Canadian Technical Report of
Fisheries and Aquatic Sciences 932

March 1980

PROCEEDINGS OF THE CANADA-U.S. WORKSHOP ON STATUS OF ASSESSMENT SCIENCE FOR N.W. ATLANTIC LOBSTER (*Homarus americanus*) STOCKS

(St. Andrews, N.B., Oct. 24-26, 1978)

V. C. Anthony[1] and J. F. Caddy[2] [Editors]

[1]Maine Department of Marine Resources
Fisheries Research Laboratory
West Boothbay Harbor, Maine 04575

[2]Department of Fisheries and Oceans
Biological Station
St. Andrews, New Brunswick EOG 2XO

This is the one hundred and twenty-fourth Technical Report from
the Biological Station, St. Andrews, N.B.

© Minister of Supply and Services Canada 1980
Cat. No. Fs 97-6/932 ISSN 0701-7626

TABLE OF CONTENTS

Page

A. ABSTRACT v

B. FOREWORD vi

C. PAPERS AND DISCUSSIONS 1

I. Growth
a) The determination of growth rates for American lobsters by H. J. Russell, Jr. 1
b) Recent and current Canadian research on growth of lobsters in the wild by G. P. Ennis . . 9
c) Rapporteur - E. Smith 16

II. Mortality Estimates
a) Review of lobster mortality estimates in the United States by V. C. Anthony 17
b) A review of mortality estimates of lobster populations in the Canadian Maritimes by A. Campbell 27
c) Rapporteur - T. Woithe 36

III. Yield Per Recruit
a) Assessment of yield per recruit for the American lobster (*Homarus americanus*) by M. J. Fogarty 37
b) Canadian efforts to assess yield per recruit in lobsters by G. P. Ennis 45
c) Rapporteur - D. Bennett 49

IV. Maturity and Fecundity
a) Maturity and fecundity in the American lobster, *Homarus americanus* - a review by W. A. Van Engel 51
b) Maturity and reproduction in the American lobster by D. E. Aiken and S. L. Waddy 59
c) Rapporteur - R. Harris 70

V. Problems of Gear Selectivity
a) Recent U.S. lobster trap gear research: applications and implications by R. J. Smolowitz and F. M. Serchuk 73
b) Lobster gear selectivity - a Canadian overview by R. W. Elner 77
c) Rapporteur - J. Fair, Jr. 84

VI. Measure of Effort
a) Measures of effort by J. Thomas 85
b) Rapporteur - P. Briggs 92

VII. Catch-Effort Trends and Estimates of MSY
a) Catch-effort trends and estimates of maximum sustainable yield in the U.S. lobster fishery by B. Halgren 93
b) Rapporteur - G. P. Ennis 100

VIII. Statistical Reporting Systems
a) Statistical reporting systems by E. M. Smith 101
b) Canadian statistical reporting system by M. C. Cormier 107
c) Rapporteur - B. Halgren 122

IX. Research Surveys
a) Application of U.S. bottom trawl survey and commercial data to offshore lobster assessments by T. Burns and S. H. Clark 125
b) Rapporteur - A. Stasko 133

X. Tagging
a) Summary of lobster, *Homarus americanus*, tagging studies in American waters (1898-1978) by J. S. Krouse 135
b) Tagging and lobster movements in Canada by A. B. Stasko 141
c) Rapporteurs - S. Keefe and E. Smith 151

XI. Larval Studies and Recruitment Indices
a) U.S. surveys of lobster larvae by J. J. Fair, Jr. 153
b) Lobster larval surveys in Canada by A. B. Stasko 157
c) Rapporteur - D. G. Robinson 166

XII. Lobster Fishery Regulations
a) Current status of European lobster management by D. B. Bennett 171
b) Change in minimum size limits, gear regulations and the berried lobster laws in the U.S. by T. Morrissey 175
c) Rapporteur - S. Clark 178

Page

C. SCIENTIFIC RECOMMENDATIONS FOR MANAGEMENT 180

D. RESEARCH NEEDS 181

E. SUMMARY 183

F. ACKNOWLEDGMENTS 185

G. APPENDIX - Definition of Refugium 186

ABSTRACT

Anthony, V. C., and J. F. Caddy [editors]. 1980. Proceedings of the Canada-US Workshop on status of assessment science for N.W. Atlantic lobster (*Homarus americanus*) stocks (St. Andrews, N.B., Oct. 24-26, 1978). Can. Tech. Rep. Fish. Aquat. Sci. 932, vii + 186 p.

The lobster workshop reviewed the present state of knowledge of lobster population parameters, problems of gear selectivity, measures of effort used in each lobster fishery, research-vessel surveys, and methods of statistical reporting. The feasibility of defining management units and the problem of recruitment prediction were also discussed. Finally, a general session provided the opportunity to compare the recent U.S. State-Federal management plan with experience of lobster research and management in Canada and Europe.

Key words: Lobster, *Homarus americanus*, *Homarus gammarus*, Canada, United States, Europe, growth rates, mortality estimates, yield per recruit, maturity, fecundity, reproduction, traps, gear research, gear selectivity, measures of effort, catch effort, maximum sustainable yield, statistics, reporting systems, research surveys, distributions, assessments, tagging, migration, movement, larvae, larval surveys, fishery management, gear regulations, size limits, recommendations, research needs

RÉSUMÉ

Anthony, V. C., and J. F. Caddy [editors]. 1980. Proceedings of the Canada-US Workshop on status of assessment science for N.W. Atlantic lobster (*Homarus americanus*) stocks (St. Andrews, N.B., Oct. 24-26, 1978). Can. Tech. Rep. Fish. Aquat. Sci. 932, vii + 186 p.

Un groupe de travail a revisé l'état actuel des connaissances sur la population du homard, sur les problèmes de la sélectivité des engins de pêche, sur les mesures d'effort pour chaque pêche de homard, sur les études faites en bateaux de recherche, et sur les méthodes de reportage des statistiques. On a aussi discuté la possibilité de définir les unités d'administration et le problème de la prédiction du recrutement. Finalement, une assemblée générale a fourni l'occasion de considérer le plan de gestion de l'Etat-Fédéral des Etats-Unis avec l'expérience acquise sur les recherches du homard et leur administration au Canada et en Europe.

THE DETERMINATION OF GROWTH RATES FOR AMERICAN LOBSTERS

by

H. J. Russell, Jr.

N.E. Fishery Management Council
1 Newbury St.
Peabody, Massachusetts 01960

ABSTRACT

Russell, H. 1980. The determination of growth rates for American lobsters. Can. Tech. Rep. Fish. Aquat. Sci. 932.

The majority of recent work to determine growth rates among U.S. populations of American lobsters has been conducted by investigators associated with the Lobster Scientific Committee under the auspices of the State-Federal Fisheries Management Program.

This paper is a review of the methods employed by the Scientific Committee, the resulting estimates of the von Bertalanffy growth parameters for lobster populations from Maine to Virginia, and a brief discussion of some of the more serious problems associated with the derivation of such estimates.

INTRODUCTION

A basic assumption of the State-Federal Lobster Scientific Committee has been that the von Bertalanffy growth model, while inadequate to describe the details of the discontinuous growth pattern in lobsters, is, nevertheless, appropriate for the basic stock assessments needed for lobster management. Moreover, the von Bertalanffy model is particularly well integrated with other classical formulations such as the Beverton-Holt yield-per-recruit model and various production models.

A new model for lobster growth which might, for example, incorporate temperature and intermolt periods to generate a step function may be more satisfying but from the point of view of lobster management may not be as useful as the von Bertalanffy model.

The purpose of this paper is to review some of the more recent work by U.S. authors concerned with the determination of lobster growth rates. Its scope will be largely restricted to recent efforts by members of the Lobster Scientific Committee and should not be viewed as an exhaustive treatment of the subject.

METHODS USED FOR DETERMINATION OF GROWTH RATES

MINIMAL DATA AVAILABLILITY

The simplest procedure considered by the Lobster Scientific Committee requires a set of size-frequency data from either survey or commercial catches plus an estimate of L_∞. The latter might be represented by the largest lobster ever reported in the entire history of the fishery in the area of interest.

From a plot of the size-frequency data, modes may often be discerned particularly among the smaller and more numerous size ranges. The method requires two consecutive modal lengths among the smaller animals taken in the commercial fishery. Consecutive modal lengths within this size range are assumed to represent mean lengths of consecutively aged lobsters. These data may then be applied to the relation:

$$e^{-K} = \frac{L_\infty - l_{t+1}}{L_\infty - l_t}$$

thus, $K = -\log_e (e^{-K})$.

To estimate the age at zero length, t_0, the age, t, of the lobsters at one of the given modal lengths must be known or assumed,

then: $$t_0 = t + \frac{1}{K} \log_e \left(1 - \frac{l_t}{L_\infty}\right).$$

ANALYSIS OF SIZE-FREQUENCY DATA

Using the procedures outlined by Cassie (1954) for partitioning polymodal frequency distributions with the use of probability graph paper, several investigators have applied lobster size-frequency data with varying degrees of success. Thomas (1973) found that the procedure yielded mode means which were in apparent agreement with measured molt data. Whether they may also be considered size at consecutive ages is a dilemma he was not able to resolve.

Working with lobsters in Plymouth, Massachusetts waters, Fair (1976) was unable to develop reproducible estimates of growth parameters, using the Cassie (1954) method.

