—	—
	Am. Plaice	265	529	0	0	0	667	11	18	—	5	>1000	0	0	—	3
	Witch	286	>1000	—	—	0	—	56	—	—	28	—	—	—	—	—
	Yellowtail	—	0	0	—	0	—	0	6	—	0	—	0	0	—	0
Fed. Rep. Ger.	Cod	23	—	—	0	63	10	29	—	26	67	—	—	—	—	—
	Redfish	29	—	0	—	0	0	0	—	0	0	—	—	—	—	—
	Pollock	—	—	0	—	0	—	—	—	—	—	—	—	—	—	—
	Illex	—	—	17	—	101	—	—	—	—	—	—	—	—	—	—
	Turbot	—	—	—	0	0	0	0	—	0	0	—	—	—	—	—
	Am. Plaice	—	—	—	—	—	0	0	—	—	0	—	—	—	—	—
	Witch	—	—	—	—	—	0	—	—	—	0	—	—	—	—	—
GDR	Cod	14	6	—	15	27	16	0	0	29	76	—	—	—	26	37
	Redfish	44	8	—	0	0	0	0	0	0	63	—	—	0	3	12
	Turbot	60	111	—	0	0	—	—	—	692	0	—	—	0	0	0
	Roundnose Grenadier	—	—	—	40	49	—	—	—	14	68	—	—	0	17	79
	Am. Plaice	333	0	—	—	0	—	—	—	—	—	—	—	—	—	—
	Witch.	150	0	—	—	0	—	—	—	—	—	—	—	—	—	—
Greenland	Shrimp	0	0	0	0	0	—	—	—	—	—	—	—	—	—	—
Ireland	Illex	—	—	10	—	98	—	—	—	—	—	—	—	—	—	—
Italy	Silver Hake	—	—	200	—	50	—	—	—	—	—	—	—	—	—	—
	Illex	—	—	2	87	86	—	—	—	—	—	—	—	—	—	—

TABLE 1. *(Concluded)*.

Country	Species	1979 Efficiency 1	2	3	4	% observed	1980 Efficiency 1	2	3	4	% observed	1981 Efficiency 1	2	3	4	% observed
Japan	Cod	0	0	>1000	1000	42	0	0	333	>1000	1665	—	—	667	>1000	5 720
	Haddock	—	—	667	444	0	—	—	516	169	37	—	—	>1000	200	100
	Redfish	0	0	—	154	0	0	0	>1000	947	3	—	—	>1000	0	43 225
	Pollock	—	—	63	333	0	—	—	240	87	65	—	—	250	0	92
	Silver Hake	—	—	179	>1000	219	—	—	817	>1000	99	—	—	777	0	104
	Illex	—	—	18	16	60	—	0	55	59	87	—	—	35	14	58
	Argentine	—	0	19	54	45	—	0	27	74	27	—	—	64	0	21
	Am. Plaice	0	0	—	—	3	—	—	>1000	—	100	—	—	—	—	—
	Albacore	0	—	—	42	16	—	—	—	10	11	—	—	80	49	27
	Big Eye	0	—	—	14	18	—	—	—	4	15	—	—	21	14	23
	Yellowfin	—	—	—	—	—	—	—	—	—	—	—	—	667	59	57
	Blue Fin	—	—	—	1000	2800	—	—	—	6	30	—	—	27	8	34
	Swordfish	—	—	—	—	—	—	—	—	7	29	—	—	39	15	46
Norway	Cod	0	0	0	—	0	0	0	—	—	32	—	66	—	—	90
	Shrimp	0	0	28	22	2	0	266	326	—	108	—	—	—	—	—
	Turbot	0	0	—	—	0	—	—	—	—	—	—	—	—	—	—
Poland	Cod	19	60	66	73	45	21	0	360	4	64	32	0	750	3	54
	Redfish	183	183	40	250	0	5	0	0	0	46	—	0	0	0	70
	Illex	—	—	8	3	20	—	—	73	0	97	—	—	42	—	92
	Am. Plaice	4	>1000	333	—	0	0	0	0	0	0	0	0	0	0	0
	Witch	29	57	389	—	33	21	74	—	0	101	65	47	0	0	92
	Turbot	38	37	72	70	51	0	417	24	0	0	23	32	140	14	77
Portugal	Cod	17	13	4	20	14	29	11	30	83	62	—	—	275	71	87
	Redfish	72	0	0	10	8	0	1	6	0	4	—	—	—	2	22
	Silver Hake	—	—	—	—	—	—	—	200	0	60	—	—	—	—	—
	Illex	—	—	9	17	63	—	—	72	18	134	—	—	—	—	—
	Turbot	0	0	0	0	0	—	—	227	—	233	—	—	—	72	0
	Am. Plaice	14	23	0	98	0	8	152	0	—	24	—	—	—	0	7
	Witch	34	10	0	0	3	0	0	—	0	0	—	—	—	0	50
	Yellowtail	—	0	0	—	0	—	—	—	—	—	—	—	—	—	—
	White Hake	—	—	—	—	—	—	—	—	—	—	—	—	—	5	100
Romania	Cod	0	—	—	—	0	—	—	—	—	—	—	—	—	—	—
	Redfish	0	—	—	—	1	—	—	—	—	—	—	—	—	—	—
	Silver Hake	—	—	1000	—	0	—	—	—	—	—	—	—	—	—	—
	Illex	—	—	19	—	116	—	—	—	—	—	—	—	—	—	—
	Am. Plaice	—	—	—	0	0	—	—	—	—	—	—	—	—	—	—
	Witch	0	—	—	—	0	—	—	—	—	—	—	—	—	—	—
Spain	Cod	0	1	30	6	8	0	32	16	28	38	—	—	—	—	—
	Redfish	—	—	636	71	0	—	—	—	—	—	—	—	—	—	—
	Illex	—	—	5	—	49	—	—	27	1	56	—	—	—	—	—
	Turbot	—	—	0	0	0	—	—	—	—	—	—	—	—	—	—
	Am. Plaice	—	—	188	0	0	0	145	110	0	0	—	—	—	—	—
	Silver Hake	—	—	—	—	—	—	—	800	200	21	—	—	—	—	—
United Kingdom	Cod	—	23	—	—	68	—	46	—	—	113	—	—	—	—	—
	Redfish	—	65	—	—	0	—	—	—	—	—	—	—	—	—	—
	Turbot	—	82	—	—	95	—	—	—	—	—	—	—	—	—	—
	Am. Plaice	—	0	—	—	0	—	—	—	—	—	—	—	—	—	—
	Witch	—	45	—	—	0	—	—	—	—	—	—	—	—	—	—
USSR	Cod	—	23	—	—	68	—	46	—	—	113	—	—	—	—	—
	Haddock	—	156	33	0	0	—	266	>1000	—	72	—	424	859	—	84
	Redfish	0	3	21	0	5	0	14	1	0	22	4	6	0	0	38
	Pollock	—	0	0	—	0	—	34	23	—	49	—	45	7	—	14
	Silver Hake	0	7	11	—	28	—	24	19	200	45	—	22	21	—	50
	Illex	—	28	2	<1	6	—	60	12	200	44	—	97	21	—	30
	Argentine	—	22	20	—	71	—	68	69	333	67	—	171	34	—	21
	Am. Plaice	0	0	0	2	0	—	636	133	—	77	—	0	0	—	0
	Witch	0	0	0	0	0	—	77	—	50	10	67	53	0	—	28
	Yellowtail	—	—	—	—	—	—	—	—	—	—	—	0	0	—	0
	Capelin	—	0	10	8	41	—	—	9	5	95	—	—	0	0	78
	Roundnose Grenadier	0	24	7	6	8	—	—	0	0	3	—	—	30	1	40
	Turbot	—	—	—	5	10	—	—	—	39	124	>1000	0	46	392	457

Generally, Table 1 shows that where sampling effort does take place, number of samples per 1000 t considerably exceeded the minimum value, implying a properly sampled stratum. In addition and particularly in 1979 and 1980, substantial numbers of by-catch samples were taken. These are useful especially where there is considerable species overlap such as in the squid/silver hake/argentine complex on the Scotian Shelf.

The overall foreign coverage of fishing days by observers amounted to about 55% of that reported in 1979 although deployments were well spread over the various fisheries. Of approximately 125 strata (by NAFO division) where catches exceeded 100 t, 80% were sampled at the minimum efficiency level or better. Many of the small catches were covered as well. For the 20% of strata not sampled, only 28% had catches in excess of 300 t indicating that almost all of the major fisheries were covered adequately.

Strata where redfish was the directed species are excluded from the calculations because only limited samples were collected in those years. In 1979, observer sampling efficiency for the Canadian fishery was very low because domestic coverage was limited in the first year of operation. Consequently, only about 20% of the strata were sampled efficiently. In that year, the shore sampling program (see Stevenson 1983) produced the bulk of the offshore domestic data. The observer program contributed for the first time to the overall domestic data base.

In 1980, sampling efficiency of foreign catches changed little from the previous year with 23% of the strata missed. Again only 29% of those missed, exceeded 300 t indicating good overall coverage, particularly in the larger fisheries. The most significant change occurred in the domestic sector where 55% of the strata (from about 20% of days observed) were sampled in excess of the minimum efficiency level. Particular gains were for shrimp stocks that previously went unsampled. Stevenson (1983) examined the combined efficiencies of the 1980 shore and sea sampling and his data indicated fairly complete coverage.

In 1981, foreign sampling efficiencies decreased slightly to 76% in spite of the slight increase in coverage. This drop was due mainly to large USSR fisheries in December which were poorly covered. Domestic sampling was up from the previous year. As in the other years, the only stocks inadequately sampled were of minor commercial importance, those outside 200 mi or those deemed less important in the context of surveillance needs.

Since the introduction of the observer program, sampling in both the foreign and domestic sectors has been greatly improved. The ratio of expenditures to sample returns is starting to reach a plateau because the small fisheries are less accessible and more expensive to cover. This is particularly the case in the foreign fisheries where coverage is high. Further expansion in the domestic offshore sector would, however, yield improvements in the sampling efficiency for certain stocks.

Discussion

The need for observers at sea as collectors of biological data was recognized long before the existence of such a program. Paulsen (1956) made the following comment in the context of sampling salted cod: "The method does not offer a reliable substitute for sampling at sea by means of observers. The sampling by observers, although more expensive (in money and time), must continue to be our main way of studying size-distributions. Our efforts to carry out and develop this kind of sampling should not in any way be lessened through the adoption of the method of measuring landed, salted cod." More recently T. Williams stated in Gulland (1977) that "Large well-equipped laboratories complete with costly research vessels and highly qualified staff, attempt to carry out quantitative studies of fish stocks without utilizing the enormous amount of information relatively cheaply obtainable from the operations of the commercial fishing fleet.... A properly organized program of work at sea on commercial fishing vessels and onshore at fish markets and in processing plants provides the basic data for removals by the fishery and also information on the abundance, distribution, migrations and mortality of the exploited fish stocks." Certainly the need for a large scale in situ program has long been realized. In 1977, coinciding with the extension of jurisdiction to 200 mi, Canada put such a program in place.

The observer programs from all three Atlantic regions aim at the surveillance of the fisheries and the collection of scientific data. Such an approach is very efficient because each task performed by the observer requires only a portion of the working day. Hence all aspects together can be done by a single observer per vessel. This is further enchanced since in most circumstances, both surveillance and scientific objectives are similar. A common criticism of at sea commercial data collection, as noted by Paulsen (1956), is the expense, but the cost effectiveness of the Atlantic program has been demonstrated by internal studies on several occasions for the surveillance aspects alone. The multiaspect approach supplies much needed information and reliable data to various groups within management, at little or no extra cost to the users.

The observers' direct access to catches yields set by set estimates accompanied by detailed effort and age-length data. Age, length, and other demographics can be extracted in as detailed a manner as is deemed necessary and can even be taken from subsets of the catch such as discards, landings, or size-culled fish depending on the use to which they are to be put. They can be recombined into any specified strata, properly weighted at each level. For example, length-age sampling of catches at a rate of 1–2 sets per d can be easily done in conjunction with other duties. With a 25% deployment on Canadian offshore vessels, about 3% of all sets were sampled in 1981, an unprecedented level of coverage. On foreign vessels, where deployment averages about 85%, the portion of sets sampled was about 10%.

Examination of individual sample frequencies of a particular species taken in the same area and by the same vessel over a short period of time reveals that there can be considerable difference in both size and sex composition at the set level. This is due to the complicated and characteristic clumping in areal distribution of fish by size and sex (Zwanenburg and Smith 1983). Previously, all Canadian commercial length-age samples were extracted from landings on shore, where generally, single samples per vessel were taken. It is possible that a single sample may not be representative if it includes fish from only a small proportion of the fish retained. Hence the daily sampling of sets at sea (about 7 per vessel per trip) represents an improvement in sampling design.

Presently, the impact of sample error on the stock assessment process is uncertain and the amount of samples required is unknown for this area. Since biological data are the basis for management, they must be as accurate as possible and sampling must be as intense as is practically possible. Regardless of whether the sea sampling strategy represents an improvement in sample design, this fairly extensive scheme considerably enhances the overall data base and also allows for the statistics to be weighted on a set by set basis.

The expense of obtaining these samples is low in relation to other existing sampling programs. Certainly the pitfall of oversampling adds unnecessary cost but undersampling can lead to misinterpretations of the state of various stocks, is much more serious and, in the long run, is a much costlier problem.

Presently there are about 40 stocks (15 species) fished by 16 countries in the offshore sector composing about 220 strata. This commercial operation presents an immensely large sampling problem because catches from each stock must be sampled adequately by gear, quarter, or month. The observer program provides an opportunity to accomplish such a task. Prior to 1978, Canadian managers depended on data supplied to ICNAF (NAFO) by each country either from sampled landings or from sea samples done by technicians from each of the countries. Deficiently sampled or unsampled stocks were not uncommon particularly in the foreign sector and the scientists responsible for assessment had little or no way of controlling sample quantity, quality, or distribution (Anon. 1979). Between country differences in measuring and recording methods for a number of species often made the data incompatible or at best difficult to combine with other sets. One example was the different ways in which roundnose grenadier were measured, i.e. total, anal, or anal fin length (Atkinson 1981). With a single collection agency, the observer program, the sampling techniques are standardized.

In 1979, prior to observer coverage, Rivard et al. (1980) showed that 30% of all stocks fished by the domestic fleet in the Atlantic were not sampled adequately in terms of the NAFO minimum standard of one sample per 1000 t landed. It should be noted that this standard is arbitrary, not based on statistical analyses, and may represent a level that is less than adequate. Presumably, when extracting a reasonably large sample (200+ individuals) from 1000 t of a relatively homogeneous catch, a single sample would likely be representative of that group of fish. This ideal situation, however, does not occur because the fish are removed from a widespread area where size distribution, sex ratio, and even size at age might vary. In this situation, larger numbers of small samples would be a more appropriate sampling strategy. It is exacty this kind of sampling scheme that is executed by the observer program.

The program has only been in existence since 1978; therefore the value of data in assessment studies is just now being investigated. It is usual to work with an appropriately long time series of commercial data to obtain useful answers to management questions. The utilization of data has recently expanded rapidly and the information has proved to be quite beneficial for many users. Both catch and effort and length-age data are used regularly in stock assessments for a wide variety of species. It has also proved useful in quite a number of circumstances where only in situ observations could reveal a given problem.

In certain cases and particularly the foreign sector, observer data are the only source of information and therefore are indispensable. For example, all of the commercial shrimp, large pelagic data, and much of the silver hake and squid data used for stock assessments have been collected by observers. Nearly 100% of all porbeagle sharks and associated by-catch species landed by the Faroes were measured for several morphometric characteristics, sexed, and weighed, yielding an unprecedented amount of commercial and biological data from a fishery with considerable potential.

Acquisition of such data would not have been possible without an observer program. The program data provided the basis for 1980 and 1981 4VWX silver hake assessments and were a major source of assessment and other biological data on squid and argentine stocks (Waldron and Wood 1980; Waldron and Sinclair 1980; Waldron 1981). The limited deployment on domestic vessels has also provided data valuable to stock assessment. In particular, data on the 1980 4VN winter cod fishery played a key role in the assessment of that stock for 1981.

From time to time, it becomes quite useful to know the size composition of fish being discarded, and only in situ observations allow for such data to be collected. For example, in 1980, the observer data base allowed the reconstruction of the removals-at-age for 1- and 2-yr-old cod in 4VsW (discards). This data assisted in raising the TAC by almost 400% over what it would have been using landed data only (Maguire 1981). Another situation occurred during the 1981 foreign fishery on the Scotian Shelf where several vessels encountered large concentrations of juvenile haddock. Existing regulations forbid haddock retention of more than 1% of total weight on board but this regulation is only sensitive to weights and not numbers removed. In a matter of hours, these vessels caught almost 70 t of small haddock. Observer communications with DFO provided immediate input to management and the situation was quickly rectified. Without the presences of the observers, very large numbers of juvenile haddock could have been removed. The action taken by the Government of Canada was based on the presence and ability of the observer to estimate fish quantities and fulfill sampling protocols.

Knowledge gained on by-catches in small-mesh gear fisheries on the Scotian Shelf has established that such removals were one of the most significant factors in reduced cod and haddock yields during the late 1960s and early 1970s (Waldron 1980). The monitoring and the control of small-mesh fisheries are essential to protection of the productivity of resources which are of great importance to the Canadian fishing industry. The inability to identify and quantify this problem through boarding and fishery officer inspection testifies to the need for, and value of the observer programs. Certainly, it has helped fill one major gap in our knowledge — the impact of foreign fishing — a problem that has created major uncertainties in stock assessment work in the past. These are but a few of the many examples where observer data contributed in a special way to management.