Russell and Borden (1975) and Russell et al. (1978) successfully used the procedure for separating molt groups between both inshore and offshore populations of lobsters off Rhode Island but only with the aid of measured molt data for interpretation of the results. They hypothesized that in the defined area, relatively discrete, twice-yearly molting periods produced their respective mode means which were detected by the graphical procedure. Observed molt data were consistent with the assumption that alternate mode means from the length-frequency analyses represented size at consecutive molts and that molts occurred once annually among the majority of inshore lobsters in the size range 70-90 mm. Halgren (1976) was also able to use the procedure for estimation of size at consecutive molts for lobsters in the waters off New Jersey.

A persistent weakness of the method by Cassie (1954) as applied to lobster length-frequency data is the difficulty in obtaining reproducible results from the efforts of different scientists working on the same set of data. It seems apparent that the procedure has the greatest utility in areas where growth rates are relatively high and where measured molt data are available as supportive evidence. In western Long Island Sound, for example, where growth rates are apparently relatively slow, inadequate separation of mode means appears to invalidate the procedure.

Once a set of mean size data at consecutive molts has been obtained, two alternate procedures have been followed by workers associated with the Lobster Scientific Committee. These include a method developed by Ricker (1975) involving the use of Ford-Walford plots and a least squares procedure described by Tomlinson and Abramson (1961). The former procedure has been used extensively by Lobster Scientific Committee members (Fair 1976; Halgren 1976; Harris and Van Engel 1978; Krouse 1977) but a general criticism of the method is its extreme sensitivity to the estimates of lengths-at-age in the determination of the catabolic growth coefficient, K, particularly in the case of heavily exploited lobster fisheries where no more than four or five year-classes may be represented.

It should be noted as a caveat that the assumption that consecutive molt groups represent consecutive year-classes should not be applied indiscriminately. Insofar as only intermediate-sized lobsters are treated in the analysis, the risks associated with molting intervals of less than or greater than 1 yr may be minimized. Thus, slopes of greater than one in a Ford-Walford plot may indicate that the assumption has been violated. In such cases, neither procedure will yield valid estimates of the von Bertalanffy growth parameters. Fair (1976) was unable to use length-frequency data from catches of Plymouth lobsters for this reason, thus was forced to rely entirely upon measured molt data.

A useful aspect of the procedure by Tomlinson and Abramson (1961) is that confidence limits on the estimates of growth parameters may be readily

derived thus facilitating comparisons between areas.

ANALYSIS OF MOLT DATA

Directly measured molt data resulting from tagging studies have typically been analyzed by the Ricker (1975) method (Fair 1976; Harris and Van Engel 1978; Krouse 1977).

Most tagging studies, for reasons of lobster availability, concentrate their activity on animals at or near the minimum size limit in the commercial fishery. Premolt-postmolt carapace length data are particularly amenable to the Ford-Walford plot, but the lack of an adequate number of different age groups has typically precluded application of other procedures such as that by Tomlinson and Abramson (1961). With the consequent lack of a replicate procedure, considerable data are necessary to develop estimates of the growth parameters which may be viewed with confidence.

ESTIMATES OF GROWTH PARAMETERS FOR U.S. LOBSTERS

Estimates of the von Bertalanffy growth parameters for inshore and offshore populations of U.S. lobsters are summarized in Tables 1 and 2, respectively, as given by authors as cited. The methods by which these estimates were derived are again indicated as were previously discussed. The preliminary estimates for western Long Island Sound were derived by this author using the minimal data availability method applied to data supplied in a personal communication from P. Briggs.

The envelope of the eight different growth curves for inshore lobsters, seen in Fig. 1, suggests that relatively minor differences may exist between the growth patterns of U.S. lobster populations. Growth curves 1 and 2, both from Maine lobsters (Thomas 1973; Krouse 1977), nearly encompass the boundaries of the entire envelope. The preliminary growth curve for western Long Island Sound lobsters (curve 7) appears to reflect the existing growth pattern (pers. comm., P. Briggs).

Despite the apparent uniformity in the resultant growth curves for inshore populations there appear to be subtle differences in the growth rates as expressed by the catabolic growth coefficient, K, and the asymptotic length, L_∞. Figures 2 and 3 indicate that there may exist a north-south gradient in the value of these parameters with the largest and most rapidly growing lobsters in the inshore Gulf of Maine populations. An attempt has been made here to illustrate the statistical variability of these growth parameters by applying uniformly the 95% confidence limits calculated by Thomas (1973) (see Table 1). Thus there may be statistically significant differences in the value of the coefficient, K, between widely separated populations but it is doubtful whether such differences are demonstrable among the values for L_∞.

It is difficult to make similar generalizations regarding the U.S. offshore lobster populations owing to the limited number of studies which have been made. It is apparent, however, from the available estimates appearing in Table 2 that values for L_∞ are substantially larger than those for most of the inshore populations, particularly for those south of Cape Cod.

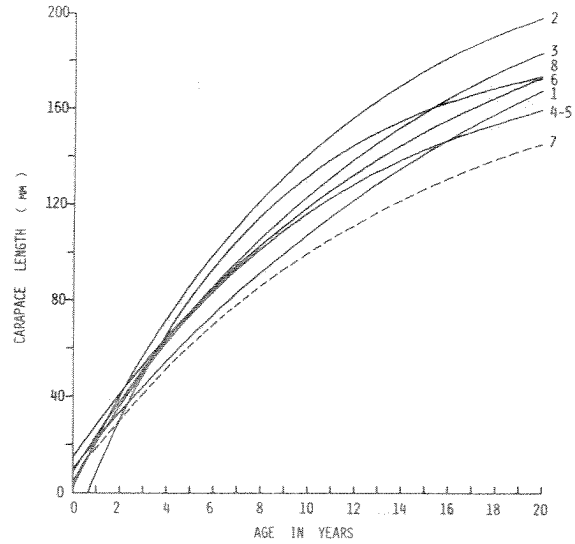


Fig. 1. The envelope of growth curves for inshore populations of U.S. American lobsters. Curves are numbered to conform to Table 1. Curves 4 and 5 are shown as a single line because of their similarity and to preserve clarity.

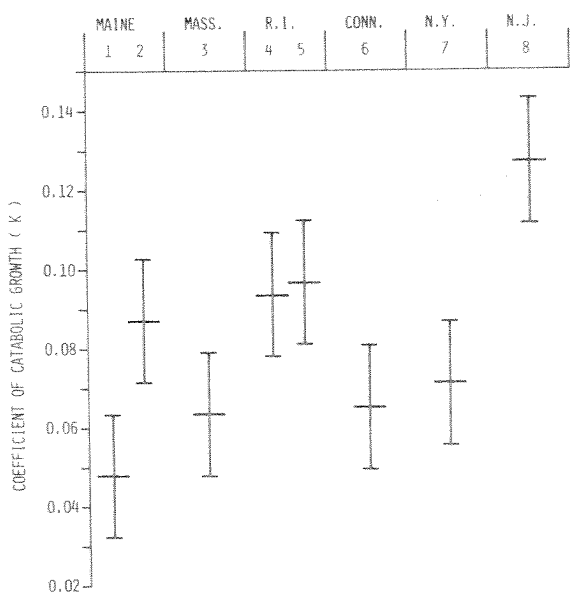


Fig. 2. The catabolic growth coefficients for inshore populations of U.S. American lobsters. Population number corresponds to those given in Table 1. Brackets indicate approximate 95% confidence limits (see text).

Table 1. Von Bertalanffy growth parameters for American lobsters, inshore waters.

Investigator (equation no.)	K	L_∞	t_0	Method[a]
Maine				
1. Thomas (1973)	0.04785 ±0.01566	266.77 ±59.04	-0.77250 ±0.43685	(1)
2. Krouse (1977)	0.087	241	-0.096	(2)
Massachusetts				
3. Fair (1976)	0.0634	253	-0.5485	(2)
Rhode Island				
Russell et al. (1978)				
4. Males	0.09361	189.55	-0.29012	(1)
5. Females	0.09664	184.59	-0.19756	(1)
Connecticut				
6. Smith (1977)	0.065	233	-0.98	
New York-W.L.I.S.				
7. Preliminary (Briggs' data)	0.071	190	-0.427	(2)
New Jersey				
8. Halgren (1976)	0.127	190	+0.653	(3)

[a]Methods of analysis:

(1) Polymodal analysis of length-frequency data (Cassie 1954) and application of the derived mode means to the method by Tomlinson and Abramson (1961).
(2) Application of molt data from tagging studies to the Ford-Walford analysis.
(3) Polymodal analysis of length-frequency data (Cassie 1954) and application of the Ford-Walford analysis.

Unless otherwise indicated, data are for sexes combined.

Table 2. Von Bertalanffy growth parameters for American lobsters, Continental Shelf - slope waters.

Investigator	K	L_∞	t_0	Method[a]
Southern New England				
Uzmann et al. (1977)				
Males	0.115	253	-0.140	b
Females	0.080	230	-0.360	b
Russell and Borden (1975)				
Males	0.081	281	+0.179	(1)
Females	0.071	240	-0.134	(1)
Virginia				
Van Engel and Harris (1978)	0.087	287	-0.30	(2)

[a]Methods of analysis are coded as indicated for inshore waters investigations.
[b]Molt data from tagging studies as interpreted by relation between initial carapace length and time at large.
See footnotes, Table 1.

Unless otherwise indicated, data are for sexes combined.

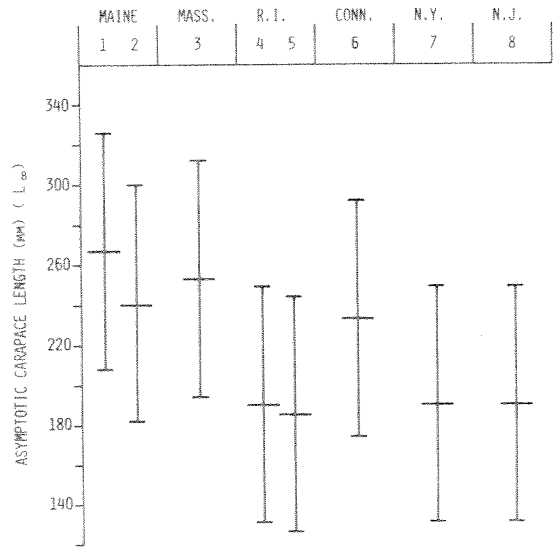


Fig. 3. The asymptotic carapace length for inshore populations of U.S. American lobsters. Population number corresponds to those given in Table 1. Brackets indicate approximate 95% confidence limits (see text).

MAJOR PROBLEMS ASSOCIATED WITH DEVELOPMENT OF GROWTH EQUATIONS

One of the major problems confronting lobster biologists encountered most directly when interpreting molt increment data is to define the intermolt period in terms of the premolt carapace length for specified areas. Given such a relationship, raw data may be adjusted and fitted to a Ford-Walford plot. Usually the number of observations have been insufficient to develop even an empirical relationship. Consequently, the usual approach has been to assume, *a priori*, an intermolt period of 1 yr. The risks associated with such an approach, even when only a restricted size range is considered, are obvious. Moreover, such a discriminatory process is self defeating since only a very short segment of the total growth curve is thereby examined.

Finally, the major problem confronting lobster biologists may be the question of aging. The Lobster Scientific Committee has not directly attacked the problem. In developing growth equations for lobsters, the approach has been to assume ages that provide some "reasonable" value to the age at zero length, t_0, leading to an evaluation of the age at entry to the fishery consistent with similar estimates by co-workers in adjacent areas. The risks associated with this approach are obvious but probably unavoidable until an independent method of aging is developed.

REFERENCES

Cassie, R. M. 1954. Some uses of probability paper in the analysis of size frequency distributions. Aust. J. Mar. Freshw. Res. 5: 513-522.

Fair, J. J., Jr. 1976. Lobster investigations in management area 1: southern Gulf of Maine. Prog. Rep. No. 4, Mass. Div. Mar. Fish. Contract No. 03-5-043-328. NOAA, NMFS.

Halgren, B. A. 1976. Management of the lobster, *Homarus americanus*, resource of the continental shelf, canyons and slope of the northern portion of lobster management Area IV. Prog. Rep. for period 10/1/75- 12/31/75, New Jersey. Contract No. 03-4-043-359. NOAA, NMFS.

Harris, R. E., and W. A. Van Engel. 1978. Biology and management of the American lobster. Prog. Rep. for the period 7/1/77-12/31/77. VIMS. Contract No. 03-4-043-353. NOAA, NMFS.

Krouse, J. S. 1977. Lobster tagging project. Completion Report. Maine Dept. Mar. Res. 88-309 Project #3-228-R. NOAA, NMFS.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191, 382 p.

Russell, H. J., Jr., and D. V. D. Borden. 1975. Management studies of inshore lobster resources. Prog. Rep. 5. Rhode Island Div. Fish Wildl. Contract No. 03-4-043-360. NOAA, NMFS.

Russell, H. J., Jr., D. V. D. Borden, and M. J. Fogarty. 1978. Management studies of lobster resources. Completion Report. Rhode Island Div. Fish Wildl. Contract No. 03-4-043-360. NOAA, NMFS.

Smith, E. M. 1977. Some aspects of catch/effort, biology, and the economics of the Long Island Sound lobster fishery during 1976. Completion Report. NOAA, NMFS Comm. Fish. Res. Dev. Act Project #3-253-R-1. State of Connecticut, Dept. Environ. Protect.

Thomas, J. C. 1973. An analysis of the commercial lobster (*Homarus americanus*) fishery along the coast of Maine, August 1966 through December 1970. NOAA Tech. Rep. NMFS SSRF-667.

Tomlinson, P. K., and N. J. Abramson. 1961. Fitting a von Bertalanffy growth curve by least squares. Calif. Dept. Fish and Game, Fish. Bull. 116, 69 p.

Uzmann, J. R., R. A. Cooper, and K. J. Pecci. 1977. Migration and dispersion of tagged American lobsters, *Homarus americanus*, on the southern New England continental shelf. U.S. Dept. Com. NOAA Tech. Rep. NMFS SSRF-705.

RECENT AND CURRENT CANADIAN RESEARCH ON GROWTH OF LOBSTERS IN THE WILD

by

G. P. Ennis

Department of Fisheries and Oceans
Research and Resource Services
P.O. Box 5667
St. John's, Newfoundland A1C 5X1

ABSTRACT

Ennis, G. P. 1980. Recent and current Canadian research on growth of lobsters in the wild. Can. Tech. Rep. Fish. Aquat. Sci. 932.

In recent years Canadian work on the growth of lobsters in the wild has included probability paper analysis of length frequency distributions to provide estimates of the number of age groups over a particular size range and the mean length at successive ages. In addition, molt increment data are being obtained using "sphyrion" or similar tags and estimates of molt frequency or proportion molting are being obtained by means of molt stage and shell condition determination throughout or following the molting period. Data on size at tagging, size at recapture, and time at large have also been used to estimate the parameters of the von Bertalanffy growth equation following the method of Fabens (1965).

INTRODUCTION

Canadian researchers are pursuing a number of approaches towards estimating growth rates in lobster populations. These include the use of the probability paper method of Cassie (1954) to analyze length frequency distributions, the combination of molt increment and proportions molting (or molt frequency) data, and the use of tag-recapture data to estimate von Bertalanffy parameters by the method of Fabens (1965). This paper provides a brief review of this work.

ANALYSIS OF LENGTH FREQUENCIES

Length frequencies from a diver-caught sample of 677 lobsters ranging from 7 to 80 mm carapace length obtained during winter months (i.e. between molting periods) in Placentia Bay, Newfoundland, were analyzed by the method described by Cassie (1954). The analysis indicated six age groups for males and eight for females over this size range (Ennis, unpubl. data). Despite the subjectivity associated with the method, the estimates of mean length-at-age coincide reasonably well in many instances with peaks in the length frequency distributions (Fig. 1). A mean carapace length of 61 mm was estimated at age six for males and age seven for females. Cooper and Uzmann (1977) reported ages three for males and four for females at 60 mm carapace length for a population of U.S. offshore lobsters. They concluded that U.S. inshore populations grew more slowly than offshore populations. By comparison, the above estimates would appear reasonable for a northern population.

The Cassie method appears to have worked reasonably well in this instance; however, in view of the conclusions reached by Caddy (1977) with regard to the probability of lobster size frequency modes representing age groups, one should use the results of such analyses very cautiously.

COMBINING MOLT INCREMENT AND PROPORTIONS MOLTING

The sphyrion tag has been used in Newfoundland lobster investigations to obtain molt increment data since 1968. Recent studies in the Maritimes, however, have used a Floy T (anchor) tag which is inserted in the same position and functions in a manner similar to the sphyrion tag (Robinson, pers. comm.). Analysis of these data is normally by a linear regression of premolt and postmolt carapace lengths (Ennis 1978). Mauchline (1976) is very critical of this so-called Hiatt growth diagram. He argues that, for crustaceans, premolt and postmolt lengths are better fitted by a hyperbola than a straight line. The data of Fig. 2 (Ennis 1978), however, did not fit a hyperbola, possibly because the range of premolt lengths considered (50-106 mm) was too restricted.

Estimates of proportions molting are being obtained in Newfoundland investigations by means of shell condition sampling following the molting period (Ennis 1977). Such sampling is felt to be quite reliable in an area such as Newfoundland where the molting season is relatively short and no lobsters larger than 60 mm molt more than once annually. In analyzing these data the premolt length of each new-shelled lobster is calculated using the premolt-postmolt regression equation. Numbers examined and numbers molted at each 1-mm carapace length interval are then subjected to probit analysis (Ennis 1978) (Fig. 3).

In Maritime areas, particularly the southern Gulf, the molting season is quite protracted and many animals molt twice annually. Here, shell condition sampling is being carried out throughout the molting season. The molt stage of old-shelled lobsters is being determined by the pleopod method described by Aiken (1973) and, by compiling the data, it is intended to provide estimates of proportions molting by size (Robinson, pers. comm.).

Caddy (1977) suggested that estimates of the frequency of occurrence of post-ecdysial lobsters (determined by the Aiken method) as a function of size in a catch sample, as well as the percentage of berried females as a function of size, may provide indirect estimates of molt frequency.

A growth curve can be obtained by combining molt increment and proportions molting data by first assigning an arbitrary or estimated age to the smallest carapace length for which these data are available and adding to this the product of the molt increment and proportion molting for that size to obtain the next length-at-age. Subsequent lengths-at-age are obtained in the same manner (Fig. 4).

TAG-RECAPTURE DATA

Data on size at tagging, size at recapture, and time at large from one of the sphyrion tagging studies in Newfoundland were run on a slightly modified version of the Fabens (1965) computer program. The following von Bertalanffy equations resulted:

$$l_t = 104.9\ [1-e^{-0.3896(t-0.7964)}] \quad \text{for males, and}$$

$$l_t = 111.6\ [1-e^{-0.2396(t-0.6894)}] \quad \text{for females.}$$

These equations give estimates of 61 mm at age three for males and age four for females compared to ages six and seven from the probability paper analyses of the size frequencies obtained from the same study area. The curves from these equations indicate faster growth and a larger asymptotic length than indicated by the curves produced by combining molt increment and proportion molting (Fig. 5). However, if age is ignored and one set of curves is superimposed on the other, there is very close agreement over the 60-95 mm length range. In fact, over this size range there is no difference in annual growth between the two sets of curves (P = 1.0 for both sexes).