The concept of an observer program was accepted by the Government of Canada mainly as a deterrence to both foreign and domestic non-compliance to regulations. In these presentations, dealing only with offshore surveillance, the scientific role of the program was seen as a secondary benefit. On the operational level in the regions, however, the program is definitely managed as both a surveillance and scientific program with equal emphasis on both functions. The program has been operating with these two mandates since its inception and both the scientific and enforcement personnel involved are quite satisfied with the arrangement. As outlined above, the scientific component of the observer program offers many advantages for obtaining data to be used in stock assessment; however, it also has a set of unique problems associated with it. Once most of these problems were overcome, an extensive and reliable data base was made available to the managers.

Aside from its present usefulness in assisting with stock assessment, the data being collected are leading to a better understanding of the biology of many species as well as a better understanding of the various fisheries. Perhaps new and more precise assessment techniques will be developed now that more detailed data are available. Also, data for presently underutilized but potentially commercial species are being collected and may well play a role in developing new fisheries. Certainly an ongoing observer program will add valuable knowledge and improve the fisheries management scheme.

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Planning the Sampling of Commercial Catches in the Gulf Region

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POWLES, H. 1983. Planning the sampling of commercial catches in the Gulf region, p. 263–267. *In* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

The Gulf region is a new administrative unit of Canada's Department of Fisheries and Oceans, responsible for the management of fisheries in the Gulf of St. Lawrence. Creation of this new organization permits designing a sampling program from the top down; the present paper outlines elements to be incorporated into an eventual sampling plan for the region. Landings of groundfish and pelagic fish were mapped by statistical area/gear/quarter strata and sampling effort was allocated to these strata via the "NAFO criterion" to determine the general distribution and intensity of sampling effort required in the region. An assumption underlying this approach is that sampling should be spread geographically in proportion to landings; this assumption would appear important in the Gulf where marked intraregional differences in fisheries exist. Sampling effort should be concentrated in three major areas: western Newfoundland/Quebec lower north shore; Gaspé peninsula/northeast New Brunswick; and Prince Edward Island/Magdalen Islands. Sampling bases will be established in these areas to maximize sampling efficiency.

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La région du Golfe est une nouvelle unité administrative du Ministère des Pêches et Océans du Canada, ayant comme responsabilité la gestion des pêches du Golfe Saint-Laurent. La création de ce nouvel organisme a permis l'organisation d'un programme d'échantillonnage nouveau; cet article présente un aperçu de quelques éléments qui seront incorporés dans un éventuel plan d'échantillonnage pour la région. Les débarquements de poissons de fond et de poissons pélagiques ont été alloués à des strates de région statistique/engin de capture/trimestre et cartographiés. On a ensuite alloué l'effort d'échantillonnage à ces strates en se servant du «critère de l'OPANO» afin de déterminer la distribution et l'intensité de l'effort d'échantillonnage. Une supposition menant à cette approche est que l'effort d'échantillonnage doit être distribué géographiquement en proportion aux débarquements, supposition qui semble importante dans le Golfe, où des différences importantes existent entre les pêches des parties de la région. L'effort d'échantillonnage devrait être concentré dans trois aires majeures: ouest de Terre-Neuve/basse Côte-Nord du Golfe; Gaspésie/nord-ouest du Nouveau-Brunswick; et Île-du-Prince-Edouard/Îles-de-la-Madeleine. On établira des bases d'échantillonnage dans ces régions afin de maximiser l'efficacité d'échantillonnage.

Introduction

The Gulf region is a new administrative entity of the Department of Fisheries and Oceans which has responsibility for managing fisheries in the Gulf of St. Lawrence. Fisheries research is one activity of this new entity; its basic objective is to provide the biological advice necessary to manage the fisheries of the Gulf of St. Lawrence to achieve optimum social and economic benefits.

As part of this fisheries research activity, commercial catches must be sampled to provide the data required for stock assessment and other research projects. The objective of this paper is to outline elements to be incorporated into a sampling plan for the region. Sampling will be the responsibility of a section within the research organization.

Before creation of the Gulf region, sampling was carried out by the Maritimes region and Newfoundland region in areas bordering the Gulf of St. Lawrence (reviewed in other papers presented at this workshop). Quebec region, where fisheries research began in 1978, has had sampling programs directed at snow crab (reviewed by Bailey 1983) and at pelagic fishes. These various components will be replaced by the Gulf sampling program. Other sources of fishery biological data in the Gulf are the Direction générale des pêches maritimes of Quebec province (sampling program reviewed by Lussiaà-Berdou et al. 1983) and the Domestic Observer program begun by the Quebec region of DFO in 1981. This latter program directed some 200 observer days at groundfish, shrimp, and herring purse seiner fisheries in 1981.

The overall objectives of the sampling plan are: (1) to achieve *effective* sampling of catches — that is, to supply data with defined limits of precision, coverage, and intensity such that stock assessments of acceptable accuracy and precision can be conducted; and (2) to achieve *efficient* sampling — that is, to minimize costs of attaining objective (1).

Description of the Area

The Gulf of St. Lawrence (Fig. 1) is bordered by five provinces: Quebec, New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland. Major research laboratories involved with Gulf stocks are located at Moncton and Quebec. Sampling of 14 "stocks" is required (Table 1); although other species are fished in the Gulf, these are the major species for which quotas are required.

Several characteristics of the region add complexity to the problem of efficiently sampling catches. Fisheries are characterized by a mixture of many vessels and gear types, and a high proportion of catches is taken by coastal gears (traps, longlines, gill nets, etc.). Partly in consequence, landings are to a large extent decentralized, rather than being concentrated at a few major ports. Sociocultural diversity is high; besides incorporating the two major language groups (English and French), the region is inhabited by subgroups (Quebec and Acadian French-speaking groups; Newfoundland and Maritimes English-speaking groups), and these groups may be further subdivided (e.g. federalist and separatist québécois). On some wharves in Quebec, federal government personnel may have limited success in obtaining samples. The impact of this diversity on sampling is difficult to assess quantitatively but it appears evident that efficiency will be greatest when sampling personnel

TABLE 1. Stocks which Gulf region sampling plan must cover, and within-Gulf landings for 1979 ('000 t). (Source — NAFO 1981 and regional statistics offices.)

	Landings
Groundfish	
Cod — 4RS / 3Pn	60.6
Cod — 4T / 4Vn	46.7
Redfish — 4RST	15.0
American plaice — 4T	13.0
Witch — 4RS	4.6
Greenland halibut — 4RS	8.8
Pelagic fish	
Herring — 4RS	18.8
Herring — 4T	47.7
Mackerel — 4RST	6.6
Capelin — 4RST	9.1
Invertebrates	
Snow crab (western Gulf, Cape Breton)	17.8
Shrimp (northern Gulf, Esquiman Channel)	7.7
Scallops (southern Gulf, Strait of Belle Isle)	3.4
Lobster (southern Gulf except Quebec, western coast Newfoundland)	11.8

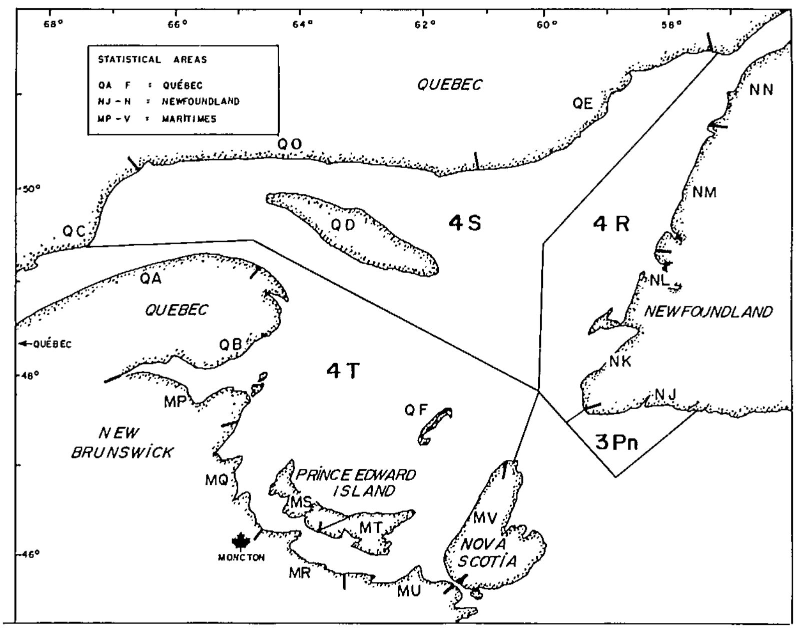

FIG 1. The Gulf region, showing NAFO divisions, statistical areas and laboratory locations referred to in this paper.

are of the same sociocultural group as fishermen and industry personnel. Finally, the area is geographically "fragmented" so that travel between major fishing areas can be lengthy or expensive or both.

Under the former administrative setup, where Gulf research was carried out by organizations in Newfoundland, the Maritimes, and Quebec, these constraints were present but were of somewhat less importance than under the new organization. For example, Newfoundland west coast sampling was conducted from St. John's, minimizing sociocultural and travel constraints.

Objectives and Strategy for the Commercial Sampling Program

Effectiveness

The intensity and distribution of sampling required to produce data on the accuracy and precision required for stock assessments and other projects must be determined prior to the field organization of the sampling program. Since the results of this workshop will influence this aspect of the sampling program for the Gulf, I have used the "NAFO"[1] criterion (one sample/quarter/gear component/1000 t landed) as a preliminary criterion for determining sampling intensity. In addition, I have assumed that catch sampling should be distributed geographically among landing areas in proportion to landings to accommodate geographic variability in stock distribution and fishery characteristics. For some species, some strata (area/gear/quarter combinations) may have insufficient landings to require a sample (i.e. landings < 500 t), but the sum of such strata over area may give landings sufficient to require taking of a sample. In such cases samples can be obtained wherever convenient from a gear/quarter combination. Application of the NAFO criterion to landings provides a general picture of sampling distribution required which can be considered the basis of the sampling plan.

The final sampling plan will depend on results of this workshop and on stock or area-specific considerations that come to light with experience. Biologists responsible for individual stocks must be involved in sampling program planning. It would appear essential, to permit response to changing fishery or stock events, that the sampling program be fully reviewed annually.

Efficiency

Minimization of cost (dollars and person-days) will require consideration of the constraints mentioned above. Travel costs would appear fairly easy to estimate, but in fact their estimation may be complex. In particular, choice of a sampling cycle (length of sampling trips, basing of samplers) affects costs per sample. Sociocultural differences may increase sampling costs (since more time in the field may be required of a "stranger" than of a "local" to obtain a given number of samples), but this is difficult to estimate. Changes in fishing patterns, i.e. uncertainties as to temporal and seasonal distribution of landings, may also increase costs. These factors are considered in the paper by Silvert and Powles (1983).

[1]Northwest Atlantic Fisheries Organization.

Strategy

The general approach envisaged for development of the Gulf sampling plan, and that taken in the rest of this paper, can be outlined as follows:

1) Landings by species, area, gear, and quarter are mapped for districts of the Gulf region, for the most recent year for which data are available.

2) A sampling intensity criterion (for this paper, the "NAFO criterion") is applied to the landings distribution.

3) Number of samples required by species, gear, quarter, and district, generated from 1) and 2), is mapped.

4) The preliminary plan thus generated is modified, through consultation with biologists or otherwise, to provide a final sampling plan.

5) Resources are deployed in such a way as to minimize costs while meeting objectives of the sampling plan.

6) The plan is modified during the year as necessary to adjust for changes in fishery patterns.

7) The cycle is repeated for the succeeding year.

Example — the 4RS/3Pn Cod Stock

Data from 1979 indicated total landings in Gulf region ports to be 60 562 t. Many gear types were used, but bottom trawls, gill nets, and longlines accounted for the greatest proportion of the landings (Table 2). Significant landings from this stock were made outside the Gulf region (in southeast Newfoundland); however, these are not included in the Gulf region sampling plan since sampling is performed by the region in which landings are made.

Landings for 1979 were used to develop a map of sampling intensity and distribution for this stock. Landings by gear, quarter, and area were supplied by statistics branches in the three former administrative regions (Newfoundland, Maritimes, and Québec). Landings by gear, by quarter were mapped on a

TABLE 2. Landings (t) of 3Pn/4RS cod by gear type in Gulf region — 1979. (Source — Newfoundland and Quebec statistics branches).

	Landings (t)
Bottom trawls (side and stern)	23 802
Midwater trawls	890
Shrimp trawls	2 260
Traps	2 780
Gill nets	13 394
Longlines and handlines	17 436
Total	60 562

schematic map of the Gulf of St. Lawrence (Fig. 2 shows the map generated for bottom and midwater trawls). The "NAFO criterion" was applied to the landings maps to generate number of samples required by gear/quarter/area, and number of samples from all gears were then summed to obtain number of samples required by quarter/area for this stock (Fig. 3).

Sampling Intensity and Distribution for Groundfish

Total samples required for groundfish stocks were mapped by quarters (all gears combined), based on 1979 landings data (Fig. 4). Number of samples required (127) in gear/area/quarter strata is lower than total number estimated from total landings within the Gulf (ca. 150 000 t, Table 1). This is due to insufficient (< 500 t) landings in a number of strata. This shortfall could in practice be made up by sampling non-area-specific gear/quarter combinations; these are species-specific and not listed in detail here. In any case, sampling intensity will in practice undoubtedly be higher than indicated by the preliminary plan generated in this way.

A sampling plan based on these data would concentrate sampling in three major areas (southwest Newfoundland, northeast New Brunswick, and Gaspé peninsula) and three "minor" areas (northern Newfoundland/Quebec lower north Shore, Prince Edward Island, and Magdalen Islands). As expected, sampling should be concentrated in the second and third quarters except in southwest Newfoundland where first quarter landings are high.

Sampling Intensity and Distribution — All Finfish

Sampling maps for pelagic species (Fig. 5) were developed and summed with the map for groundfish to provide an overall finfish sampling map (Fig. 6). It should be noted that sampling intensity for pelagics (particularly herring) has generally been considerably higher than what the NAFO criterion would require, and this will undoubtedly continue. Again, however, the map gives a general overview of sampling distribution required.

Invertebrates have not been considered in this plan; sampling schemes will be developed by sections and carried out either by biologists or sampling personnel.

Efficiency of Sampling

Two general options for deployment of sampling resources were considered early in planning sampling for this region:

1) All catch sampling to be done by technicians based at the major centers (Quebec and Moncton), traveling out to fishing areas.

2) Sampling to be at least partly decentralized to "forward bases" in or near fishing areas.

Additional costs associated with each option can be enumerated: basing sampling at central laboratories increases costs resulting from sociocultural differences, less rapid response time to changes in fishing patterns and

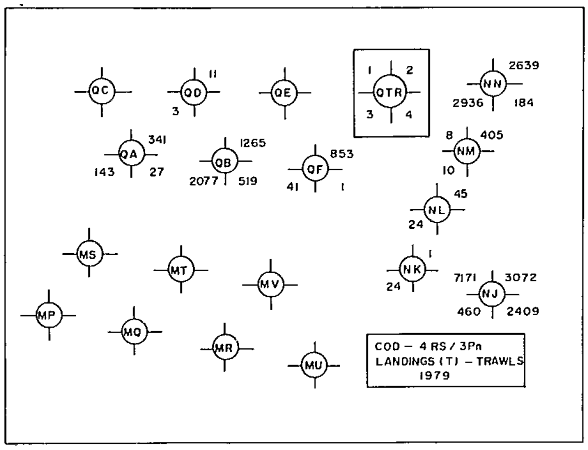

FIG 2. Landings (t) by quarter by statistical area (see Fig. 1 for identification of areas), 1979, for 4RS/3Pn cod caught by otter and midwater trawls.

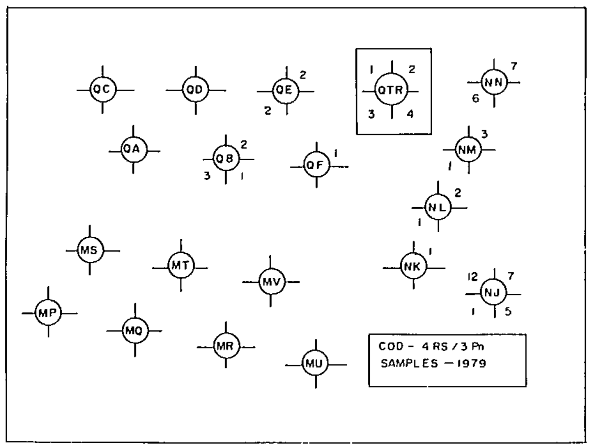

FIG 3. Samples required by statistical area for 4RS/3Pn cod, all gears, based on 1979 landings.

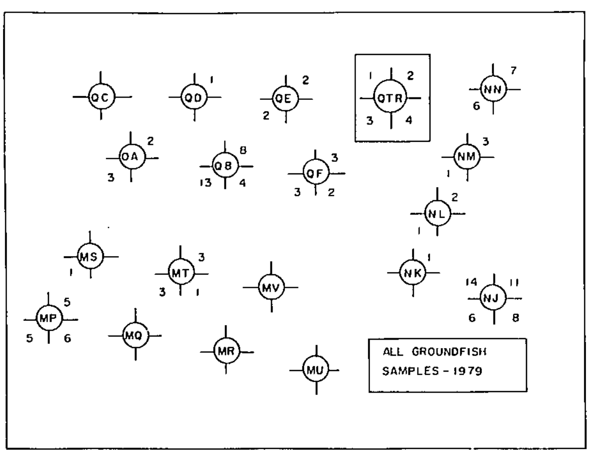

FIG 4. Samples required by quarter by statistical area for all groundfish, all gears, based on 1979 landings.