At the author's request, a colleague, R. K. Misra, has examined the Fabens' program. His opinion is that the program is quite simplistic and lacks statistical input. He is in the process of writing a much more sophisticated and statistically oriented program to analyze these data according to the same equation that Fabens derived from the usual form of the von Bertalanffy equations. The intention is to assess the usefulness of this approach in the study of lobster growth.

REFERENCES

Aiken, D. E. 1973. Preecdysis, setal development and moult prediction in the American lobster (*Homarus americanus*). J. Fish. Res. Board Can. 30: 1337-1344.

Caddy, J. F. 1977. Models of growth in the American lobster, *Homarus americanus*, and approaches to a simplified yield model. Fish. Mar. Serv. MS Rep. 1445, 14 p.

Cassie, R. M. 1954. Some uses of probability paper in the analysis of size frequency distributions. Aust. J. Mar. Freshw. Res. 5: 513-522.

Cooper, R. A., and J. R. Uzmann. 1977. *In* Workshop on lobster and rock lobster ecology and physiology. CSIRO, Div. of Fish and Oceanogr. Circ. No. 7: 187-208.

Ennis, G. P. 1977. Determination of shell condition in lobsters (*Homarus americanus*) by means of external macroscopic examination. Proc. Nat. Shellfish. Assoc. 67: 67-90.

MS 1978. Growth curves for Newfoundland lobsters from data on molt increment and proportion molting. Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) Res. Doc. 78/29, 11 p.

Fabens, A. J. 1965. Properties and fitting of the von Bertalanffy growth curve. Growth 29: 265-289.

Mauchline, J. 1976. The Hiatt growth diagram for Crustacea. Mar. Biol. 35: 79-84.

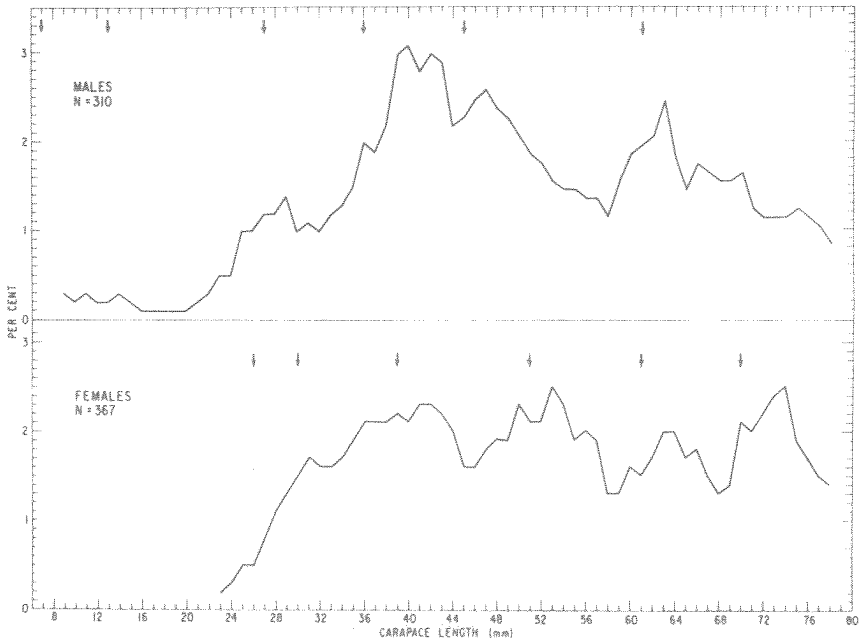


Fig. 1. Size frequency distributions with a moving average of 5 for sub-commercial lobsters (<81 mm) collected by diving in Placentia Bay, Newfoundland. Arrows indicate mean sizes of successive age-groups as determined by the probability paper analysis.

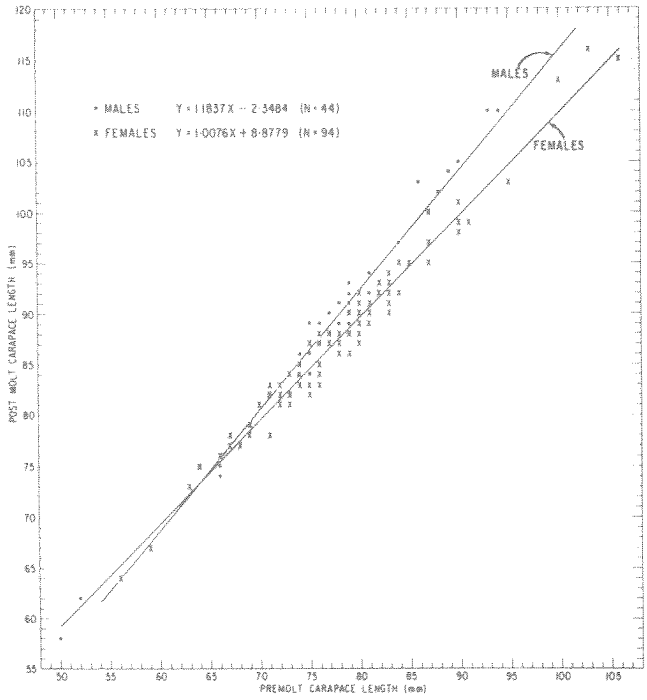


Fig. 2. Premolt-postmolt regression lines for sphyrion tagged lobsters in Placentia Bay, Newfoundland.

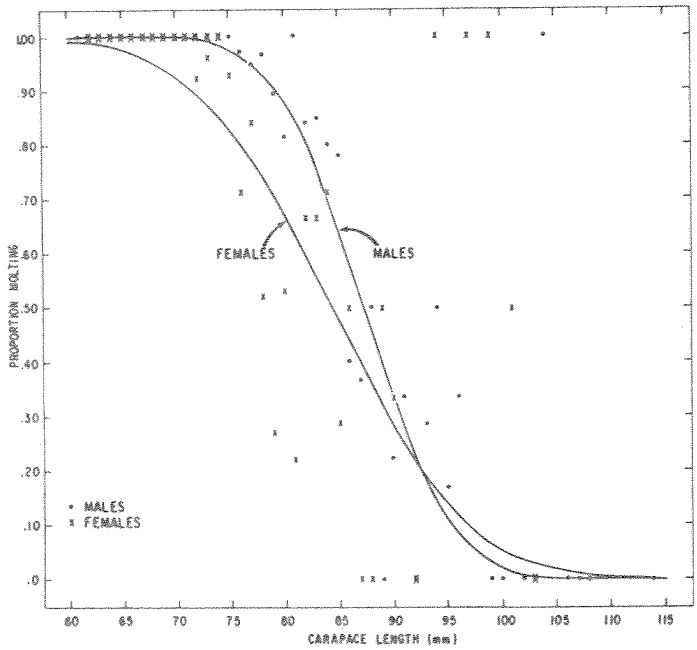


Fig. 3. Proportions molting based on shell condition sampling following the 1975 molting period in Placentia Bay, Newfoundland.

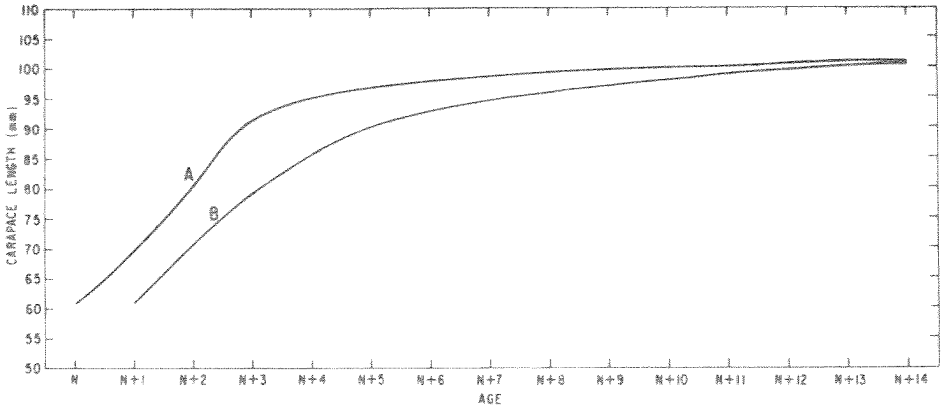


Fig. 4. Growth curves based on the combination of molt increment and proportion molting data presented in Fig. 2 and 3 (A-males, B-females).