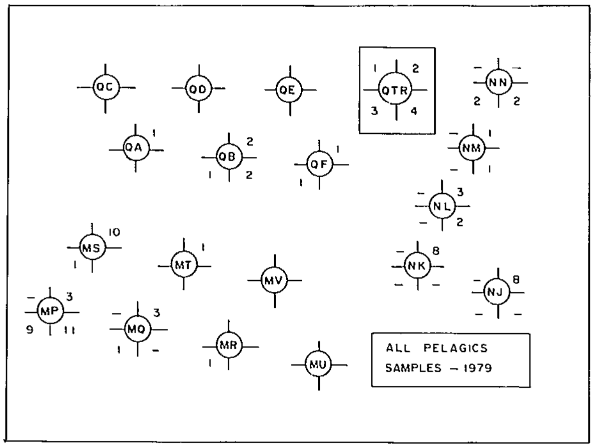

FIG 5. Samples required for all pelagic species, all gears, 1979.

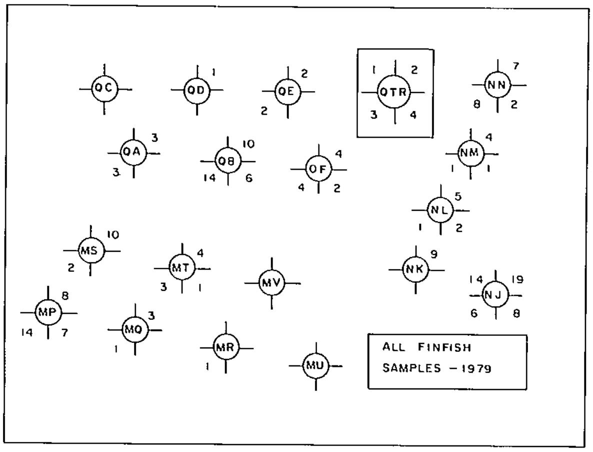

FIG 6. Samples required for all finfish, all gears, 1979.

increased travel costs, while setting up forward bases involves costs for their maintenance and for possible seasonal underemployment of sampling personnel. These options are further considered in the paper by Silvert and Powles (1983).

As indicated in that paper, the option of basing sampling technicians near the fishing areas appears more cost-effective and this approach will be used in the Gulf sampling plan. A sampling base will be set up in Cornerbrook, west Newfoundland, from which personnel will be able to cover west coast fisheries. Further analysis is required to determine seasonal allocation of sampling effort in western Newfoundland but based on Fig. 4, sampling will be required in all four quarters, with a peak of effort required in the second quarter. Sample distribution for the area to be covered by this base (Newfoundland coast and Quebec lower north Shore) is: first quarter, 14; second, 26; third, 16; and fourth, 8. Basing of seasonal sampling personnel in northeast New Brunswick (to cover the Gaspé peninsula as well), in the Magdalen Islands and in Prince Edward Island, which was done by Maritimes region, will probably be continued.

Discussion and Conclusions

Implementation of the Gulf region has provided an opportunity to examine planning for sampling "top-down," i.e. for setting up an ideal program to achieve overall objectives. This paper has laid out elements of an eventual sampling plan. Implementation of the plan will follow synthesis of the results of this workshop and further work by the region's sampling section.

An advantage of the general approach to planning sampling distribution used here is that it could probably be programmed easily. The input data consist of matrices of landings that are divided by a sampling intensity factor to produce a matrix of samples required. It should be possible to program this procedure so as to update the sample plan easily, through incorporation of revised sampling intensity criteria or updating of landings subsequent to changes in fishing plans.

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Applications of Operations Research to the Design of Field Sampling Programs

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Sampling programs are carried out in order to come up with numbers to help in the management of fish stocks. Good sampling programs give more precise estimates than do poor programs, and precise estimates are more useful to fisheries managers. Operations research can help by designing sampling programs that use limited resources as effectively as possible. This paper presents a theoretical basis for the optimization of sampling design and illustrates the methodology by calculations based on the cod fishery in the northern Gulf of St. Lawrence.

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Les programmes d'échantillonnage sont effectués afin de générer les données qui aideront à la gestion des stocks de poissons. Un bon programme permet des estimations plus précises qu'un programme médiocre et des estimations précises sont plus utiles aux gestionnaires des pêches. Une recherche sur les opérations peut aider à la conception de programmes d'échantillonnage qui utiliseront les ressources disponibles, qui ne sont pas sans limite, aussi efficacement que possible. Le présent rapport décrit une base théorique pour l'optimisation du processus d'échantillonnage et illustre la méthode par des calculs basés sur la pêche de la morue dans la partie septentrionale du golfe Saint-Laurent.

Introduction

Fisheries managers, in order to meet their objectives, need certain numerical information such as stock sizes, maximum sustainable yields, and year-class strengths. What they get are not exact numerical values for these parameters, but rather joint probability distributions for sets of parameters. These joint distributions in turn are obtained by analysis of raw data, and the amounts of different types of data that are obtained depend on the sampling design. A different sampling design means a different distribution of the sampling effort, and this generally means that the joint distribution of the parameter values changes as well. One of these distributions is likely to be more useful than the other, and thus the sampling design on which this distribution is based is preferable. Design of an optimal sampling program means the specification of a distribution of sampling effort which leads to the most useful possible probability distribution for the estimates of the parameter values needed by management. Operations research is a branch of applied mathematics concerned with the solution of this type of problem, and in this paper we show how optimal sampling can be formulated as a mathematical problem and solved. This is illustrated by an example based on the sampling situation in the Gulf of St. Lawrence.

The concept of optimal sampling is not a new idea. The problem of optimizing the size of trawl samples is considered by Taylor (1953) who in turn cites papers going back to 1936. The type of analysis used in this paper was developed by Ackoff (1962), and similar studies have been carried out in other areas of marine science, such as the work by Kelley and McManus (1969) on sediment sampling which was subsequently extended to upwelling studies (Kelley 1971). Kelley's work has been applied to benthic sampling (Saila et al. 1976) and to ichthyoplankton surveys (Smith 1978).

This paper deals with sampling design on a fairly broad scale, but operations research methods can also be used for relatively detailed research planning. Leming and Holley (1978) have developed a computerized system for optimizing the cruise tracks of groundfish surveys, and Ibanez (1980) describes a linear programming approach for optimizing the daily sampling schedule of a research vessel. The type of sampling design problem described in this paper describes a particular application of operations research to fisheries sampling, but it must be remembered that many other kinds of applications are possible.

Statement of the Problem

The process described in the Introduction is shown in Fig. 1. The problem is to put in the feedback loop represented by the dashed line, and to vary the sampling design in such a way that it approaches the optimum.

In order to do this we need some way to assess the value of a particular joint distribution of parameter estimates from the viewpoint of management. For a single parameter this is relatively simple to do; the broader the distribution, the less useful the information is likely to be. However, when several parameters have to be estimated, then the shape as well as size of their mutual confidence region can change, and it is necessary to balance improvements in the confidence limits on one parameter against broadened confidence limits for another. For example, in assessing the stock sizes for two species of fish when one is of much greater commercial value than the other, managers will seek the best information possible on the commercially important stock even at the expense of information on the other species.

The evaluation of a set of estimates in terms of how well they contribute to achieving management objectives must clearly reflect the factors that determine these objectives, and these include economic, social, and even political considerations as well as biological factors. It is essential that we be prepared to provide a quantitative measure of the adequacy for management purposes of any particular joint distribution function for the parameter estimates. In a fisheries context the adequacy of a set of parameter estimates is measured by the probable "regret" associated with possible errors in assessments and allocations (White 1983). The definition of regret is basically the responsibility of the managers; this is how they tell the scientists how adequate their assessments are. In fact, perhaps the greatest single contribution of operations research to management science has been the insistence that managers must specify an "objective function" to be maximized or minimized, since if this is not done, there is no meaningful way in which to compare different options; certainly the historical record shows that the failures of operation research can almost invariably be traced to inadequate or incorrect specifications of the objectives.

Once the objective function has been determined, the optimization of the sampling design is conceptually simple and straightforward; one simply compares all possible strategies and selects the best one, namely the design that minimizes probable regret. Actually it is almost always impossible to enumerate all possible strategies, so one has to resort to mathematical shortcuts. Because the mathematical techniques involved tend to be very complex and sophisticated, operations research has developed a forbidding mystique that may discourage prospective users from attempting to implement it. Some discussion of the mathematics is inevitable, but in the following discussion we have focused less on rigor and generality than on clarity of presentation.

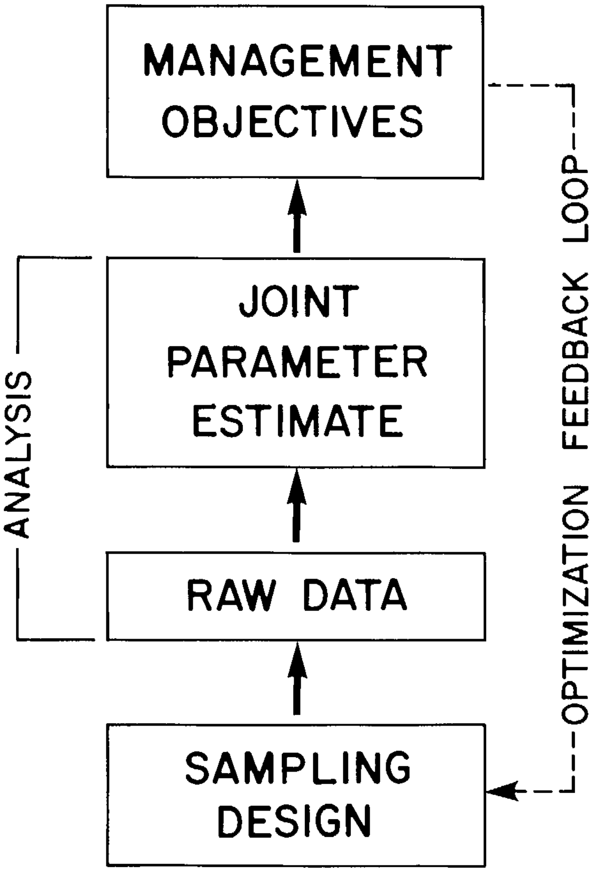

FIG. 1. Illustration of the problem of optimal sampling design. The boxes connected by solid arrows represent the assessment process. The problem is to put in the feedback loop represented by the dashed arrow.

Optimization Techniques

In some cases one can actually carry out optimization by discrete enumeration of all possible choices. For example, suppose that a fishery scientist visits a remote Pacific atoll and is asked to make a single-handed estimate of the number of fish in the lagoon. He has an outrigger canoe equipped with butterfly nets for catching fish, and he decides to use catch per unit area to estimate biomass B. In order to estimate the number of fish, N, he also needs to subsample the catch to obtain a figure for the weight of individual fish, W. Once he has estimated the two parameters B and W, the number is given by $N = B/W$. To obtain the most precise possible estimate of N, he therefore needs to maximize the precision of the estimates of both B and W, which means maximizing both the amount of fishing effort and the number of fish measured. This is only meaningful if we impose some constraints on the total amount of time available. We will assume that he only has 3 d to carry out the work before his airplane leaves, and we also assume that each day is devoted entirely either to fishing or to measuring the fish (the time required to weigh the catch and to carry out the calculations is considered negligible). This leaves him with four possible choices. The first choice, which is to do no fishing at all, is pointless because there would not be any fish to measure. The other extreme alternative, which is to spend all 3 d fishing, would give him the best possible estimate of biomass but no information at all on the size of the fish. He is thus left with a choice between 1 d fishing with 2 d measuring, or 2 d fishing and 1 d measuring. The final selection of one of these two alternatives would depend on calculating the probable precision of the estimate of B/W in each case.

If we make this problem continuous by allowing the 3-d assessment period to be divided in any ratio between fishing and measuring, then we have an infinite number of sampling strategies to choose from, and simple enumeration of the alternatives is no longer possible. However, this problem does not require difficult mathematics. If B and W are lognormally distributed, then we obtain an estimate, $\bar{N}$, for the number of fish from the equation $\log \bar{N} = \log \bar{B} - \log \bar{W}$, where $\log \bar{B}$ and $\log \bar{W}$ are the means of all measured values of $\log B$ and $\log W$, respectively. Since the probable error in using the mean of n observations to estimate the center of a normal distribution is proportional to $n^{-1/2}$, we can infer that the probable errors in the estimates $\log \bar{B}$ and $\log \bar{W}$ are inversely proportional to the square roots of the times spent on each type of measurement, T_B and W_W. If we define the regret to be the square of the error in $\log \bar{N}$, its expectation value can be written as

$$<\text{regret}> = E_B^2 + E_W^2$$

where $E_B = \sigma_B/\sqrt{T_B}$ and $E_W = \sigma_W/\sqrt{T_W}$. Thus the mathematical formulation of the problem is to find two sampling times T_B and T_W which minimize the probable regret

$$<\text{regret}> = \sigma_B^2/T_B + \sigma_W^2/T_W$$

while satisfying the constraint

$$T_B + T_W \leq 3 \text{ d}.$$

In the present case we can find the optimal sampling design by elementary calculus; from the constraint equation let $T_W = (3 \text{ d}) - T_B$ and substitute in the expression for regret. Minimization of regret with respect to T_B requires simply that we set its derivative equal to zero. An alternate and more general technique is to use the method of Lagrange multipliers (Wagner 1975); we define the new function

$$L = <\text{regret}> + g(T_B + T_W)$$

where g is a constant known as the Lagrange multiplier. We then find the optimal strategy by solving the simultaneous equations

$$\partial L/\partial T_B = \partial L/\partial T_W = 0$$

$$\partial L/\partial_g \leq 3 \text{ d}.$$

Using either approach we find that the fraction of total sampling time to be spent fishing is $\sigma_B/(\sigma_B + \sigma_W)$, and the ratio of the two times is $T_B/T_W = \sigma_B/\sigma_W$. This has a reasonable interpretation in that it means that more time should be spent sampling the quantity which exhibits the largest standard deviation.

This example has been worked out in some detail because it illustrates several aspects of the application of operations research to sampling design. First of all, as stressed previously, one cannot carry out mathematical optimization without an objective function to maximize or minimize. Second, one must take into account constraints on the sampling strategy such as those imposed by cost, manpower, shiptime, and other factors. The method of Lagrange multipliers and its generalizations enable any number of such constraints to be taken into account. Third, we need to be able to estimate errors arising from the finite size of the samples and to be able to calculate how these errors propagate through the calculation of the desired parameter values. This is relatively simple to do if the variables are all normally distributed and the calculation uses only linear models, but most statistical distributions encountered in fisheries are not normal and many models are nonlinear, so the latter point requires some elaboration.

Sample Size and Measurement Error

Suppose that we want to measure some quantity x, but that there are errors in our measuring apparatus. Given a set of measurements $x_1, x_2, \ldots, x_n$ we want to obtain an estimate of x. The problem of finding the best estimate of x occupies a large proportion of the statistical literature and will not be considered in this paper, since we are concerned only with the size of the probable errors in these estimates. For example, if the errors are normally distributed with standard deviation σ, then the best estimate of x is the arithmetic mean $(x_1 + x_2 + \ldots + x_n)/n$, and the probable error of this estimate is $\sigma/\sqrt{n}$ (Gelb 1974). If the errors are not normally distributed, then some other estimate of x is usually preferable, such as the median (Huber 1981). However, a general property of most robust estimators is that even though errors in the individual measurements may not be normally distributed, the probable error of the estimator is usually at least asymptotically normal with a standard deviation proportional to $n^{-1/2}$ (Huber 1981; C. Field, personal communication). This property is extremely useful and facilitates the development of a general approach to optimal sampling design.

To illustrate this, suppose that we want to design a sampling program to estimate the percentage weight of gonads in a spawning fish stock. The measurements clearly cannot be normally distributed, since a normal variate is unbounded while the quantity we are measuring falls between 0 and 100%; in fact, the distribution is likely to be bimodal if we sample without regard to sex. However, the estimator that we obtain from a set of n measurements generally has a normal distribution with a standard deviation proportional to $n^{-1/2}$, at least for large values of n.

We can generalize this result to continuous observations, such as towing a net for a specific length of time. If we think of such a tow as a set of discrete 1-s tows, then n is simply the duration of the tow measured in seconds, and the probable error in the result of such a tow (e.g. fish density) should be proportional to the inverse square root of the duration of the tow. If we treat the number of fish in the tow as a Poisson variate, then the fish density is basically the parameter of the distribution; the maximum likelihood estimate of this parameter is N/T, where N is the number of fish caught in time T, and the probable error of this estimate is $(N/T)^{1/2}$. Whether we measure sample size in discrete observations or in terms of a continuous variable like sampling time, we can still speak in general terms of a quantifiable amount of sampling. For practical purposes we can conclude that the probable error in the estimation of a quantity from a single set of measurements is inversely proportional to the square root of the sample size, which we call the "sample size assumption."

Sensitivity Analysis of Assessment Models

In our original characterization of the assessment process shown in Fig. 1, the process of deriving a set of parameter estimates from the raw data was identified as a single step vaguely labeled "analysis." The examples given above show that this process is better illustrated by Fig. 2, in which data analysis is broken down into two components: one first derives a set of values characterizing the population from which the samples are taken, which are then used as input for a computational model of the desired parameter estimates. In our first example, the two sampling techniques were fishing and the measurement of individual fish; one measured biomass B, and the other the weight W. Let $\bar{B}$ and $\bar{W}$ represent the estimates of these two quantities obtained from the raw data; these are "input parameter" estimates used in computation of the "output parameter" N, which is the quantity need for management purposes. The computational model in this case is $\bar{N} = \bar{B}/\bar{W}$, or $\log \bar{N} = \log \bar{B} - \log \bar{W}$. From the additive form of this model we see that the probable error in the estimate $\bar{N}$ is given by $E_N^2 = E_B^2 + E_W^2$, as discussed earlier. What we have in effect done is carry out a sensitivity analysis of the computational model to see how the distribution of the estimate of the output parameter depends on probable errors in the input parameters, which are in turn determined by the sizes of the different samples. This is basically how one determines the effect of sampling design on precision in any assessment model, although of course the calculations may not be equally straightforward in every case (see Rivard 1983 for a more detailed discussion).

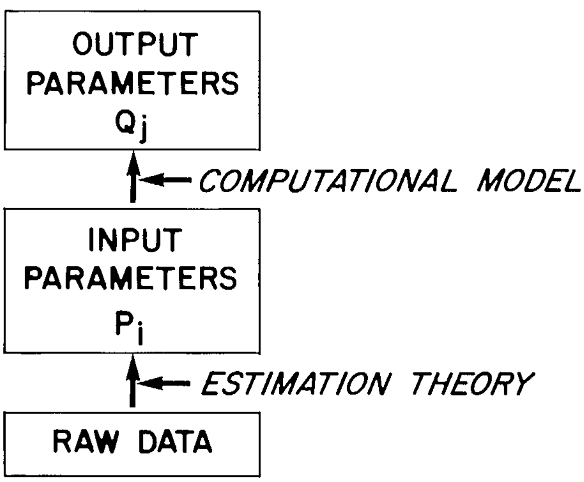

FIG. 2. Expanded representation of the process labeled "analysis" in Fig. 1, which obtains a joint parameter estimate from the raw data. An intermediate set of input parameters is computed which is assumed to have an asymptotically normal error distribution, even though the raw data may not be normal.

We now turn to a more general analysis of how the precision of an assessment can be estimated from a set of samples. Let P_i denote the input parameters, each of which is obtained as the result of n_i separate measurements (n_i can also represent sampling time or any other measure of sample size). Using the sample size assumption introduced before, each of the estimates of P_i is subject to a probable error $(V_i/n_i)^{1/2}$ where V_i is some constant (for normal distributions V_i is the variance). From the estimates $\bar{P}_i$ of these input parameters we need to compute estimates of the desired output parameters $\bar{Q}_j$, and from the probable errors in the $\bar{P}_i$ we need to estimate the errors in the $\bar{Q}_j$. The calculation of the $\bar{Q}_j$ can be expressed as some system of equations of the form

$$\bar{Q}_j = f_j(\bar{P}_1, \bar{P}_2, \ldots)$$

and, if we assume that the errors in the $\bar{P}_i$ are uncorrelated and that they are small enough for us to use linear sensitivity analysis, we obtain

$$\langle E_j E_k \rangle = \sum_i \frac{\partial f_j}{\partial P_i} \frac{\partial f_k}{\partial P_i} \frac{V_i}{n_i}$$

for the expectation values of the variance-covariance matrix of the errors E_j (but see White 1983 for a discussion of possible problems with linear sensitivity analysis). From this we can in turn compute the joint probability distribution of the set of parameter estimates $\bar{Q}_1, \bar{Q}_2, \ldots$, so that from a given sampling design represented by the measurements n_1, n_2, etc., we can calculate the probable errors in the $\bar{P}_i$, then the variance-covariance matrix for the errors E_j in the $\bar{Q}_j$, and finally the probable regret associated with the joint estimate. In our previous example of estimating the number of fish we have a single output parameter, $Q_1 = \log N$, and two input parameters, $P_1 = \log B$ and $P_2 = \log W$; the computational model is $\bar{Q}_1 = f_1(\bar{P}_1, \bar{P}_2) = \bar{P}_1 - \bar{P}_2$, and the mean squared error is $\langle E_1^2 \rangle = V_1/n_1 + V_2/n_2$. This is the same as the equation we obtained before for probable regret, which illustrates that these equations are simply a generalization of the calculation we carried out before.

Constraints

Since the probable regret can be estimated, given a sampling design, it can be written in a functional form as $F(n_1,n_2,...)$. The optimal sampling problem is to minimize this function subject to constraints on the n_i which we shall assume can be expressed as linear inequalities of the form

$$c_{m1}n_1 + c_{m2}n_2 + ... \leq C_m.$$

In particular, we often find that several of the input parameters P_i are determined by the same measurement, as when a size-frequency distribution is obtained by measuring a given sample of fish. In this case, let n_1 be the number of fish in the sample and P_1, P_2, etc. the fraction of fish in each size-class. All we have to do to cover this very common situation is include the constraint $n_1 = n_2 = ...$, which can always be written as a set of inequalities such as $n_1 - n_2 \leq 0$, $-n_1 + n_2 \leq 0$, and so on. Although this method is cumbersome, it does facilitate the development and use of powerful and general computer packages for the solution of optimization problems. In particular, we can use the method of Lagrange multipliers described previously to help carry out the constrained maximization; we define

$$L = F(n_1, n_2, ...) + \sum_m g_m \sum_i c_{mi}n_i$$

where g_m are the Lagrange multipliers, and solve the system of equations

$$\frac{\partial L}{\partial n_i} = \frac{\partial F}{\partial n_i} + \sum_m g_m c_{mi} = 0$$

$$\frac{\partial L}{\partial g_m} = \sum_i c_{mi}n_i \leq C_m.$$

Although these equations may appear forbidding, there is a wealth of useful literature on nonlinear optimization to turn to, and many applicable computer packages exist as well (Wagner 1975).

When there is only one constraint to be satisfied, the solution of the above equations is relatively easy to interpret. Since

$$\frac{\partial L}{n_i} = \frac{\partial F}{\partial n_i} + g_1 c_i = 0$$

in this case, we see that the ratios $(\partial F/\partial n_i)/c_i$ are all equal. If we interpret c_i as the unit cost of measuring P_i, then this quantity is the marginal decrease in probable regret due to a unit expenditure on this aspect of the sampling program. In other words, if one has an optimal sampling design and invests an additional sum of money, or of manpower or shiptime or whatever else is the operative constraint, the reduction in regret should be the same no matter how the additional resource is allocated. An alternate way to viewing this result is that the transfer of a small amount of resources from one part of the sampling program to another should not affect the probable regret associated with the assessment.

Case Study of the Gulf of St. Lawrence

Some preliminary calculations related to the sampling program for cod in subarea 4RS of the Gulf of St. Lawrence illustrate the application of these ideas to the design of a sampling program. There are three major landing regions within this subarea: these are southwest Newfoundland (NJ), northern Newfoundland (NN), and the Gaspé peninsula (QB), as described by Powles (1983). Landings within these three regions account for a large majority of all landings from 4RS, so it should not be difficult to generalize these results to include the rest of the subarea. Our original intention was to compare two types of sampling strategies, one of which would be to do all sampling from a centralized location (Moncton); the other was to have several small sampling teams located in forward bases close to the sampling areas (such as Cornerbrook and Caraquet). To carry out this comparison we needed to estimate the costs of the two options, and in doing so we took both time (person-days) and money (including travel costs) into account. For simplicity we decided to estimate a set of fixed costs per sample, even though this does not adequately reflect the actual cost structure; when travel costs are taken into account, clearly the cost of two samples taken on the same trip is less than twice the cost of a single sample. The details of the cost estimates are contained in Appendix A and the results are given in Table 1.

The first part of the optimization analysis is trivial, once the costs for the different sampling strategies have been determined. It is evident by inspection of Table 1 that the costs of centralized sampling, the quantities given in parentheses, are in every case higher than the costs associated with sampling from forward bases. Thus the localized sampling program is clearly preferable, and it is not necessary to carry out any sophisticated mathematical analysis to reach this conclusion. This is not an unusual occurrence in applications of operations research; quantification of the costs and objectives is generally the most critical part of the analysis, and once this has been ac-

TABLE 1. Costs of locally based versus centralized sampling in three Gulf regions. The first entries correspond to sampling from Cornerbrook and Caraquet, the entries in parentheses to centralized sampling from Moncton.

	Region		
	NJ	NN	QB
Person-days per sample	1.0(1.2)	1.5(1.9)	1.8(2.1)
Cost per sample	$52($94.25)	$67.50($152.50)	$91.50($157.00)

complished the actual optimization, if not actually trivial, is a straightforward application of suitable mathematical techniques. To illustrate these techniques, we shall assume that the forward-based sampling option has been adopted, and we consider the problem of obtaining an optimal distribution of samples from the three regions. There is a considerable range in sampling costs among the three regions, with the Gaspé being the most expensive area in which to sample and southwest Newfoundland being the least costly.

We first consider the problem of estimating a stock population parameter such as size at age which can be assumed constant throughout the region. In this case we do not need to sample in all three regions, and given the much lower costs of sampling in southwest Newfoundland we could conserve both time and money by doing all of the sampling there. However, this is an unusually simple problem in that both the time and dollar costs in NJ are lower than anywhere else. If the cost per sample in NJ were increased to $100, then the choice between NJ and NN would depend on whether time or money was the more important constraint. For example, under the constraints that the total number of person-days must not exceed 33 and a budget of $2000, then by maximization of the total number of samples $n_{\mathrm{NJ}} + n_{\mathrm{NN}}$ subject to

$$1.00n_{\mathrm{NJ}} + 1.50n_{\mathrm{NN}} \leq 33.00$$

$$100.00n_{\mathrm{NJ}} + 67.50n_{\mathrm{NN}} \leq 2000.00$$

we find that the optimal sampling in $n_{\mathrm{NJ}} = 16$ and $n_{\mathrm{NN}} = 9$ for a total of 25 samples. If we sample in only one location then the best that we can do is 22 samples in NJ or 20 samples in NN. Thus even in this trivial case a very simple calculation can lead to a reduction in the variance of the estimate of over 10%.

In this first calculation we sought simply to maximize the total number of samples taken without concern for where the samples were taken, with the result that there was no sampling at all in the Gaspé. Usually one cannot assume that population parameters are uniform, so it is necessary to sample at all ports. Consider for example the problem of estimating the number of new recruits landed in subarea 4RS by sampling in the specified regions subject to constraints on the total time available and on the budget. Futhermore, assume that two types of gear are used, trawls and gill nets. Since age selection characteristics of the gear types are different and the age structure of the population may vary from one location to another, sampling effort must be spread over regions and gear types to obtain an accurate estimate of total new recruits landed. Although this is a relatively simple problem, the solution is not obvious, and therefore we shall work it out in some detail to illustrate the operations research methods used.

The estimation problem itself is a classical ball-and-urn problem involving straightforward but messy combinatorial analysis. It turns out that if we measure n samples from a very large population in which the fraction of new recruits is R , then the fraction of new recruits in the samples, r, is the maximum likelihood estimator for R and has a probable error proportional to $R(1-R)/n^{1/2}$. Thus the probable error is very small when the fraction is close to zero or one, and it is inversely proportional to the square root of the sample size as we would expect from the sample size assumption discussed earlier.

If we denote the quantities corresponding to each of the three regions and two gear types by a single index i running 1–6, the estimated number of recruits in the entire catch would be

$$N = \sum_i N_i r_i$$

with probable mean squared error

$$E_N^2 = \sum_i N_i^2 R_i (1 - R_i)/n_i$$

to within some multiplicative factor depending on the number of fish in each sample. Since we are again only trying to estimate a single quantity, the definition of regret is not critical and we can define it to be the squared error of the estimate. The optimal sampling design is therefore that which minimizes the mean squared error E_N^2 subject to constraints on total cost and total sampling time.

To estimate the quantities N_i and R_i we can use historical data on the fishery, and some 1979 figures are given in Tables 2 and 3. Table 2 contains data for landings in the three regions by gear type; actually the figures given are biomasses, but for simplicity we have assumed that the mean weight of the fish is 1 kg, which turns out to be quite close to the correct mean value. The factors $N_i^2 R_i(1-R_i)$ are shown in Table 4, and it is clear that the trawl fishery in southwest Newfoundland is the most critical region in terms of its role in the sampling design.

To establish constraints for calculation of an optimal sampling design, we first used the cost figures given in Table 1 to calculate the resources required for a sampling scheme based on the "NAFO criterion" requiring one sample for every thousand tonnes of fish landed (Beckett 1983). Table 5 shows the NAFO sampling design, which is based directly

TABLE 2. Total landings in three Gulf regions, selected 1979 data (see Appendix A). Units are 10^6 kg.

	Region		
	NJ	NN	QB
Trawls	13.10	5.76	3.86
Gill nets	0.412	4.83	1.38

TABLE 3. Fractions of new recruits landed in three Gulf regions, selected 1979 data (see Appendix A).

	Region		
	NJ	NN	QB
Trawls	8.66%	9.93%	7.66%
Gill nets	1.5%	3.16%	3.24%

on the values in Table 2. Using the figures from Table 1 we obtain a total cost of 42.3 person-days and $2071.50. The sampling design which minimizes the probable squared error E_N^2 subject to the constraints that the costs must not exceed these values is shown in Table 6. There are more samples in NJ, and in fact over half of the total number of samples come from the NJ trawl fishery. The number of samples in northern Newfoundland and the Gaspé is correspondingly reduced from 17 to 15, and this shift from NN and QB to NJ reflects the greater cost of sampling in these locations, which is an important factor in the optimization procedure but is ignored in the NAFO sampling protocol. There is also a shift from gillnet samples to trawl samples because of the higher value of R for the trawl fishery shown in Table 4. Finally, the expected value of E_N^2 is 7% lower for the optimal sampling scheme than for the design based on the NAFO criterion.

Summary

In the first part of this paper we defined the concept of optimal sampling design in terms of maximizing the value of estimates for management purposes given constraints on the total sampling effort. This requires specification of an objective function which can be used to specify the utility or adequacy of a set of parameter estimates. This objective function, which we term the "regret" of the estimates, depends on how the estimate will be used in management decisionmaking and must be obtained through consultation with the managers themselves. Similarly, the constraints on manpower, budget, ship time, and other resources must realistically reflect management policy. Thus the formulation of optimal sampling design cannot be undertaken by scientific or technical staff without detailed input from those responsible for using their results to formulate management policy.

Once the optimal sampling design problem has been clearly stated and the objectives as well as the constraints are specified, the determination of the optimal distribution of effort is a straightforward although sometimes difficult technical task. We have not dwelt on the technical difficulties in this paper, because we think that they tend to be overstated and are not really relevant to problems in the design of optimal sampling programs. For example, the calculations we carried out for the northern Gulf of St. Lawrence cod fishery involve the branch of operations research known as nonlinear integer programming, and such problems are notoriously difficult to solve. However, the mathematical problems encountered are strictly technical, and often it suffices to find a better solution by trial and error without having a rigorous proof that it is the true optimum. The central idea behind the approach is that when given a choice between several sampling strategies, the design that will probably cause the least regret should be chosen; the use of mathematical optimization techniques is simply a way of broadening the choice.

Since the 4RS cod example used in this paper is considerably simpler than the actual situation in the Gulf of St. Lawrence, one can question how realistic the predicted 7% improvement in the probable squared error of the estimate is, and whether this level would be achieved in practice. This depends very much on the range of such factors as cost constraints, which are taken into account in the operations research approach but are ignored in the NAFO sampling criterion. In fact, we used a model appropriate for large sample numbers which required that at least one sample be taken for each gear–region combination, when a better model might have indicated that sampling of the gillnet landings in NJ and QB was superfluous. The question of whether at least one sample is required if there are any landings at all is a significant one, since most of the divisions in the Gulf do not land large quantities of fish (Powles 1983). An operations research approach might provide an effective way to deal with this question. The question of sampling different size classes is another important question (Beckett 1983), and optimization of stock assessments based on sensitivity analysis of age-structured population models (Rivard 1983) may be the best way to resolve this issue.

Optimization is a bit like motherhood, in that one cannot readily quarrel with the idea of trying to do one's best. Consequently the only reason for not using optimization techniques is that they are not applicable to the problem at hand. We have tried to show that operations research can play a useful role in the design of field sampling programs and can lead to appreciably better assessments in realistic situations.

TABLE 4. Factors $N^2R\ (1 - R)$ for three Gulf regions, where N is the total landings in kg from Table 2 and R is the fraction of new recruits in the landings from Table 3. Units are 10^{12} kg^2.

	Region		
	NJ	NN	QB
Trawls	13.57	2.97	1.05
Gill nets	0.0025	0.71	0.060

TABLE 5. NAFO sampling design for three Gulf regions in 1979 based on landings in Table 2 (see Appendix A). Costs are 42.3 person-days and $2071.50.

	Region		
	NJ	NN	QB
Trawls	14	6	4
Gill nets	1	5	2

TABLE 6. Optimal sampling design for three Gulf regions, based on constraints of 42.3 person-days and $2071.50.