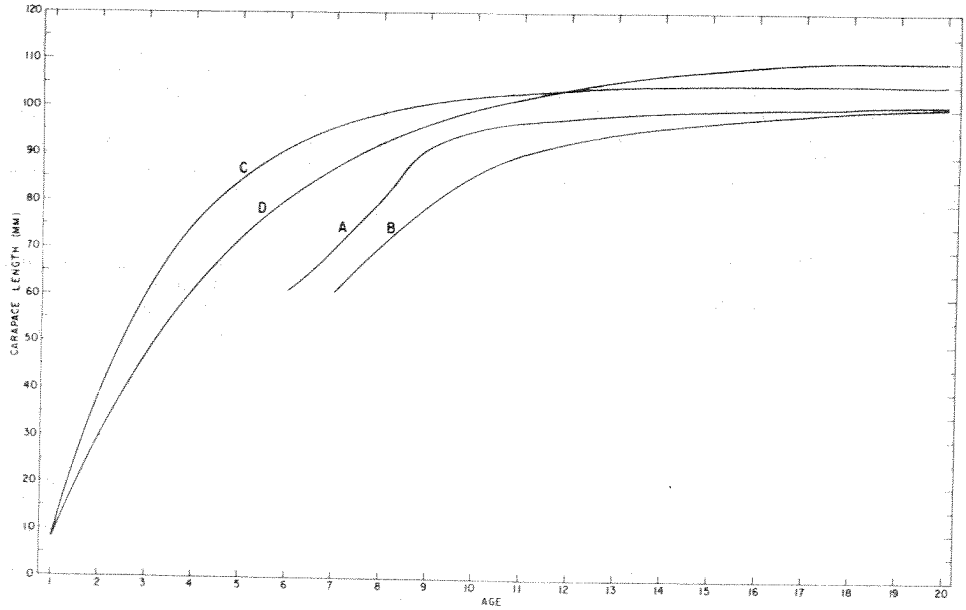


Fig. 5. Growth curves based on the combination of molt increment and proportion molting (Fig. 4) (A-males, B-females) and on the von Bertalanffy parameters (C-males, D-females) estimated from tag-recapture data by the Fabens' (1965) program.

GROWTH (E. Smith, rapporteur)

A consensus about the inapplicability of the Fabens' method in growth analyses gave way to a general discussion of the merits of tagging vs. modal analysis in estimating molt frequency and increment. Caddy suggested that the possibility of polymodalities within a "year-class" may be due to both variability in the frequency of molt during the first year and artificial modes created by the minimum legal size. Robinson suggested that modal analysis is impossible with an animal undergoing 16-18 growth increments, each with its attendant variability. Caddy suggested that perhaps artificial modes would most frequently arise with an intense seasonal, rather than a year-round fishery; however, phenomena such as the decline of molt frequency with onset of maturity should also be addressed.

Applicability of the von Bertalanffy growth equation was discussed with opinion generally divided. The consensus of the group was that it was an acceptable tool for preliminary yield-per-recruit analysis (e.g. assuming molt frequency is constant). Reliability of K and L_∞ was discussed with the observation expressed that extrapolation upwards from small commercial sizes may yield inappropriate values for L_∞. In many cases, L_∞ is known to be too low simply because individuals larger than that size are routinely observed in the commercial catch. Since molt frequency changes with time, estimates of L_∞ and K made from growth data showing one molt per year do not apply when the number of molts per year decreases. Since the method is particularly sensitive to the set of data to which it is applied, it was felt that extreme caution should be used in the interpretation of results. Robinson pointed out that we may be measuring growth of juveniles and extrapolating incorrectly to the adult size group which is relatively more intensively exploited in modern fisheries. The von Bertalanffy growth parameters were not felt to be precise enough for practical purposes beyond a limited size range, and the main value of the equation is that it facilitates use of the Beverton-Holt yield-per-recruit model. The concern was expressed that, once the von Bertalanffy parameters are derived and applied to yield equations, the growth parameters tend to become "set in stone" and the imprecision or assumptions on which they were derived tend to be forgotten.

Anthony suggested that frequency of molt and incremental growth data are some of the most important information obtained to date. He also suggested that the von Bertalanffy equation may not be too useful in long-term studies and perhaps should be replaced by some other method such as a probability or molt increment approach.

Susan Waddy observed that egg-laying cycles may be different for different groups of females which may bias growth determinations. Robinson supported this observation by his tagging results; however, Thomas expressed an opposite point of view in discussing the relative uniformity and dependability of seasonal egg-laying cycles along the Maine coast. Ensuing discussion emphasized that different areas quite probably have largely dissimilar maturity, fecundity, and growth cycles which would tend to suggest separate studies for dissimilar areas. These phenomena were discussed relative to what might induce them, i.e., either latitude or degree/days, or a combination of both.

REVIEW OF LOBSTER MORTALITY ESTIMATES IN THE UNITED STATES

by

V. C. Anthony

Maine Department of Marine Resources
Fisheries Research Laboratory
West Boothbay Harbor, Maine 04575

ABSTRACT

Anthony, V. C. 1980. Review of lobster mortality estimates in the United States. Can. Tech. Rep. Fish. Aquat. Sci. 932.

Total instantaneous mortality rates for Maine lobsters, calculated by several methods, averaged 2.2 for 1967-70. Two estimates of fishing mortality made in 1942-43 and 1946-47 indicated a sharp increase in fishing mortality from 0.87 to 1.77. A tagging study in Maine produced wide estimates of F although all were greater than 1.3. Estimates of total mortality from Maine, New Hampshire, Massachusetts, Rhode Island, New York, New Jersey, offshore waters of southern New England, and Virginia averaged 1.94. Fishing mortality rates in Massachusetts and Rhode Island averaged 2.0 for 1974-75. Fishing mortality estimates for offshore southern New England waters increased steadily from 1968 (0.07) to 1971 (0.67). Estimates of natural mortality were made in Maine, Massachusetts, and Rhode Island and averaged 0.15, ranging from 0.02 to 0.35. The M/K ratio for lobsters in the United States suggests M to be less than 0.15 if crustacean growth is similar to that of fish.

The purpose of this paper is to review the status of the mortality rates of lobsters within United States waters in recent years. Probably the greatest amount of work on lobster mortality rates in the U.S. has been done in the State of Maine under Jim Thomas (Thomas 1973). Tables 1 and 2 indicate the results of estimating mortality rates from a variety of methods. Under method 1, estimates of Z were made from the Robson-Chapman (1961) survival rate procedure. These estimates were made over year-classes within each year, assuming constant year-class strengths and that growth is constant over the ages concerned at 14% in length each year. The instantaneous estimates of Z per year average 2.49. Declines in catch per effort were used in methods 2 and 3 between years for each assumed year-class. The effort unit in method 2 is the trap-haul or the total number of traps hauled for the daily catch. In method 3 the effort unit is the trap-haul-set-over-day or the number of traps hauled for each day sampled multiplied by the number of days since the traps were last hauled. The catch-per-effort data for both methods were collected in May of each year. A maximum of four "ages" in each year were defined so that as many as three estimates of mortality were possible. These were averaged to provide the estimates of Z for each year. Method 4 assumes a steady state von Bertalanffy growth rate over a limited size range of the exploited population. Knowing the average length of lobsters in the catch and the length at entry to the exploited phase, Z can be estimated following the method of Beverton and Holt (1956). Method 5 is simply the decline in numbers within the catch for a single year with the age classes defined by 14% growth increments in length. The estimates of Z are then averaged over the assumed ages for each year. Method 1 in Table 2 assumes two different levels of fairly uniform fishing effort which have each produced a constant rate of fishing mortality (Silliman 1943). Then with two equations and two unknowns (M is assumed constant), the instantaneous fishing mortality rate (F) can be calculated for both time periods. Note that in these early years the estimates of F are somewhat less than in current years. Method 2 in Table 2 is from the analysis of a tagging study conducted by Maine's Department of Marine Resources in 1975. The range in F from the three tag releases is wide although the estimates of F are in agreement with the work done by Thomas.

The average level of Z in Table 1 is about 2.2. Fishing mortality is, therefore, very large even assuming a high value of natural mortality. If M is 0.2, the fishery removes 86% of the legal population each year. Only 1.2% of those reaching legal size survive to reach 4 in. carapace length, the size at which all lobsters are mature in Maine waters. The question logically arises, how is the population able to sustain itself with so few surviving to reproduce?

Table 3 shows estimates of mortality rates calculated for seven states and in the offshore waters south of Cape Cod. The calculation of mortality, for the most part, is based on known molt increments of 13, 14 or 15% in length and the assumptions that the lobsters are molting once and only once at that size. The rates, then, are calculated from simple declines in numbers from one size grouping to another. For any particular size group, several year-classes may be represented. This is true for all areas.

The mortality rates for the southern New England offshore areas were made from data collected in an offshore tagging program conducted in 1968-71 (Uzmann et al. 1977). The numbers tagged and recovered (at time of analysis) were:

Year	No. released	No. recovered	% recovery
1968	2,634	267	10.1
1969	3,076	417	13.6
1970	474	52	11.0
1971	1,142	127	11.1
Total	7,326	863	

Exploitation rates were determined for each release to the end of the calendar year for assumed natural instantaneous mortality rates (annual) of 0.05, 0.10, 0.15 and 0.20. The exploitation rates were then expressed as daily rates and F was estimated from an approximation of $F/Z\ (1-e^{-Z})$ by $Fe^{-Z/2}$ (Paloheimo 1961). Table 4 shows the accuracy of the approximation. For exploitation rates below 0.40 the error is less than 3%. Daily estimates of F were averaged over all releases for each year and then were expressed on an annual basis for each assumed level of M (Table 5). The estimates of F varied little due to variation in M. The average values of F were low in 1968-70 but increased markedly during 1971. This increase in F is substantiated by the stratified mean catch-per-tow data collected by the NMFS spring bottom trawl survey (Burns and Clark 1979 (Fig. 2)). Recent estimates of mortality are not available as the fishery catches fairly large lobsters which may be migrating into the offshore areas. The molt frequencies and molt increments are, therefore, not known with certainty and the traditional declines in catch per effort from one size group to another have not been applied to these lobsters to estimate mortality as was done for the inshore areas.