	Region		
	NJ	NN	QB
Trawls	17	7	4
Gill nets	1	3	1

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Appendix A

Sample Data and Cost Calculations

In order to apply the operations research model developed here, data on landings, sample values for the variables to be estimated, and estimates of resources required to obtain a sample were necessary. This appendix outlines the sources of the data used. The situation to which the data apply approximates that of cod in NAFO subdivisions 4RS; however, the situation has been considerably simplified to permit clear demonstration of the utility of the model (only three landing ports and two gear types, simplified cost per sample estimates, etc.).

The sampling plan proposed here assumes that sampling should be spread geographically over the area of fishery for the target stock, in proportion to areal distribution of landings. This sampling criterion has not always been used in past sampling programs but would appear to be important in an area such as the Gulf of St. Lawrence where fishery characteristics vary considerably from place to place.

Landings

Landings data (1979) from three areas (northern Newfoundland, southwest Newfoundland, Gaspé peninsula) and from two gear types (gill nets, otter and midwater trawls combined) were used (Table A1). Statistical areas correspond to areas used by Powles (1983).

Sample Values for Variable to Be Estimated

The variable to be estimated by the sampling program is proportion of a single year-class (recruiting fish) in the catches. Sample values are given in Table 1. Each value represents a single vessel landing or trip.

Cost per Sample

Cost per sample is determined by the number of samples that can be taken in a given period of time and by the total cost of taking that number of samples. The number of samples that can be obtained per unit time is dependent on (among other things) degree of concentration of the fishery (more samples per day can be obtained when landings are concentrated at a single point than when landings are dispersed over a number of small landing points), and "predictability" of the fishery (much field time can be wasted waiting for vessels to return to port, etc.).

What steps are involved in getting one cod sample (in this case taken to consist of 100 lengths and 50 ages from otoliths) onto a form ready for computer entry? Activities can be divided into five categories: field support; collection of data and samples; transport; laboratory analyses; and administrative activities.

Field support includes all activities required to put a sampler into the field and maintain him there. Two field support options have been used in the past and are considered in this section: basing samplers at landing ports and basing samplers at a central laboratory from which they travel to landing ports. Field support activities for samplers based at the ports are minimal, involving daily travel to plants, equipment maintenance, etc. Field support for centrally based technicians includes travel to the sampling area (by vehicle or air in the case of the Gulf of St. Lawrence), food and lodging in the sampling area, and shipment of equipment and materials.

Administrative activities may also differ depending on whether samplers are field based or centrally based. Centrally based technicians are in regular contact with super-

TABLE A1. Landings and percent of "recruits" for individual trips, by area and gear.

SOUTHWEST NEWFOUNDLAND								
Otter trawls	*Total landings 13 100* t							
Trip landings (t)	10.2	7.8	19.3	15.4	5.6	20.7	5.9	9.2
% recruits	13.3	11.5	5.0	3.2	15.2	5.6	5.8	15.8
Trip landings (t)	10.5	9.8	11.1	9.1	8.3	10.0		
% recruits	12.3	10.0	12.2	5.3	7.5	10.0		
Gill nets	*Total landings 412* t							
Trip landings (t)	6.3							
% recruits	1.5							
NORTHERN NEWFOUNDLAND								
Otter trawls	*Total landings 5 760* t							
Trip landings (t)	8.9	12.3	9.2	7.5	6.3	8.0		
% recruits	10.5	15.8	9.2	9.8	2.0	7.5		
Gill nets	*Total landings 4 830* t							
Trip landings (t)	3.5	6.4	5.8	2.1	3.9	1.5		
% recruits	1.8	3.9	4.8	2.7	1.9	0.8		
GASPÉ PENINSULA								
Otter trawls	*Total landings 3 860* t							
Trip landings (t)	15.3	12.5	7.8	10.2	6.8	9.8		
% recruits	5.6	8.2	7.5	11.3	12.0	3.5		
Gill nets	*Total landings 1 380* t							
Trip landings (t)	5.3	3.5	9.1					
% recruits	4.8	2.8	2.5					

visors and other technicians; thus sampling, planning, reporting, training, etc. can be ongoing processes. It is not suggested that these activities are insignificant for centrally based technicians, but that they can be combined with other program activities; thus, costs chargeable to the sampling program can be minimized. However, for field-based technicians, isolated from regular contact with the other research program components, administrative systems are required to ensure communication, monitoring of progress toward targets and training to ensure that quality standards are met. Thus, a regular (e.g. weekly) reporting system, an annual training and goal-setting exercise, and regular (e.g. every quarter) visits by supervisory personnel to the field location must be organized and accounted for in terms of costs.

Sample and data transport from the field to central laboratories for processing may differ for field-based and centrally based technicians. Centrally based technicians can accompany or hand-carry materials, while field-based technicians must ship materials (unless arrangements for hand-carrying can be made). Since at least part of these materials (unread otoliths) are irreplaceable, security is an important consideration.

Collection and laboratory analysis activities are essentially identical for field-based and centrally based technicians. Collection of one cod age sample involves:

1) contact with plant personnel to organize collection of samples and ancillary data (e.g. landing weight);
2) contact with the vessel captain for ancillary data (fishing area, landing weight);
3) obtaining a random length frequency sample on a specified weight or number of fish (e.g. 400 lb);
4) obtaining a stratified otolith sample (e.g. 3/3 cm length group);
5) entry of length-data on a data form;
6) manipulation of otoliths to storage with associated data (e.g. in envelopes);
7) ensuring that a random sampling procedure for lengths is used (stratified random in many cases, where fish are sorted into market categories prior to landing); and
8) final verification and coding of data form.

Laboratory activities for cod involve primarily otoliths, which must be prepared (breaking or cutting, mounting) and read (preferably twice, by different readers). Final coding and verification of data prior to entry on data processing systems are also carried out at the laboratory.

Based on the general description of sampling activities given above, and using several assumptions on the form and organization of sampling activities, costs were estimated for obtaining a cod age sample in each of three areas of the Gulf of St. Lawrence for use in the optimization calculations and for evaluation of the relative cost effectiveness of centrally based and field-based samplers.

Several general considerations governing this exercise should be noted. First and most important is that although the cost figures given are intended to be as realistic as possible, they represent relatively simple sampling cycles and are subject to improvement; the purpose of this exercise is to provide a clear description of rationale which can be modified for particular situations and improved by incorporation of past experience. Limited experience with field-based sampling programs means that costs are difficult to estimate. Second, it was assumed that for centrally based samplers, "goodness" of results (i.e. accuracy, precision, clarity of data) would be inversely proportional to length of sampling trips; thus trips were kept as short as possible consistent with reasonable costs. Third, a simple sampling cycle was used. The technician samples all species (not only the target species), and total costs (vehicle, food, and lodging) are divided by the number of samples obtained to give mean cost per sample.

TABLE A2. Unit costs for sample cost estimates.

1 sample = 100 length frequencies + 50 otolith ages	
FIELD SAMPLING ITEMS	
Daily expenses, field-based sampler	$10.00
Transport, per sample	5.00
Equipment, per sample	5.00
Kilometrage	0.25/km
Daily expenses, travel status	
Meals and incidentals	$30.00
Lodging	35.00
Overtime equivalents	
1st d overtime per week	1.5 person-day
2nd d overtime per week	2.0 person-day
LABORATORY ANALYSIS ITEMS	
Otoliths read (2 readings)	100/person-day
Person-days per sample (50 otoliths)	0.5/person-day
Equipment + overhead per sample	$10.00

Cost per sample (Tables A2, A3) was calculated for three sampling situations such as might be encountered in the Gulf, ranging from considerable concentration and predictability to considerable dispersion and unpredictability. These three situations correspond approximately to conditions in southwest Newfoundland, northern Newfoundland, and the Gaspé peninsula.

Sampling in *southwest Newfoundland* involves few landing facilities so that a high sampling rate is possible (2 samples/d) and little in-area travel is required (20 km/d). For the centrally based technician, travel is by air from Moncton to Deer Lake and by vehicle from Deer Lake to the sampling area. A 2-wk sampling trip is used for calculations.

In *northwest Newfoundland*, landing ports are more dispersed and 1 sample/d can be obtained. The centrally based technician travels to Deer Lake by air and by vehicle to the sampling area. A 3-wk sampling trip is used.

For the *Gaspé peninsula*, ports are dispersed and predictability of landings is low, so that a 0.75 sample/d can be obtained. For the centrally based technician, travel is by vehicle from Moncton and a 4-wk sampling cycle is used.

These cost estimates represent a first attempt and appear fairly representative of the relative expense of sampling the different kinds of areas to be found in the Gulf region. However, increasing the accuracy and precision of sampling cost estimates will require considerable experience with a sampling program for the region. Relative effectiveness of the two situations (field based and centrally based) is particularly difficult to estimate: one can imagine that a field-based sampler should be more proficient at timing his activities with those of the fleet than a centrally based technician, but that distance from the supervisory system might reduce efficiency of field-based personnel over the long term. In addition, periodic underemployment in sampling (i.e. at times when landings are low due to weather, fishery patterns, etc.) may affect efficiency of field-based samplers (who may not have alternative work) more adversely than centrally based technicians (who can perform other technical work at the laboratory when sampling needs are at a low level). Thus refinement of these cost estimates will require time and experience.

TABLE A3. Basis for cost estimates (pd = person-day).
Cost per sample (field-based): 1a) + 2 + 3
Cost per sample (centrally based): 1b) + 2

Item (sampling rate)	Southwest Nfld. (2 samples/d)		Northwest Nfld. (1 sample/d)		Gaspé peninsula (0.75 sample/d)	
	($)	(pd)	($)	(pd)	($)	(pd)
1. FIELD COLLECTION						
a) Field-based samplers						
Equipment/d	10.00		5.00		3.75	
Transport/d	10.00		5.00		3.75	
km/d	5.00		12.50		25.00	
Expenses/d	10.00		10.00		10.00	
Total daily	35.00	1.0	32.50	1.0	42.50	1.0
Cost/sample	17.50	0.5	32.50	1.0	56.67	1.3
b) Centrally based samplers						
Sampling trip length (d)	(12)		(19)		(26)	
(i) Days sampling	(10)		(15)		(25)	
(ii) Days traveling	(2)		(3)		(1)	
(iii) Days overtime	(2)		(4)		(6)	
Total cost (d) $\frac{i + ii + iii\,(1.5)}{2}$	13.5		22		30.5	
Travel to area						
Airfare	400.00		400.00		—	
Kilometrage (airport–port)	100.00		150.00		75.00	
Equipment shipment	200.00		160.00		187.50	
Expenses in area						
Food + incidentals	360.00		570.00		780.00	
Lodging	385.00		630.00		875.00	
Equipment, sample transport, kilometrage in area (see 1a))	250.00		360.00		812.50	
Total costs	1695.00		2270.00		2730.00	
Cost/sample	84.25	0.675	142.50	1.375	147.00	1.63
2. ANALYSIS (LABORATORY)						
Cost/Sample	10.00	0.5	10.00	0.5	10.00	0.5
3. ADMINISTRATION (FIELD-BASED SAMPLING PROGRAM)						
a) Travel by program supervisor to sampling area: $1200/yr Apply to 100 samples — $12.00/sample						
b) Training: 1 training trip/yr, $700 Apply to 100 samples — $7.00/sample						
c) Reporting: long-distance, postage, duplicating, etc. $600/yr Apply to 100 samples — $6.00/yr						
Total cost/sample	25.00		25.00		25.00	

Problématique de l'échantillonnage du crabe des neiges (*Chionoecetes opilio*) et du homard (*Homarus americanus*) et analyse du système d'échantillonnage au Québec

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Les variations de taille, la période de ponte et les niveaux saisonniers de PUE, chez le homard des Îles-de-la-Madeleine, justifient la délimitation de deux grandes régions d'échantillonnage à cet endroit. Les variations de taille à l'intérieur de chacune de ces deux régions nécessitent une fragmentation additionnelle du territoire en sous-régions. Les habitudes de pêche appuient également cette fragmentation. Chez le crabe des neiges, des variations importantes tant au niveau de la structure de taille que de l'abondance de crabe mou et de la PUE justifient la régionalisation actuelle de l'échantillonnage. Les variations intra-régionales de structure de taille sont faibles. Pour des populations fortement exploitées, un échantillonnage au début et à la fin de la saison de pêche permet habituellement d'obtenir une image adéquate de la structure de taille et du recrutement. Par contre, chez les populations peu exploitées, lorsque la structure de taille et la mue sont encore mal connues, il devient nécessaire d'accroître la fréquence d'échantillonnage. L'échantillonnage en mer, plutôt qu'au débarquement, permet d'améliorer la qualité des données sur le pré-recrutement. En plus, chez le crabe, il permet une meilleure estimation de l'abondance de crabe mou.

Lamoureux, P., P. Dubé, P. E. Lafleur et J. Fréchette. 1983. Problématique de l'échantillonnage du crabe des neiges (*Chionoecetes opilio*) et du homard (*Homarus americanus*) et analyse du système d'échantillonnage au Québec, p. 279–290. *Dans* W. G. Doubleday and/et D. Rivard [ed./éd.] Sampling commercial catches of marine fish and invertebrates/L'échantillonnage des prises commerciales de poissons et d'invertébrés marins. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 66.

Variations in size, spawning period, and seasonal levels of catch per unit effort of the lobster in the Magdalen Islands justify the definition of two large sampling areas in that region. Variations in size within these two areas require further division into subareas. Fishing practices also support this splitting up. In the snow crab fishery, significant variations in size class structure, abundance of soft-shell crabs and catch per unit effort vindicate the present regionalization of sampling. Size class variations within regions are low. For heavily fished populations, sampling at the beginning and at the end of the fishing season usually generates an adequate picture of size class structure and recruitment. On the other hand, it is necessary to increase sampling frequency of lightly harvested populations where size class structure and molting are not well known. At-sea sampling generates better quality prerecruitment data than dockside sampling. Furthermore, in crab populations, it gives a better estimate of the abundance of soft-shelled individuals.

Introduction

Historique de l'échantillonnage

Homard — « Les premiers travaux de recherche sur la biologie du homard au Québec furent entrepris par les scientifiques de la station biologique du Saint-Laurent en 1939, à la demande du ministère provincial des Pêcheries » (Tremblay 1943 cité par Bergeron 1967). Entre 1939 et 1981, on peut distinguer quatre périodes qui reflètent l'évolution des travaux d'échantillonnage du homard au Québec.

Période 1940–1947 — Corrivault et Tremblay (1948) rapportent que près de 30 000 homards furent mesurés durant cette période et ce, principalement dans la région de Gaspé et de la Baie des Chaleurs, et de façon moins intensive aux Îles-de-la-Madeleine et à l'île d'Anticosti. Un des objectifs de l'échantillonnage est alors de caractériser par la taille les populations et d'évaluer le degré d'homogénéité entre les différents secteurs : on cherche aussi à savoir si le homard est sédentaire dans chacune des localités, s'il appartient à des populations différentes ou si, au contraire, l'ensemble des homards des différentes régions constitue un stock unique. Depuis lors, les principaux travaux vont se poursuivre aux Îles-de-la-Madeleine. À cette époque, la longueur du homard est mesurée de la pointe du rostre jusqu'à l'extrémité du telson.

Période 1950–1959 — Bergeron (1967) note que plus de 44 000 homards ont été mesurés autour de l'archipel et dans les lagunes des Îles-de-la-Madeleine. Il distingue trois périodes d'échantillonnage : avant, pendant et après la saison de pêche. Tous les homards, soit ceux de taille commerciale et non commerciale sont mesurés, sauf pendant la saison de pêche, où seuls le sont les homards de taille légale. Puisque cet échantillonnage est le premier à être réalisé sur l'ensemble des aires de pêche, l'objectif principal est alors de mettre en évidence les caractéristiques régionales des populations. Dans cette optique, on observe l'évolution annuelle du pourcentage de homard de taille non-commerciale dans les captures afin d'identifier des zones propices au recrutement. On observe aussi le pourcentage de femelles oeuvées, le sexe-ratio et la taille moyenne des individus. C'est aussi durant cette période que la taille légale actuelle de 76 mm est progressivement mise en force et que l'on commence à utiliser la longueur du céphalothorax pour décrire la taille (Montreuil 1959).

Période 1962–1967 — L'échantillonnage est effectué seulement durant la saison de pêche, soit au début, au milieu et à la fin. Pour chaque période et chaque région, on procède alors simultanément à deux types d'échantillonnage :

1) Échantillonnage des captures complètes : un pêcheur rapporte au quai tous les homards capturés, soit ceux de taille commerciale ou non commerciale.
2) Échantillonnage des captures commerciales : un pêcheur est choisi au hasard et seuls les homards de taille légale sont mesurés. Le nombre de régions échantillonnées varie de sept à treize. Pour chaque aire échantillonnée, les statistiques de captures et d'efforts de pêche sont cumulées. L'objectif principal est de suivre, d'année en année, l'évolution de la pêche en tenant compte à la fois des structures des

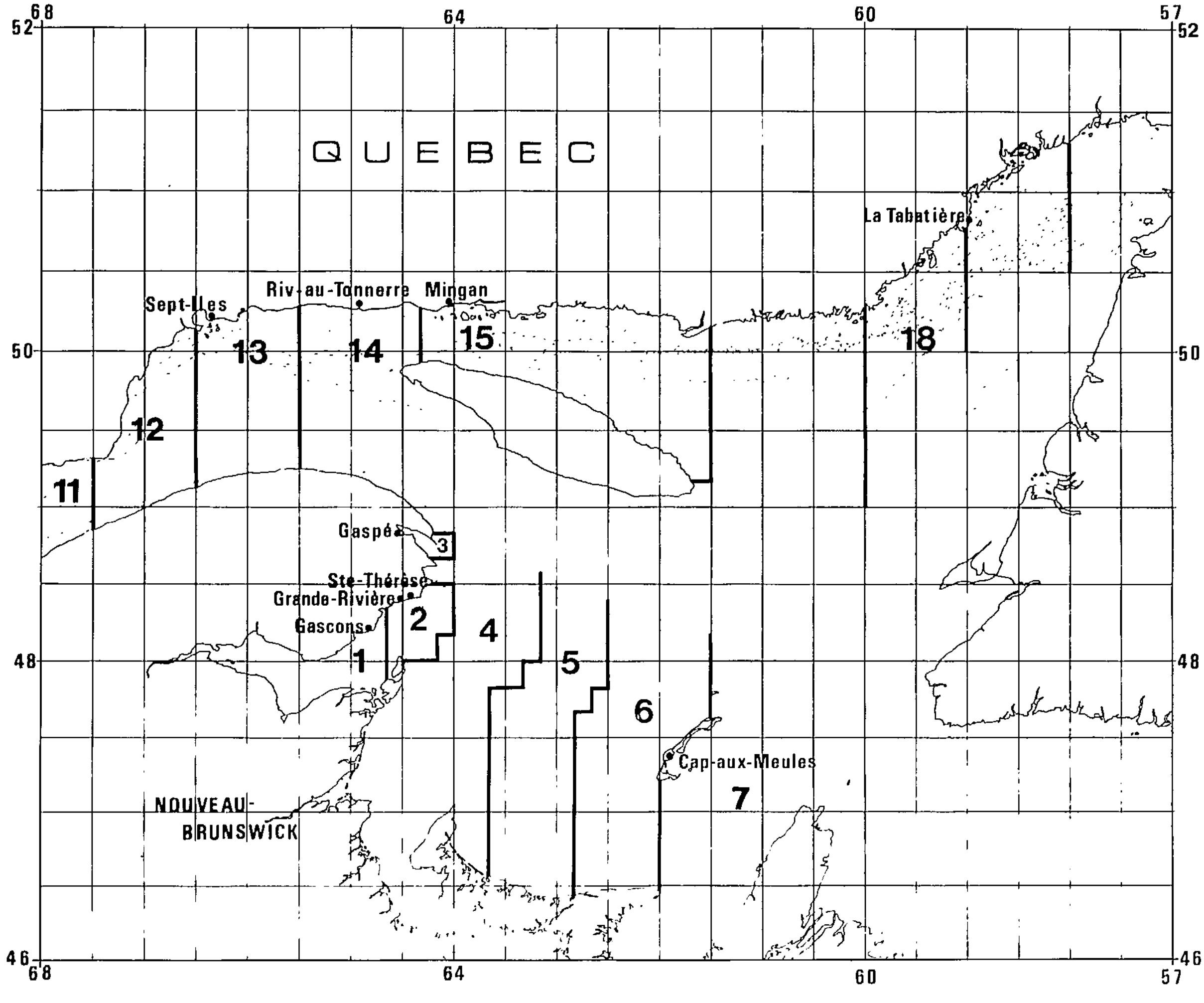

FIG. 1. Identification des régions d'échantillonnage pour le crabe des neiges dans le golfe du Saint-Laurent, de 1975 à 1981.

populations et des rendements de pêche (Bergeron 1964; Carbonneau 1965, 1966, 1967).

Période 1979-1981 — Nous avons effectué les mêmes types d'échantillonnage que ceux décrits pour la période précédente, sauf que l'échantillonnage des captures complètes s'effectue en mer.

L'échantillonnage en mer des captures complètes s'est poursuivi durant ces trois années, tandis que l'échantillonnage des captures au débarquement a été interrompu à partir de 1980.

Crabe des neiges — Les premiers débarquements importants de crabes de neiges au Québec remontent à 1968. Face à l'abondance accrue du crabe mou dans les captures, un système d'échantillonnage au débarquement fut mis sur pied en 1975. À ce moment, les débarquements se faisaient uniquement dans les ports de Grande-Rivière et Sainte-Thérèse, en Gaspésie. Par la suite, les ports suivants s'ajoutèrent : Gascons, en Gaspésie, en 1979; en 1980, Cap-aux-Meules et Hâvre-Aubert, aux Îles-de-la-Madeleine et Rivière-au-Tonnerre, Sept-Îles et Mingan sur la Moyenne-Côte-Nord.

L'échantillonnage au débarquement fut effectué de façon à couvrir l'ensemble des fonds visités par les crabiers du Québec. Les fonds furent divisés en un certain nombre de régions, tel qu'illustré à la figure 1. En 1981, l'échantillonnage au débarquement fut abandonné au profit de l'échantillonnage en mer.

L'échantillonnage en mer vise, de la même façon que celui au débarquement, à couvrir l'ensemble du territoire de pêche visité par les crabiers du Québec. En 1980, les observations ont porté uniquement sur les captures obtenues par les casiers des pêcheurs. Ces casiers possèdent une maille de 130 mm (maille étirée). En 1981, nous avons pris entente avec ces capitaines afin qu'ils utilisent des casiers à mailles de 50 mm que nous leur fournissons durant leurs opérations normales de pêche.

Les observations prises depuis 1975, autant en mer qu'au débarquement, ont porté sur la taille déterminée par la largeur maximale de la carapace et la dureté de carapace des crabes mâles. Les données sur la dureté de la carapace furent prises afin de déterminer la période de mue. Les femelles furent dénombrées uniquement. Leur présence dans les captures commerciales est réduite, étant donné que leur taille est beaucoup plus faible que celle des mâles, ce qui les rend d'ailleurs impropres à l'exploitation. Notons enfin que la taille légale est de 95 mm chez le crabe des neiges.

Objectifs de l'échantillonnage

L'échantillonnage des captures commerciales de homard et de crabe vise à évaluer l'impact de l'exploitation sur les stocks et à prévoir le recrutement à la pêche. La prise de données sur les captures cherche à atteindre les objectifs suivants :

a) obtenir des données sur l'ensemble des populations exploitées par la flotte québécoise;
b) obtenir une image précise de la structure de taille de chacune des populations, afin d'évaluer l'effet de la pêche sur les stocks. Cette information, jointe aux données de captures et d'efforts provenant de la fiche de pêche, permettra d'obtenir une image globale des stocks et de leur exploitation;
c) obtenir des données sur le pré-recrutement, principalement au niveau des populations fortement exploitées, afin de prévoir à court terme le recrutement à la pêche;
d) obtenir des données qui éventuellement serviront à établir une estimation de la mortalité et de la croissance;
e) obtenir si possible des données de base sur la biologie de l'espèce.

Délimitation des régions d'échantillonnage et variations régionales

Établissement d'un système d'échantillonnage régional pour le homard des Îles-de-la-Madeleine

Identification des deux régions de gestion — Les recaptures obtenues en 1979 et 1980 à partir des 12 000 homards marqués en 1978 dans les régions de Pointe-aux-Loups, Grosse-Île, Grande-Entrée et Hâvre-aux-Maisons, ont montré qu'il n'y a que très peu d'échanges entre le homard des parties nord et sud de l'archipel (P. Dubé et J. Fréchette 1980, données inédites).

Deux grandes régions furent délimitées de part et d'autre d'une ligne tracée selon l'axe de l'archipel, à partir de la pointe de l'Est jusqu'au bassin de Hâvre-Aubert : la région nord et la région sud (fig. 2).

La figure 3 illustre l'une des différences importantes rencontrées entre les régions nord et sud de l'archipel. Les gros homards sont relativement plus abondants au nord qu'au sud. Cette caractéristique a été observée à maintes reprises aux Îles-de-la-Madeleine (Bergeron 1967; Axelsen et Dubé 1978).

D'autres différences importantes existent, telles la période de ponte, et l'évolution des PUE au cours de la saison. Dans la région sud, les PUE sont plus élevées durant la première semaine et diminuent progressivement jusqu'à la fin de la saison de pêche, tandis que dans la région nord, les PUE augmentent jusqu'au milieu de la saison et diminuent par la suite (fig. 4).

Variations régionales — À l'intérieur de chacune de ces deux grandes régions, des variations régionales peuvent être observées. La figure 5 montre les distributions de taille observées au début de la saison de pêche de 1979, dans trois sous-régions de la partie sud de l'archipel. Pour les sous-régions de Grande-Entrée, Hâvre-aux-Maisons et de la baie de Plaisance, la proportion de pré-recrues (63–76 mm) est respectivement de 33 %, 47 % et 63 %. Ceci semble indiquer une ségrégation des classes de taille le long de la côte. Il existe donc des variations locales dont il faut tenir compte dans l'établissement d'un système d'échantillonnage.

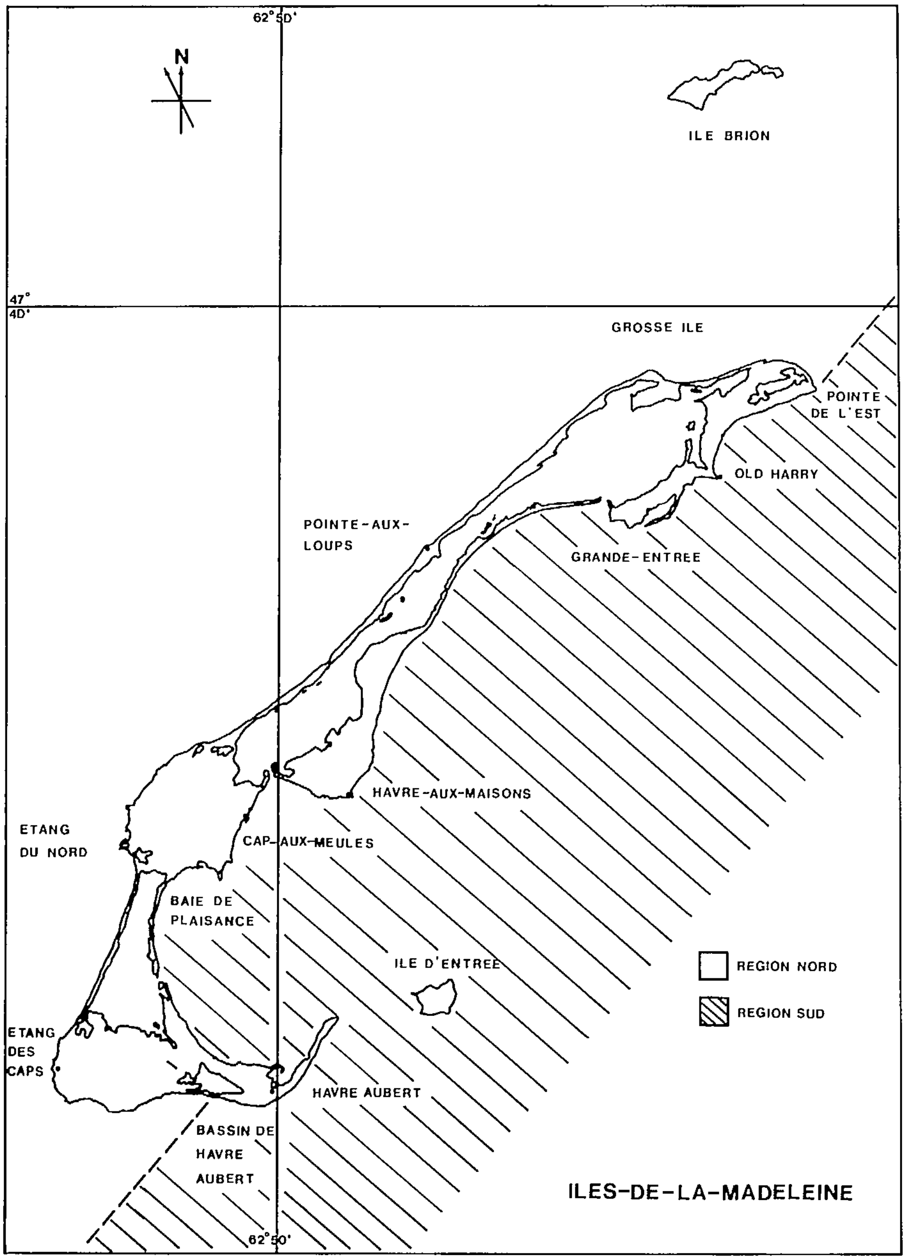

FIG. 2. Identification des régions d'échantillonnage nord et sud aux Îles-de-la-Madeleine.

Identification des sous-régions d'échantillonnage — D'autres facteurs incitent à une fragmentation de l'échantillonnage. Aux Îles-de-la-Madeleine, la flotte des homardiers est peu mobile, les bateaux pêchant en majorité sur des fonds situés à proximité de leur port d'attache. Une aire de pêche n'est dans la plupart des cas, visitée que par les bateaux qui opèrent à partir d'un même port de débarquement. C'est pourquoi la division de l'aire de pêche en sous-régions d'échantillonnage est définie à partir de l'aire d'influence de ces ports. De plus, les statistiques générales de débarquement et d'effort de pêche sont cumulées à partir de chacun des ports.

Pour fin d'analyse éventuelle des captures par port, la détermination de sous-régions d'échantillonnage devra donc tenir compte, en plus des caractéristiques biologiques, des habitudes de pêche.

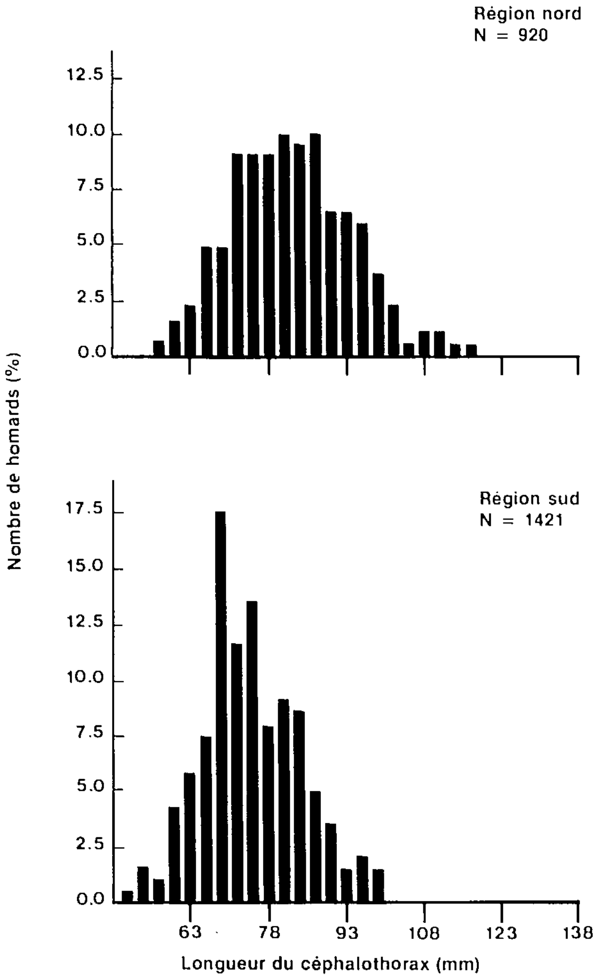

FIG. 3. Distribution de fréquence de taille chez le homard des régions nord et sud aux Îles-de-la-Madeleine, en mai 1979.

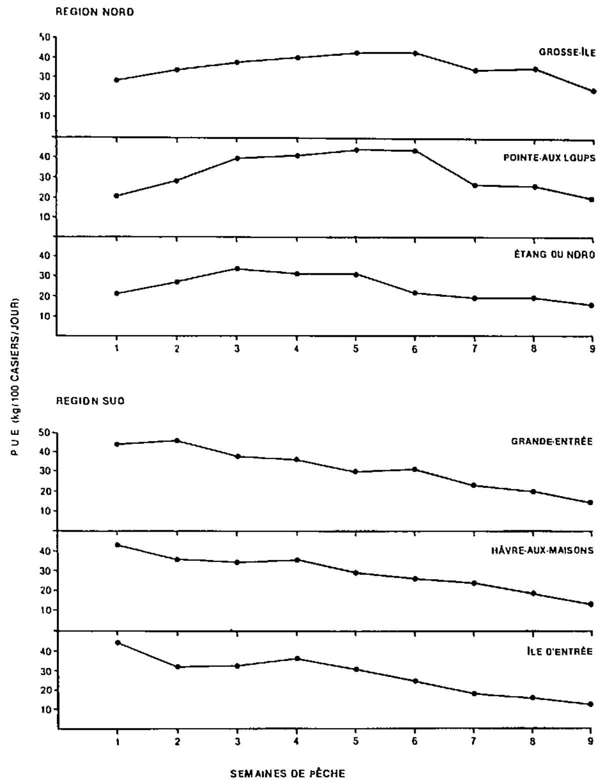

FIG. 4. Prise hebdomadaire par unité d'effort chez les homardiers de Grosse-Île, Pointe-aux-Loups et Étang du Nord (région nord), et Grande-Entrée, Hâvre-aux-Maisons et Île d'Entrée (région sud) aux Îles-de-la-Madeleine en 1979.