After 1972 the estimate of abundance continued to increase. The offshore trap fishery began in about 1969 and the number of traps fished increased steadily to 1973. The catch of lobsters by traps was only 52 metric tons (MT) in 1969 but the catch increased to 666 MT in 1970, 1,480 MT in 1971 and to 2,890 MT in 1972 (Table 6). The number of days fished by otter trawls for lobsters in the offshore area increased from 1967 to 1972 and then declined, reportedly due to a lack of lobsters on the flat bottom which was suitable for trawling. The catch of lobsters by otter trawls peaked in 1969-70 and then declined to 1973 (Table 6). These catch statistics all suggest an increase in fishing mortality rate to 1973 and 1974 at least, with a slight but continued decline in abundance of the offshore southern New England lobster population to 1978 as shown by the survey information (Burns and Clark 1979).

The total mortality in all fisheries, therefore, is probably around 2.0. The offshore mortality may be less but I doubt that it was less than 1.5 by 1978 due to the continued expansion in this fishery to areas as far east as Corsair Canyon and as far south as Norfolk Canyon.

There are few estimates of natural mortality rates of lobster in the U.S. Table 7 indicates the

estimates made by Thomas (1973). The methods used are the same as those for estimating total mortality except the lobsters are smaller than legal size so that the total mortality is equal to the natural mortality. The rates vary from 0.02 to 0.35 and average 0.15.

Estimates of M are also available from the tagging studies done in Massachusetts and Rhode Island (Table 3). The total mortality rate was estimated from 15% growth increments and probability mode analysis while the fishing mortality rates were estimated independently from tagging studies. Subtracting estimates of F from Z in Table 3 provides preliminary estimates of M of 0.26 for Massachusetts and 0.07 for Rhode Island. Additional tag returns through 1978 have produced better estimates of M for both Massachusetts and Rhode Island that are about 0.15 (pers. comm. J. Fair, Massachusetts; M. Fogarty, Rhode Island).

An examination of M/K ratios provides an additional idea of the level of M. K is the catabolic coefficient in the von Bertalanffy growth equation. Table 8 gives M/K ratios for several groups of fish from Beverton and Holt (1959). Except for gadiforms the M/K ratios range from 1.0-1.6. An average of the ten K values calculated from Virginia to Maine is 0.094. If the M/K ratios for lobsters were assumed to be 1.0 and 1.6, the estimates of M would be 0.094 and 0.15 respectively. If M were as large as 0.2 and 0.3 the M/K ratios would be 2.13 and 3.19 respectively. To conform with the M/K ratios of the fish groups in Table 8, M, therefore, must be less than 0.2 and probably less than 0.15. Of course, there is no rule that crustacean growth or the M/K ratio must be similar to those of fish. The von Bertalanffy growth curve is also only a very rough approximation of lobster growth over a limited portion of its entire life span.

In summary, the total mortality rate for lobsters throughout the northeastern U.S. is 2.0 or greater. Mortality rates in the offshore waters may be less than 2.0 but probably not substantially so. The question persists: where does recruitment come from with Z so large for immature lobsters in so many areas? The level of M appears to be less than 0.2 and probably less than 0.15.

REFERENCES

Beverton, R. J. H., and S. J. Holt. 1956. A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. Rapp. Cons. Explor. Mer 140: 67-83.

1959. A review of the lifespan and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. *In* Ciba Foundation colloquia on aging. G. E. W. Wolstenholme and M. O'Connor (eds.). Vol. 5, The lifespan of animals. p. 142-180.

Burns, T., and S. H. Clark. 1980. Application of U.S. bottom trawl survey and commercial data to offshore lobster assessments. Can. Tech. Rep. Fish. Aquat. Sci. 932, 186 p.

Krouse, J. S. 1979. Movement, growth and mortality of American lobsters (*Homarus americanus*) tagged along the coast of Maine. Fish. Bull. U.S. (in press).

Paloheimo, J. E. 1961. Studies on estimation of mortalities. I. Comparison of a method described by Beverton and Holt and a new linear formula. J. Fish. Res. Board Can. 18: 645-662.

Robson, D. S., and D. G. Chapman. 1961. Catch curves and mortality rates. Trans. Am. Fish. Soc. 90: 181-189.

Silliman, R. P. 1943. Studies on the Pacific pilchard or sardine (*Sardinops caerulea*). 5. A method of computing mortalities and replacements. U.S. Fish Wildl. Serv. Spec. Sci. Rep. 24, 10 p.

Thomas, J. C. 1973. An analysis of the commercial lobster (*Homarus americanus*) fishery along the coast of Maine, August 1966 through December 1970. U.S. Dept. Com., NOAA Tech. Rep. NMFS SSRF-667, 57 p.

Uzmann, J., R. Cooper, and K. Pecci. 1977. Migrations and dispersion of tagged American lobsters, *Homarus americanus*, on the southern New England continental shelf. NOAA Tech. Rep., NMFS, SSRF-705, 92 p., Wash., D.C.

Table 1. Estimates of total instantaneous mortality rate (Z) for Maine lobsters (Thomas 1973).

	Method of analysis	Year 1967	1968	1969	1970
1	Robson-Chapman Survival within years - rate age defined by 14% growth increments.	2.30	2.45	2.55	2.65
2	Declines in catch per trap-haul between years, - age defined by 14% growth increments.	2.17	1.26	1.94	
3	Declines in catch per trap-haul-set-over-day, - age defined by probability modes.	2.85	2.87	2.90	
4	Steady state von Bertalanffy growth.	2.20	2.31	2.20	1.50
5	Decline in catch within years (simple catch curve) - age defined by 14% growth increments.	1.95	2.09	1.98	1.88

Table 2. Estimates of instantaneous fishing mortality rates (F) by Maine lobstermen (Thomas 1973).

Method of analysis		
1	Silliman (1943)	Years 1942-43 - .87 Years 1946-47 - 1.77
2	Tagging (Krouse 1979)	Year 1975 - 1.3-3.4

Table 3. Instantaneous mortality rates of the American lobster.

Area	Years	Sex	Coefficient of mortality total (Z)	Coefficient of mortality fishing (F)	Comments
Inshore					
Maine	1949-53	Sexes combined	1.92		(Z) estimated from length-frequency analysis on basis of 14% annual growth increments.
	1967-70	Sexes combined	2.20		
New Hampshire	1972-74	Sexes combined	1.98		(Z) estimated from length-frequency analysis on basis of 13% annual growth increment from tagging studies.
Massachusetts	1974	Sexes combined	1.99		(Z) estimated from length-frequency analysis on basis of 15% annual growth increment from tagging studies. Estimates of (F) are preliminary from tagging studies in progress.
	1975	Sexes combined	2.29	2.03	
Rhode Island	1974-75	Sexes combined	2.05	1.98	(Z) estimated from length-frequency analysis on basis of growth equation from tagging and probability mode analysis. Preliminary estimate of (F).
New York	1975	Male	1.94		Length-frequency (Long Island Sound) analysis on basis of assumed 14% annual growth increment.
	1975	Female	2.80		
New Jersey	1975	Sexes combined	1.63		Length-frequency analysis on basis of assumed 14% annual growth increment.
Offshore					
S. New England	1968	Sexes combined		0.07	Hudson Canyon North; analysis of tag return data.
	1969	Sexes combined		0.14	
	1970	Sexes combined		0.17	
	1971	Sexes combined		0.67	
Virginia	1974-75	Male	1.50		Baltimore Canyon South; analysis of length-frequency data on basis of growth equation for northern offshore area.
	1974-75	Female	0.91		
Average overall			1.94		

Table 4. A comparison of the true exploitation rate with $Fe^{-Z/2}$ (M = 0.20).

F	$Fe^{-Z/2}$	Exploitation rate
.1	.0861	.0864
.2	.1637	.1648
.3	.2336	.2361
.4	.2963	.3008
.5	.3523	.3596
.6	.4022	.4130
.7	.4463	.4616
.8	.4852	.5057
.9	.5193	.5458
1.0	.5488	.5823
1.1	.5743	.6156
1.2	.5959	.6458
1.3	.6141	.6733
1.4	.6291	.6983
1.5	.6411	.7212

Table 5. Estimates of F in the offshore lobster fishery.

Year	M				Average
	.05	.10	.15	.20	
1968	.066	.067	.067	.069	.067
1969	.141	.143	.143	.143	.143
1970	.169	.173	.173	.178	.173
1971	.711	.690	.669	.642	.678

Table 3. Ranges of total annual mortality rates for the southern Gulf and eastern Nova Scotia during the 1977 fishing season from commercial port samples. Total mortality rate is interpreted as percentage of catch within 1 yr of growth above legal minimum size (Robinson, pers. comm.). Percentages given are within one molt of legal size except where shown.

Description of area	Legal minimum size CL (mm)	Annual molt into legal size (%)	Instantaneous total annual mortality (Z)
Western Northumberland Strait, fall fishery, landings and effort stable	63.5	95.8-99.5	3.2-5.3
Central Northumberland Strait, fall fishery, recruitment failure with effort reduced	63.5	74.8-98.2	1.4-4.0
Eastern Northumberland Strait, spring fishery, recruitment declining	63.5	51.6-71.6[a]	0.7-1.3
North Shore P.E.I, spring fishery, landings and effort stable	63.5	79.9-92.3	1.6-2.6
North Cape Breton Island, spring fishery, landings and effort stable	69.8	64.2-85.9	1.0-2.0
Southeastern shore of Nova Scotia, recruitment failure with effort much reduced	81.0	39.1-59.9	0.5-0.9

[a]Substantial numbers molt more than once a year in this area.

COMMERCIAL LEGAL LOBSTERS

Newfoundland

Ennis (in press) used the commercial catch portion of the catch/effort and tag recapture data in a localized area to determine population size and exploitation rate with the Petersen method (Table 2). With two years' data he extended this method to estimate total and natural mortalities of males to be 88% and 2.2%, respectively. This method was probably reliable because lobster catchability and tag returns were high, although the limits of accuracy were unknown. Tag loss was determined to be about 4% using secondary tail punch marks. It was important to collect all tags recaptured by keeping in close contact with the fishermen during the fishing season and to obtain records of the total catch of at least one reliable fisherman. There appeared to be no tag loss due to emigration of lobsters from the study area which indicated the existence of a discrete localized fishery.

Rates of exploitation ranging from 52 to 91% have been calculated for the 1978 fishing season by Ennis (pers. comm.) for a number of areas around Newfoundland (Table 2). There seems to be a direct relationship between high stock abundance and high exploitation rates. Fishing conditions are largely determined by factors such as the degree of exposure to winds and seasonal temperatures (Ennis pers. comm).

Southern Gulf and eastern Nova Scotia

Paloheimo (1963) related tag catch-effort data to temperature in an attempt to determine catchability coefficients, population size, and rates of exploitation. He found that rates of exploitation ranged from 44-83% and could vary from one area to another and from year to year in the same area (Table 2).

Robinson (pers. comm.) calculated instantaneous total mortality rates (Z) (using the first annual molt into legal size) for selected ports throughout the southern Gulf and eastern Nova Scotia during the 1977 fishing season (Table 3). Values of Z ranged from 3.2-5.3 (A = 65-99%) in areas of high recruitment and fishing intensity (Table 3). In areas along eastern Nova Scotia (Lobster Districts 5, 7, 6b), Z values ranged from 0.5-0.9 (A = 39-60%), indicating a reduction in current fishing effort and recruitment after these lobster stocks declined in recent years.

Southwestern Nova Scotia

The instantaneous total annual mortality coefficient estimates (Z') ranged from 1.280-2.504 (A' = 72.2-91.8%) in S.W. Nova Scotia and Grand Manan during the 1940-50's (Table 4). The true instantaneous annual mortality coefficients (Z) were not estimated because the data on the intermolt periods (Δt_m) for each area and year were not available. During 1977-78, Z' values remained high at about 1.3 (A' = 73%) in Port Maitland and Seal Cove (Grand Manan). Along the south shore of Nova Scotia and in Lobster Bay Z' values have declined to 0.55-1.04 (Table 4). The low Z' values reflect poor recruitment of lobsters into legal size around the south shore; fishing effort has tended to remain high although the total weight of lobsters landed declined dramatically (Can. Fish. Statistics).

Analysis of tag-catch-effort data from Port Maitland during 1944-69 indicated a mean rate of exploitation (μ) of 41.96% (range 21.8-59.96%) (see also Table 2 for Paloheimo (1963) calculations of μ). The mean total mortality coefficient Z' estimated from annual catch curves was 1.616 (range 1.11-2.28) (A' = 80.1%, range 66.9-89.8%). During the 1960-61 fishing season at Port Maitland the mean intermolt duration for the 81-92 mm CL molt group (Δt_m) was estimated from tagged lobster growth data to be 1.322; therefore the actual values were Z = 1.40, A = 75.34%.

ACKNOWLEDGMENTS

I thank Messrs. D. Duggan, D. E. Graham, S. Bellis, Misses D. Martin and D. Hebert for technical assistance with data collection and summarizations; Dr. R. W. Elner and Mr. S. Labonté for critically reviewing the manuscript.

REFERENCES

Beverton, R. J. H., and S. J. Holt. 1956. A review of methods for estimating mortality rates in fish populations, with special reference to source of bias in catch sampling. Rapp. Cons. Explor. Mer 140: 67-83.

1957. On the dynamics of exploited fish populations. U.K. Min. Agr. and Fish., Fish. Invest. Ser. 2, 19, 533 p.

Caddy, J. F. 1977. Approaches to a simplified yield-per-recruit model for Crustacea, with particular reference to the American lobster, *Homarus americanus*. Fish. Mar. Serv. MS Rep. No. 1445, 14 p.

Elner, R. W., and G. S. Jamieson. 1979. Predation of sea scallops, *Placopecten magellanicus*, by the rock crab, *Cancer irroratus*, and the American lobster, *Homarus americanus*. J. Fish. Res. Board Can. 36: 537-543.

Ennis, G. P. Estimates of abundance and recruitment to the standing stock for a Newfoundland population of the lobster *Homarus americanus* with a method of estimating its natural mortality. *In* H. J. Thomas (ed.) Population Assessments of Shellfish Stocks. Rapports et Procès-Verbaux 175 (in press).

MS 1978. Growth curves for Newfoundland lobsters from data on molt increment and proportion molting. CAFSAC Res. Doc. 78/29, 11 p.

Gulland, J. A. 1969. Manual of methods for fish stock assessment. Part I. Fish population analysis. FAO Manuals in Fisheries Science No. 4, 154 p.

Hancock, D. A., and E. Edwards. 1967. Estimation of annual growth in the edible crab (*Cancer pagurus* L.). J. Cons. Perm. Int. Explor. Mer 31: 246-264.

Heincke, F. 1913. Investigations on the plaice. General report. 1. The plaice fishery and protective regulations. Part 1. Rapp. Cons. Explor. Mer 17A: 1-153.

Table 4. Total annual mortality estimates and first molt into legal size from catch curves of at-sea-boat samples obtained throughout the fishing season[a] at selected ports in southwestern Nova Scotia and Grand Manan, New Brunswick (Lobster Districts 4 and 2). Minimum legal size was 79.4 mm CL up to 1951 and 81 mm CL thereafter.

Port	Years	Total annual mortality Z'_m	Total annual mortality A'_m %	First molt into legal size %	Legal lobsters measured no.	Boat trips no.
South Shore, N. S.						
Stonehurst	1950-51[b]	1.662	81.0	78.8	1663	19
	1977-78	0.550	42.3	42.2	235	2
Port Mouton	1942-47	1.384	74.9	73.0	7235	80
	Dec.'78	0.550	42.5	55.8	353	3
Lockeport	1942-51	1.289	72.5	72.3	1327	13
Port Latour	Dec.'77-'78	0.620	62.0	61.8	720	5
Lobster Bay, N. S.						
Clarkes Harbour	1944-51	1.311	73.1	68.5	10901	39
	May '77	0.568	43.3	40.0	284	2
Woods Harbour	1942-43	2.504	91.8	88.9	1300	6
Abbotts Harbour	1942-51	1.511	77.9	76.9	19206	137
Lower West Pubnico	1977-78	0.627	46.6	52.4	479	4
Lower Argyle	1977-78	1.038	64.6	70.3	480	4
West Shore, N. S.						
Kellys Cove	1942-43	2.004	87.1	82.7	1877	18
Port Maitland	1944-50	1.424	75.9	75.3	22570	148
	1951-60	1.597	79.7	80.9	20115	181
	1961-69	1.864	84.5	85.0	12461	78
	1977-78	1.312	73.1	71.7	4490	17
Meteghan	1942-52	1.599	79.8	78.0	5748	42
Bay of Fundy, N. B.						
Grand Manan	1945-53	1.397	75.3	70.9	74785	245
(Seal Cove)	1977-78	1.280	72.2	70.5	596	3

[a]Fishing season 28 Nov. to 31 May for S.W. Nova Scotia; 15 Nov. to 30 June for Grand Manan, N. B.
[b]Commercial port sample.

Herrick, F. H. 1909. The natural history of the American lobster. Bull. U.S. Bur. Fish. 29: 149-408.

Mann, K. H. 1977. Destruction of kelp-beds by sea-urchins: a cyclical phenomenon or irreversible degradation? Helgoländer wiss. Meeresunters. 30: 455-467.

McLeese, D. W. 1956. Effects of temperature, salinity and oxygen on the survival of the American lobster. J. Fish. Res. Board Can. 13: 247-272.

McLeese, D. W., and D. G. Wilder. 1958. The activity and catchability of the lobster (*Homarus americanus*) in relation to temperature. J. Fish. Res. Board Can. 16: 1345-1354.

Morrissey, T. D. (editor). 1978. American lobster fishery management plan. Prepared by the Lobster Sub-board of the Northeast Marine Fisheries Board. File manuscript. NMFS State-Federal Management Program, Gloucester, Mass.

Paloheimo, J. E. 1963. Estimation of catchabilities and population sizes of lobsters. J. Fish. Res. Board Can. 20: 59-88.

Perkins, H. C. 1971. Egg loss during incubation from offshore northern lobsters (Decapoda: Homaridae). U.S. Fish. Bull. 69: 451-453.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191, 382 p

1977. The historical development. *In* Gulland, J. A. (editor). Fish population dynamics. John Wiley & Sons, 372 p.

Scarratt, D. J. 1964. Abundance and distribution of lobster larvae (*Homarus americanus*) in Northumberland Strait. J. Fish. Res. Board Can. 21: 661-680.

1973a. The effects of raking irish moss (*Chondrus crispus*) on lobsters in Prince Edward Island. Helgoländer wiss. Meeresunters. 24: 415-424.

1973b. Claw loss and other wounds in commercially caught lobsters (*Homarus americanus*). J. Fish. Res. Board. Can. 30: 1370-1373.