LE CRABE DES NEIGES DU SUD-OUEST ET DU NORD-OUEST DU GOLFE

Identification des régions d'échantillonnage — L'établissement de régions spécifiques s'est surtout appuyé sur les différences géomorphologiques du fond (fig. 1). Les probabilités de mélange entre les populations de crabe de la Baie des Chaleurs, celles du banc de l'Orphelin et celles du banc Bradelle sont faibles (Watson et Wells 1970). Ces grands secteurs ont été redivisés afin de tenir compte de caractéristiques particulières à certaines régions. D'une part, la baie de Gaspé possédait une population dont les individus étaient de taille beaucoup plus faible. La présence de coulées plus profondes de part et d'autre du banc Bradelle nous incita à établir les régions 5 et 6. Par contre, les régions 1 et 2 dans la Baie des Chaleurs reflétaient davantage les besoins d'une gestion distincte pour les crabiers de Gascon d'une part, et ceux de Grande-Rivière et Sainte-Thérèse d'autre part. En 1980, la région 7 fut introduite pour inclure les fonds nouvellement exploités à l'est des Îles-de-la-Madeleine.

Des différences, tant au niveau de la structure de taille que de l'abondance de crabe mou et de PUE justifient la délimitation de ces régions.

À la figure 6 nous illustrons la structure de taille des populations des régions 1, 4, 5 et 6 dans le sud-ouest du golfe du Saint-Laurent en 1981. Des différences marquées sont également observées entre les populations des régions 13, 14 et 15 sur la Moyenne-Côte-Nord en 1981 (fig. 7).

Nous observons également de fortes variations d'abondance de crabe mou dans les différentes régions désignées antérieurement (tableau 1).

Enfin, on note la présence de niveaux variables de PUE dans le sud-ouest du golfe. Ainsi, les régions 1, 2, 4, 5 et 6 montraient en 1981 des niveaux moyens respectifs de PUE de 24,0, 34,8, 44,1 et 54,2 (Lamoureux 1981).

Des variations importantes tant au niveau de la structure de taille que de l'abondance de crabes mous et de la PUE justifient la délimitation des régions 13 (Sept-Îles), 14 (Rivière-au-Tonnerre) et 15 (Mingan) sur la Moyenne-Côte-Nord, à partir de 1980. En 1981, nous ajoutions la région 18 (La Tabatière) sur la Basse Côte-Nord.

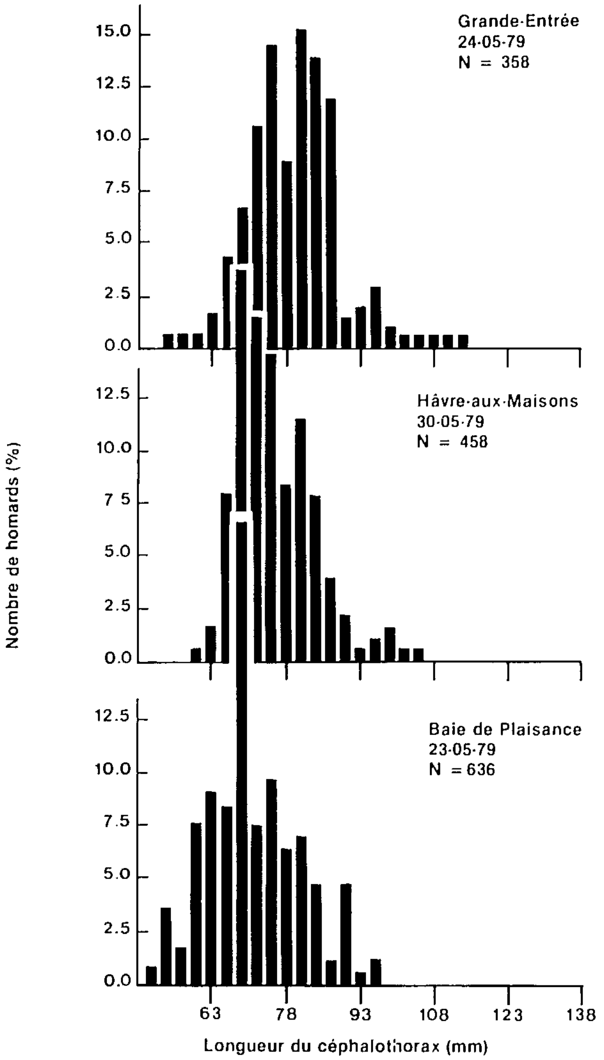

FIG. 5. Distribution de fréquence de taille chez le homard de Grande-Entrée, Hâvre-aux-Maisons et Baie de Plaisance aux Îles-de-la-Madeleine, en mai 1979.

Variations intra-régionales de la structure de taille — Nous avons vérifié s'il y avait des différences importantes de structure de taille à l'intérieur d'une même région. À cette fin, nous avons utilisé des données de 1981 provenant de la région de Rivière-au-Tonnerre. On y observe de faibles variations de la structure de taille entre trois sous-échantillons obtenus à partir de trois jours consécutifs d'échantillonnage dans la région 14 (fig. 8). Ces sous-échantillons s'étalent successivement d'ouest en est le long de la côte. Ces données bien que partielles, sont l'indication d'une faible variabilité intra-régionale, du moins au niveau des structures de taille. Elles indiquent cependant que la détermination des régions d'échantillonnage est probablement adéquate dans ce secteur. Les données de 1982 semblent également indiquer que les variations intra-

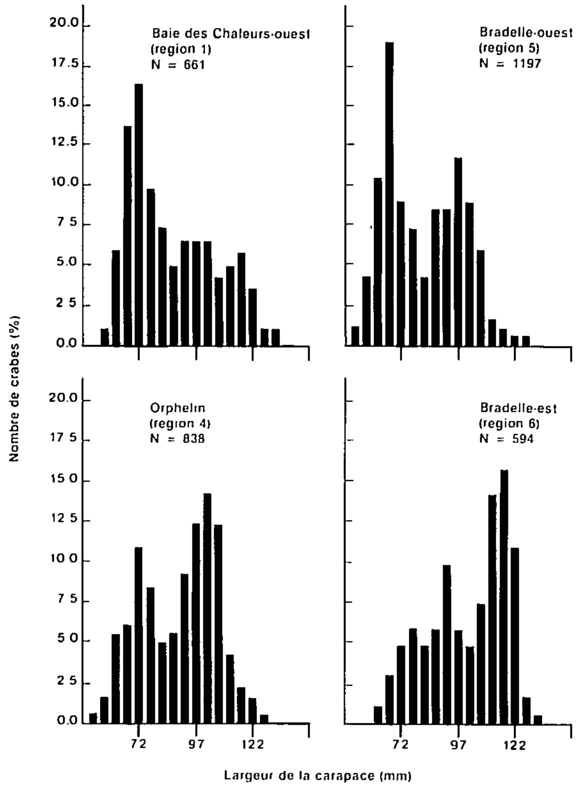

FIG. 6. Distribution de fréquence de taille chez le crabe des neiges des régions 1, 4, 5 et 6 dans le sud-ouest du golfe du Saint-Laurent, durant la période mai–juin 1981. Les casiers étaient munis de mailles de 50 mm.

régionales de structure de taille sont également faibles dans le sud-ouest du golfe (P. Lamoureux, données personnelles).

Période et fréquences optimales d'échantillonnage

Au moment de choisir un type particulier d'échantillonnage, pour le homard ou le crabe des neiges, nous pouvons être en présence de populations exploitées à des niveaux variables. Ainsi, le homard des Îles-de-la-Madeleine est soumis à une forte exploitation (Belzile et Fréchette 1983). C'est le cas également des populations de crabe du sud-ouest du golfe du Saint-Laurent. Par contre, certaines populations de crabe de la Côte-Nord sont peu exploitées.

PROBLÉMATIQUE D'UNE POPULATION FORTEMENT EXPLOITÉE : LE HOMARD DES ÎLES-DE-LA-MADELEINE

Depuis 1978, trois périodes d'échantillonnage furent établies : le début, le milieu et la fin de la saison de pêche. Le premier échantillonnage se limitant aux cinq premiers jours de pêche, il se déroule dans une période qui représente environ 10 % de la durée totale de la saison de pêche. C'est pourquoi nous considérons que ce premier échantil-

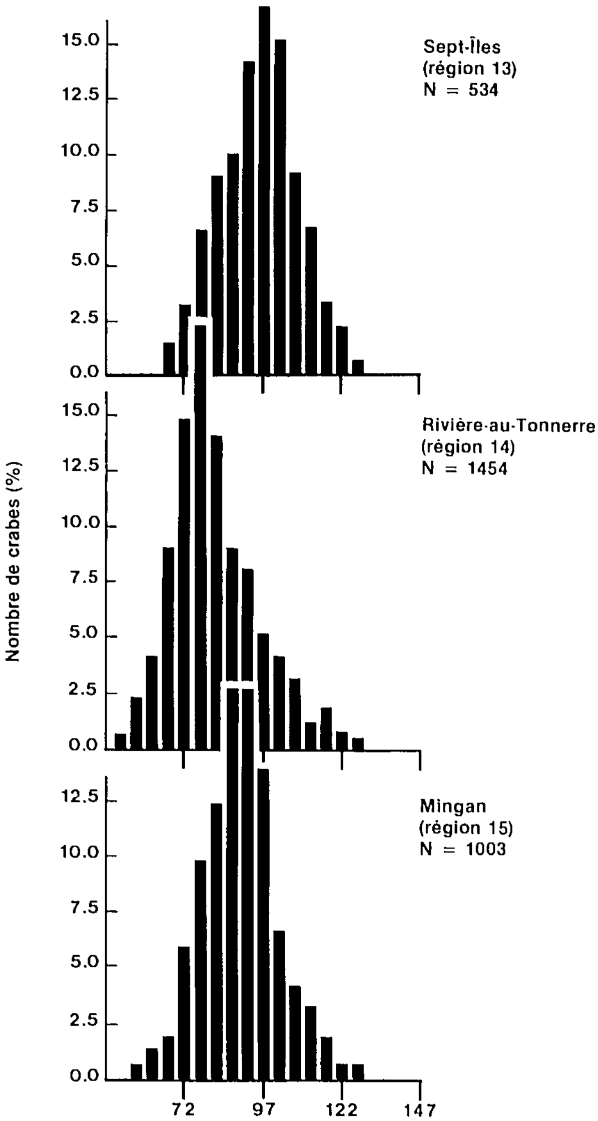

FIG. 7. Distribution de fréquence de taille chez le crabe des neiges des régions 13, 14 et 15 sur la Moyenne-Côte-Nord, en septembre 1981. Les casiers étaient munis de mailles de 50 mm.

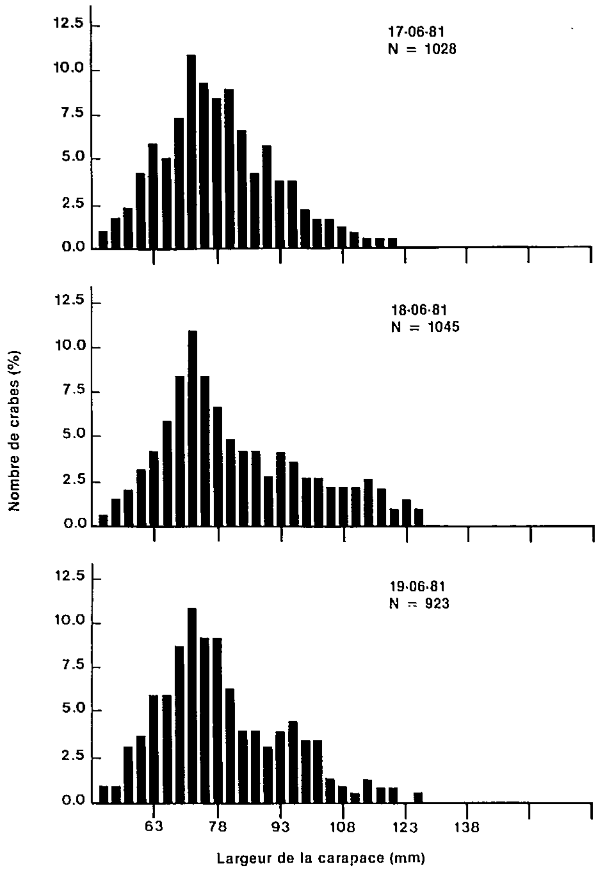

FIG. 8. Distribution de fréquence de taille chez le crabe des neiges de trois sous-échantillons définis à l'intérieur de la région 14, à Rivière-au-Tonnerre, en juin 1981. Les casiers étaient munis de mailles de 50 mm.

lonnage peut donner une image assez juste de la structure de population, avant l'exploitation. L'échantillonnage effectué au milieu de la saison a surtout servi, jusqu'ici, à accumuler des informations sur l'évolution de la ponte et sur la quantité de femelles porteuses d'oeufs. La troisième période, en plus de fournir des renseignements complémentaires sur les femelles oeuvées, nous montre l'effet de la pêche sur la population initiale. La figure 9 montre qu'il existe, entre autres pour la région de Hâvre-aux-Maisons, une différence marquée entre les structures de population au début et à la fin de la pêche. Cette particu-

TABLEAU 1. Pourcentage de crabe à carapace molle et intermédiaire (duretés 1 et 2), dans le sud-ouest du golfe du Saint-Laurent et sur la Moyenne-Côte-Nord, en juillet 1980. L'échantillonnage des captures commerciales fut effectué en mer.

Région		Pourcentage de crabe à carapace molle et intermédiaire (%)
Sud-Ouest du golfe		
Baie des Chaleurs-ouest	(rég. 1)	83,7
Baie des Chaleurs-est	(rég. 2)	81,3
Banc de l'Orphelin	(rég. 4)	49,7
Banc Bradelle-ouest	(rég. 5)	31,5
Banc Bradelle-est	(rég. 6)	58,5
Cap Saint-Laurent	(rég. 7)	43,8
Moyenne-Côte-Nord		
Sept-Îles	(rég. 13)	12,0
Rivière-au-Tonnerre	(rég. 14)	46,3
Mingan	(rég. 15)	38,3

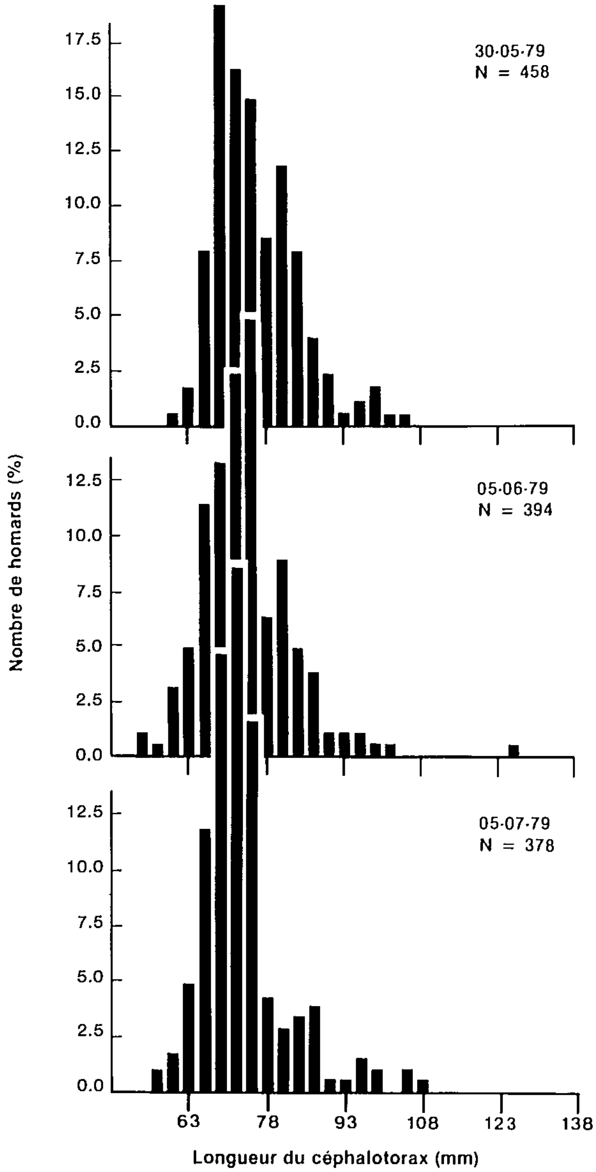

FIG. 9. Distribution de fréquence de taille chez le homard de Hâvre-aux-Maisons aux Îles-de-la-Madeleine, en mai, juin et juillet 1979.

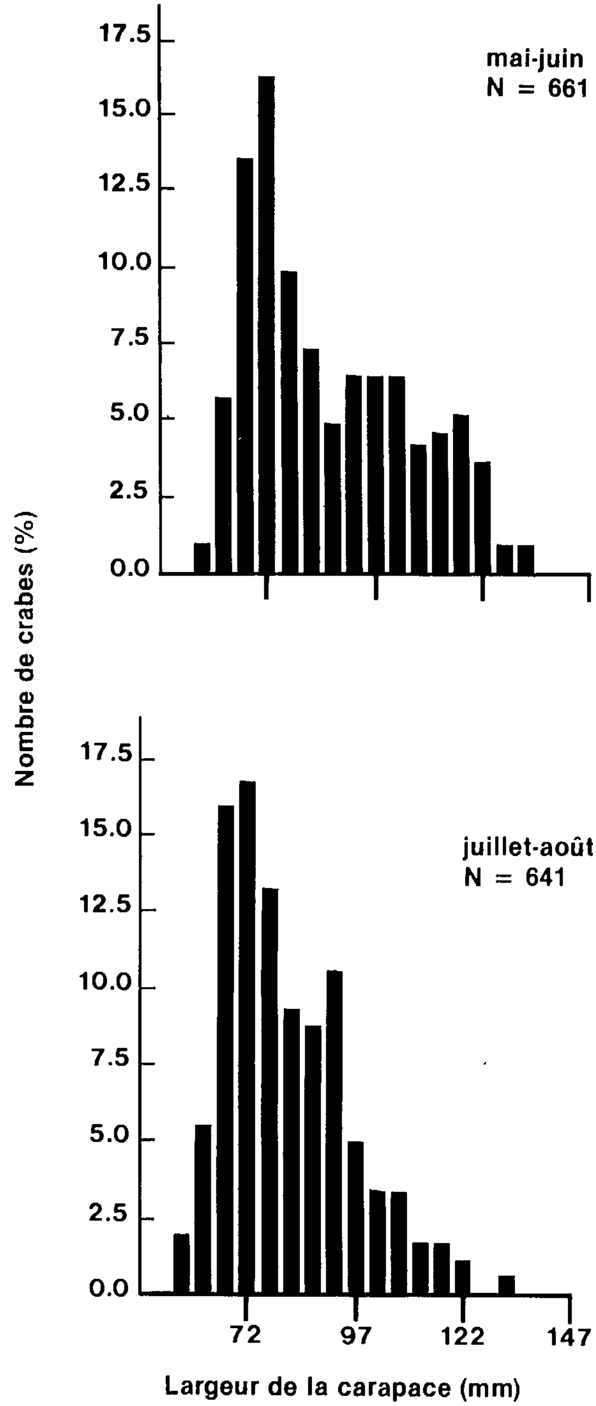

FIG. 10. Influence de la pêche sur une structure de taille du crabe des neiges de la région 1, dans la Baie des Chaleurs, en 1981. Les casiers étaient munis de mailles de 50 mm.

larité pourrait éventuellement nous permettre d'évaluer la mortalité par la pêche. Idéalement, l'échantillonnage devrait être effectué avant et après la saison de pêche afin d'obtenir une image plus fidèle des structures de taille de la population avant et après l'exploitation.

SYSTÈME D'ÉCHANTILLONNAGE ET NIVEAUX D'EXPLOITATION : LE CRABE DES NEIGES

Chez les populations de crabe fortement exploitées, lorsque les caractéristiques de la mue sont assez bien connues, un échantillonnage en début et fin de saison suffira habituellement à l'obtention des données essentielles à la gestion de la ressource. L'échantillonnage de fin de saison, juxtaposé à celui de début de saison, nous informera sur l'abondance relative des crabes de taille légale ($\geq$ 95 mm) et des pré-recrues. Cet élément de prédiction des captures sera d'autant plus utile s'il peut être associé à des indices d'abondance (P.U.E.) et éventuellement à des estimations de biomasse.

Nous illustrons, à la figure 10, l'effet typique d'une exploitation intensive sur la structure de taille d'une population de la Baie des Chaleurs (région 1). Cette région est particulièrement favorable à une telle illustration, étant donné qu'il n'y a pas eu de mue importante durant la saison de pêche 1981 (P. Lamoureux, données personnelles). On y observe une diminution importante de la proportion d'individus de taille légale, en fin de saison.

Lorsque la mue et la structure de taille sont encore mal connues, comme c'est le cas habituellement en présence de populations peu ou pas exploitées, il sera avantageux d'instaurer un échantillonnage plus fréquent. Au cours des premières années d'observation, il sera intéressant de tenter de cerner l'évolution saisonnière de la mue. À cette fin, nous croyons qu'un échantillonnage en début, milieu et fin de saison de pêche demeure un minimum. Il y a habituellement accumulation de vieux individus chez de telles populations. Il est alors important de connaître l'abondance relative des pré-recrues, afin d'éviter un épuisement rapide de la population, advenant une intensification de la pêche.

Sélectivité des engins

L'estimation du pré-recrutement est un objectif important de recherche autant chez le crabe que le homard. On peut se demander si les casiers actuellement en usage pour la pêche donnent une image juste de l'abondance des pré-recrues tenant compte de leur sélectivité.

SÉLECTIVITÉ DU CASIER COMMERCIAL À HOMARD

Chez le homard, la largeur du céphalothorax est plus petite que sa hauteur. Ayant observé qu'un homard peut passer de côté à travers une ouverture rectangulaire, Nulk (1978) suggère que la largeur du céphalothorax est le facteur de sélection qui intervient au niveau de la rétention exercée par un casier. La relation entre la longueur et la largeur du céphalothorax permet alors de prédire la taille inférieure à partir de laquelle la majorité des homards seront retenus par une ouverture rectangulaire.

Nous avons établi une relation semblable pour des homards capturés à Étang-des-Caps, aux Îles-de-la-Madeleine, en 1981 (P. Dubé 1982, données inédites). En 1980, nous avons mesuré la distance entre la première et la deuxième latte, et entre la deuxième et la troisième latte de 600 casiers appartenant à douze pêcheurs des Îles-de-la-Madeleine. Les distances moyennes observées varient de 27,8 mm (σ = 0,8) à 33,5 mm (σ = 2,1). En supposant qu'un homard puisse passer à travers une ouverture égale ou supérieure à la largeur de son céphalothorax, l'intervalle de prédiction de

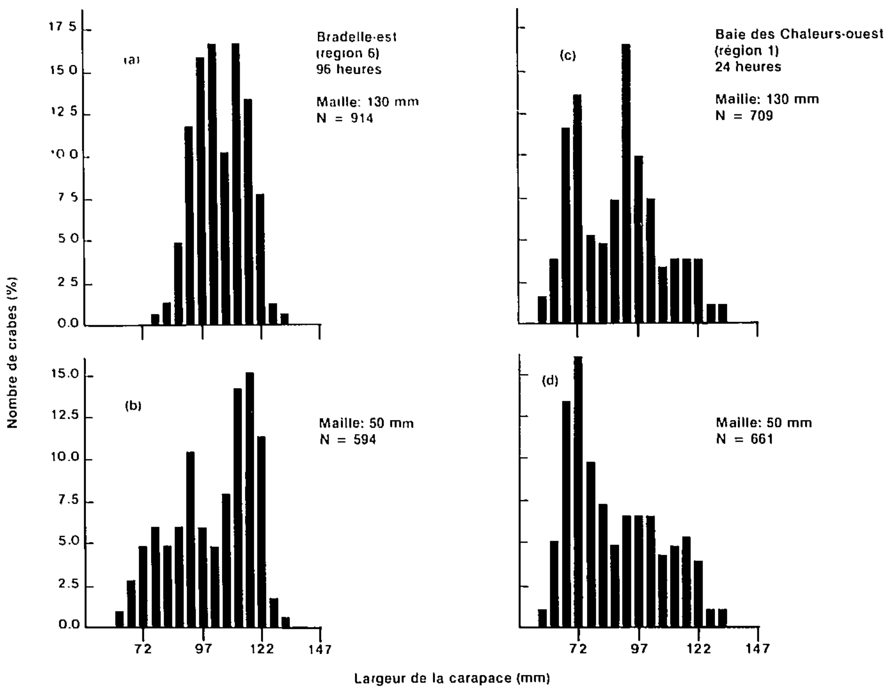

FIG. 11. Distribution de fréquence de taille chez le crabe des neiges dans le sud-ouest du golfe du Saint-Laurent, pour des casiers dont le temps d'immersion et la maille variaient, durant la période mai-juin 1981.

notre régression (α = 0,95) entre la longueur et la largeur du céphalothorax, indique que la majorité des homards dont la taille excède 63 mm est retenue par les casiers échantillonnés.

Les recaptures de homards marqués en 1978 ont montré que l'accroissement linéaire du céphalothorax au cours de la mue est indépendant de la taille et égal à 13 mm pour les sexes combinés (Dubé et Fréchette 1980, données inédites). Puisque la taille légale est de 76 mm aux Îles-de-la-Madeleine, le homard pré-recrue mesurerait entre 63 et 76 mm, en supposant qu'il n'y a qu'une seule mue par année (Dubé et Fréchette 1980, données inédites). Comme, théoriquement, ce homard est presque entièrement retenu par les casiers, l'échantillonnage en mer pourrait nous permettre d'évaluer le pré-recrutement pour différentes régions et périodes de temps.

Système d'échantillonnage et sélectivité du casier à crabe

L'un des objectifs essentiels de l'échantillonnage des captures provenant de l'exploitation du crabe demeure l'estimation du pré-recrutement. Dans cette optique, il convient d'analyser les résultats obtenus à partir des engins utilisés par la pêche commerciale. On constate en premier lieu que la maille de 130 millimètres dont est muni le casier commercial à crabe, retient principalement les classes de taille commerciale (fig. 11a), ceci même si les pré-recrues sont relativement moins abondantes dans la région de Bradelle-est (fig. 11b) que dans la Baie des Chaleurs (fig. 11d). Par ailleurs, la proportion de pré-recrues retenues par le casier muni de mailles de 130 mm pourra varier selon la durée d'immersion; elle sera plus ou moins élevée lorsque le temps de pêche est moins de 24 h (fig. 11c), mais diminuera considérablement si la période d'immersion augmente (fig. 11a.). On pourrait donc émettre l'hypothèse que, pendant une période de moins de 24 h de pêche, les différences observées au niveau de la quantité de pré-recrues capturées puissent refléter la durée effective d'attraction exercée par l'appât.

Les résultats obtenus à l'aide de l'engin de pêche commerciale ne permettent donc pas d'obtenir une estimation satisfaisante du pré-recrutement, ce qui nous a menés à utiliser un engin modifié. On a donc muni le casier rectangulaire traditionnel d'un maillage de 50 mm, afin d'être en mesure d'estimer l'importance relative de la classe prérecrutée. Ainsi, en s'assurant que les casiers soient suffisamment dispersés à l'intérieur du territoire de pêche visité, on peut obtenir une bonne représentation de l'ensemble des individus matures d'une population (fig. 11d). De plus, on observe que le temps d'immersion ne semble plus représenter un facteur aussi contraignant, au niveau de la structure de la population observée, lorsqu'on utilise une maille plus fine (fig. 11b).

TABLEAU 2. Avantages respectifs de l'échantillonnage au débarquement et en mer, pour le homard et le crabe.

Échantillonnage au débarquement	Échantillonnage en mer
1. Permet de mieux couvrir une région donnée.	1. Permet d'obtenir une meilleure image de la structure de taille de la population et notamment d'estimer le pré-recrutement.
2. Permet d'obtenir un volume important de données.	2. Au niveau du crabe, permet d'obtenir un estimé non biaisé de la proportion de crabe mou.
3. N'impose pas de contraintes logistiques.	3. Présente la possibilité d'obtenir des données complémentaires (observation sur les femelles, prises accessoires, température, profondeur).
	4. Permet de situer précisément le lieu d'échantillonnage.
	5. Permet de connaître avec précision le temps d'immersion des casiers (crabe surtout).
	6. Permet de vérifier la validité de l'information provenant de la pêche.

Échantillonnage en mer et échantillonnage au débarquement

Pour un grand nombre d'espèces exploitées commercialement, l'échantillonnage des captures commerciales effectué dans les ports de débarquement permet d'atteindre les objectifs visés par la stratégie d'échantillonnage. Toutefois, chez plusieurs espèces, notamment le homard et le crabe des neiges, la prise de données réalisée en mer contribue à augmenter de façon marquée la qualité de l'information obtenue, en particulier en regard de l'objectif principal qui est l'évaluation du pré-recrutement.

Le tableau 2 représente, pour le homard et le crabe des neiges, les avantages respectifs de l'échantillonnage au débarquement et en mer. D'une manière générale, la prise de données au port de débarquement offre l'avantage de fournir une information relativement abondante avec un minimum de contraintes logistiques. Toutefois, en regard des objectifs visés par l'échantillonnage, l'information recueillie est nettement insuffisante. Il n'est en effet pas possible d'estimer le pré-recrutement avec ce mode de collecte de données, tant chez le homard que chez le crabe, étant donné que les pêcheurs rejettent à la mer la majorité des captures de taille illégale. De plus, en particulier chez le crabe des neiges, l'échantillon prélevé au débarquement amène une estimation biaisée de la proportion de crabe mou dans la population, étant donné l'interdiction de débarquer ces individus. Ainsi, en 1980, l'échantillonnage au débarquement effectué en Gaspésie montrait une proportion de crabe mou de 30,6 % alors que les données en mer montraient 44,6 % de crabe mou dans les échantillons. On peut donc affirmer que l'échantillonnage au débarquement ne peut contribuer à obtenir des données valables sur la mue chez le crabe des neiges.

La prise de données effectuée en mer offre également la possibilité d'obtenir des données complémentaires à l'étude stricte du stock exploité. Chez le homard comme chez le crabe des neiges, on peut recueillir des données sur les femelles (homard : données sur les femelles oeuvées; crabe : abondance des femelles, stade de maturité des oeufs), de même que sur les prises accessoires capturées par les casiers. Par ailleurs, on peut obtenir de l'information sur le milieu physique (conditions atmosphériques, température de l'eau, profondeur) lors de sorties en mer. Enfin, l'échantillonnage réalisé en mer offre comme avantage de pouvoir déterminer précisément la provenance des captures et le temps d'immersion des casiers. Il permet en plus au personnel scientifique de vérifier la précision de l'information issue de la fiche de pêche, en rapport avec l'identification précise des lieux de pêche telle que fournie par les pêcheurs.

L'échantillonnage des captures commerciales effectué en mer s'ajuste très mal aux techniques conventionnelles d'échantillonnage au hasard. D'une part, cet échantillonnage entraîne un biais, étant donné que le choix du bateau ne peut se faire au hasard. D'autre part, la disponibilité du personnel limite le nombre de sorties possibles dans les différentes régions déterminées.

L'échantillonnage des captures commerciales effectué en mer impose de plus des contraintes logistiques dont l'importance peut parfois influencer la bonne marche des travaux. Ces contraintes logistiques deviennent beaucoup plus restrictives lorsque les objectifs de l'échantillonnage imposent l'utilisation d'un engin de pêche modifié (maille de 50 mm), tel qu'on le réalise présentement chez le crabe des neiges. Toutefois, la qualité de l'information obtenue selon ce mode d'échantillonnage permet de compenser pour les efforts relativement importants requis pour l'acquisition des données.

Conclusion

L'échantillonnage du crabe des neiges et du homard est différent dans ses besoins et ses objectifs comparativement aux poissons marins. L'extrême difficulté de détermination de l'âge chez les spécimens empêche la production de séries de données sur les captures à l'âge et donc partiellement l'utilisation de techniques usuelles d'estimation de stocks telle l'analyse de population virtuelle et l'analyse de cohortes. Aucune structure anatomique ne permet d'estimer l'âge comme chez les poissons; de plus, l'interprétation conventionnelle en terme d'âge sur la polymodalité des distributions de fréquence de taille, technique utilisée chez d'autres crustacés comme la crevette *Pandalus borealis*, n'est que très difficilement applicable chez le crabe et spécialement chez le homard. Une telle particularité rend, de plus, très difficile la production d'estimés de mortalité et plus spécialement d'estimés de croissance.

Toutes ces particularités, que partagent à divers degrés le crabe des neiges et le homard, expliquent que l'évaluation du pré-recrutement devienne un des objectifs premiers de l'échantillonnage au niveau de la gestion des stocks. La poursuite d'un tel objectif implique un échantillonnage en mer, puisque ces deux espèces sont réglementées par une taille légale limite au-dessous de laquelle les spécimens sont rejetés à la mer. L'échantillonnage au débarquement, face à cette limitation, ne permet que l'observation de la composition en taille des captures effectivement débarquées.

De plus, particulièrement chez le crabe des neiges, le temps d'immersion des casiers commerciaux à mailles de 130 mm joue un rôle très important dans la rétention des pré-recrues. Il devient alors nécessaire d'utiliser une maille plus petite si l'on veut obtenir un échantillonnage non biaisé en mer, puisque les temps d'immersion des casiers sont très variables.

Les variations considérables observées entre les différentes régions, telles que délimitées actuellement pour l'échantillonnage du homard et du crabe dans le golfe du Saint-Laurent, semblent justifier le maintien de ces régions. Ces variations sont présentes au niveau de la structure de taille de la population et de la PUE chez les deux espèces. Chez le crabe des neiges on note en plus des variations dans l'abondance des individus à carapace molle (post-mue) d'une région à l'autre. Toutefois, l'appariement des données d'échantillonnage aux données recueillies sur les captures et l'effort de pêche nécessitent la fragmentation additionnelle des régions d'échantillonnage pour fin de compilation.

Les périodes d'échantillonnage et leur fréquence devront varier selon les objectifs visés. Ainsi, si l'on tend qu'à connaître l'abondance relative des pré-recrues, un échantillonnage en début et en fin de saison de pêche suffira habituellement. Par contre, si l'on doit tracer en plus l'évolution de la mue durant la saison de pêche, il faudra évidemment accroître cette fréquence d'échantillonnage. Cette situation se présentera surtout chez les populations de Crabe des neiges encore peu connues. Chez le Homard, comme la période de mue change peu dans le temps d'une année à l'autre et qu'elle se situe après la saison de pêche, cet élément prend moins d'importance.

Face aux techniques conventionnelles d'échantillonnage au hasard qui donnent habituellement une image représentative de la structure du stock, l'échantillonnage en mer comporte certaines limitations. Ainsi, il entraîne des contraintes dans le choix des pêcheurs et des sites d'échantillonnage. En plus, il ne permet pas la cueillette de données aussi abondantes dans chacune des régions visées.

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