1973c. Abundance, survival, and vertical and diurnal distribution of lobster larvae in Northumberland Strait, 1962-63, and their relationships with commercial stocks. J. Fish. Res. Board Can. 30: 1819-1824.

Stewart, J. E. 1978. The lobster disease, gaffkemia, in relation to fisheries management. ICES Mariculture Shellfish Committee. C.M. 1978/F:16.

Wilder, D. G. 1959. Canada's lobster fishery. Can. Geogr. J., 20 p.

MORTALITY ESTIMATES (T. Woithe, rapporteur)

Caddy: The exploitation rates of up to 80% removal per molt in the Canadian Maritimes, given in Campbell's paper, correspond to Z values certainly higher than 1.0 and probably over 2.0.

Robinson: In fact, the exploitation rates for the southern Gulf, presented in Table 3 of my paper, have to be doubled due to two molts per year in this area (except a few females around the 64-mm size limit), indicating Z values of up to 4.0.

Anthony: It would be interesting to have a range of Z for all areas.

Campbell: We are concentrating our efforts towards estimating the growth variability, and only after this summer's work will we be able to document more than one molt from legal size.

Caddy: What we are looking at in estimating Z is numbers in successive one-molt intervals after legal size.

Robinson: In our study we did not see many animals over 100 mm carapace length. Out of a total catch/day of 10 or 20 thousand animals, only 2 or 3 lobsters would be up around 120 mm. The high fishing effort may contribute to pre-recruit mortality.

Van Engel: What is the source of recruitment for that stock? At what size does maturity occur?

Robinson: We think it is from adjacent areas in the southern Gulf, supplied by the northern part of the Northumberland Strait. Adjacent to this (District 7B) there is a spring fishery where mature lobsters could supply the gyre.

Anthony: In all areas there appears to be a very high fishing mortality. Where is all the recruitment coming from? It is obviously not from the lobsters in these areas. There must be an area somewhere of low fishing pressure. I do not know where it is - probably offshore somewhere. If areas offshore have a low fishing pressure currently, it would not take much of an increase in offshore fishing pressure to produce a very high mortality rate and perhaps significantly reduce recruitment. It is worth bearing in mind that in the southern Gulf an "offshore" population in the biological sense may occur at or below the thermocline in depths of 20-30 m, quite close to shore.

Robinson: We did our study by depths and the greater the depth the lower the mortality rate. I believe this indicates a lower population size and lower catchability in the spring fishery, and over the whole population, which is not reflected in the catch statistics.

Stasko: The idea of migration is an important consideration since, in one area (Northumberland Strait) of high exploitation, we have found individuals several molts above legal size during the summer closed period, which are not caught during the open season.

Briggs: In Long Island Sound there are areas of low fishing effort, due to large numbers of sport fishing boats in shallow water, that are inhabited by large lobsters. The lobster fishermen generally avoid these areas for fear of pot raiding, buoy cutting and other vandalism supposedly done by sport fishermen.

Smith: "F" values are based on the exploited stocks and not on the parent stock. Connecticut (Long Island Sound) has found many egg-bearing lobsters under legal size and we feel that parent stocks may not have been fished as heavily as the "F" values indicate.

Anthony: We have the same phenomenon in western Maine but not in eastern Maine; that is, some of the lobsters that are carrying eggs are less than the minimum size.

Briggs: The ocean (south) side of Long Island also shows the same thing.

Fair: The migration of lobsters into or out of an area will affect the estimate of total mortality and is very important in the calculation of natural mortality.

Anthony: We all could be overestimating "F" values due to migration. We should look at what size they move to deep water.

Stasko: In offshore areas west of Browns Bank, if size frequencies were used to estimate F values, we would find very high F's at the very start of the fishery, while on eastern Browns where the fishery has been continuing for several years, F values would have been low. I suspect that the size-frequency differences resulted from migration.

Caddy: Average size in offshore waters is going down but fishermen rationalize by saying they modified their traps so that they do not catch the large ones anymore, while others explain that they found new areas where they only catch small ones. I believe we can analyze the data too closely.

Anthony: What bothers me is that we should be finding some minus "F" values or very low "F" values with the migration of the large lobsters.

Bailey: Fishing mortality is being reported as an order of magnitude greater than natural mortality. Are your offshore or any other data sufficient to be realistic?

Anthony: Yes, we believe "M" is realistic. Errors in "M" are not very important since "F" is so high.

Bailey: "M" is important if "F" drops drastically.

Anthony: "F" is not going to go down drastically. Even if it were reduced by 50%, "F" would still be high in relation to "M".

Caddy: Local variations in estimates could be due to error in data collection, the different methodologies used or to the different fishing areas.

Bailey: Are the estimated errors different?

Anthony: We could go back to the data and develop an error scheme, but is it worth it?

Caddy: An error scheme could include a significant element of bias at this stage in our knowledge.

Anthony: The ranges of mortality estimates are not said to be significantly different among areas, but just high. How can we have such a high rate of exploitation and still have large lobsters unless "M" is possibly overestimated?

ASSESSMENT OF YIELD PER RECRUIT FOR THE AMERICAN LOBSTER (*Homarus americanus*)

by

M. J. Fogarty

Rhode Island Department of
Environmental Management
150 Fowler St.
Wickford, Rhode Island

ABSTRACT

Fogarty, M. J. 1980. Assessment of yield per recruit for American lobster (*Homarus americanus*). Can. Tech. Rep. Fish. Aquat. Sci. 932.

Estimates of yield per recruit were derived for the American lobster, *Homarus americanus*, in the territorial waters of the United States by the State-Federal Lobster Scientific Committee. We employed the Beverton-Holt yield-per-recruit model as a first approximation in evaluating yield as a function of the instantaneous rate of fishing mortality and age at entry to the exploited phase. Parameter inputs to the model were derived from lobster tagging programs conducted along the Atlantic coast of the United States and systematic sampling of the commercial catch. These analyses indicate that current levels of fishing mortality for all areas are an order of magnitude higher than that which would maximize yield per recruit. For current levels of fishing mortality, the optimal age at entry to the fishery is considerably higher than present entry levels. The relative magnitude of reductions in fishing mortality required to maximize yield per recruit does not appear to be economically viable and a program of increased minimum legal size coupled with an effort limitation scheme are proposed as alternatives.

INTRODUCTION

Recent evaluations of the population dynamics of the American lobster, *Homarus americanus*, along the Atlantic coast of the United States have relied primarily on the application of the Beverton-Holt (1957) yield model (Thomas 1973; Morrissey 1978) and surplus yield assessments (Marchesseault et al. 1976). This report summarizes yield analyses conducted by the Lobster Scientific Committee of the State-Federal Lobster Management Program under the auspices of the National Marine Fisheries Service. These data were collected in conjunction with a coastwide research effort initiated in 1972 with the purpose of developing a comprehensive management strategy for lobster in the territorial waters of the United States.

The application of dynamic pool models requires detailed knowledge of growth and mortality rates. The Beverton-Holt yield formulation assumes isometric growth, constant mortality rates, stable age-class structure, knife-edge recruitment and that growth may be expressed by the von Bertalanffy growth function. Clearly, these are simplistic approximations of the characteristics of *Homarus* stocks. The von Bertalanffy growth equation does not accurately model the discontinuous growth of crustacea (Bennett 1974; Mauchline 1976; McCaughran and Powell 1977). A growth function that incorporates both molt increment and molt frequency is required to satisfactorily model lobster growth, although data on molting frequency can be difficult to obtain. The ICES working group on *Homarus* stocks concluded, however, that lobster growth may be adequately approximated by the von Bertalanffy model when molt frequency does not diverge from an annual cycle (Anon. 1977). The assumption of an annual molt is at least reasonable for male lobsters within the size range of interest for management (Morrissey 1976).

Despite the potential problems of employing the Beverton-Holt model, the general utility of this approach in evaluating yield relationships with varying mortality rates and ages at first harvest warranted its use. However, lobster yield assessments based on the Beverton-Holt model should be considered qualitative rather than precise indicators of the dynamics of the system.

PARAMETER ESTIMATION

Analytical techniques for the estimation of growth and mortality parameters are discussed in detail elsewhere in this volume and will only be briefly mentioned here. Growth and mortality data were derived from intensive lobster tagging efforts in the inshore waters of the Gulf of Maine (Krouse 1977; Fair 1977), southern New England (Russell et al. 1978), the mid-Atlantic (Halgren 1976), on the continental shelf off southern New England (Cooper and Uzmann 1977) and Virginia (Van Engel et al. 1975). In addition, supplemental data were available for all areas, based on length-frequency analyses of the commercial catch. Growth rates were determined from tag-return data, where size at recapture was known, and from probability mode analyses of length-frequency data. The instantaneous rate of fishing mortality (F) was estimated from tag-recapture data. Total mortality was determined from length-frequency data and tag-return analyses.

Current estimates of the instantaneous rate of fishing mortality (F) for all areas were typically high, ranging from 1.43-2.55 with annual exploitation rates generally in excess of 85%. Estimates of total mortality (Z) were correspondingly high, ranging from 1.70-2.80, depending on area. Instantaneous rates of natural mortality, determined as the difference of independently derived estimates of total and fishing mortality, approximated 0.15 for most areas. It should be noted that estimates of natural mortality less than 0.10 have been reported for lobster (Thomas 1973; Anon. 1977).

Derived values of the von Bertalanffy growth parameters varied widely by location with distinctive differences between inshore and offshore areas. Carapace length at first harvest ranged from 78-81 mm, depending on area and minimum size restrictions. Estimates of age at entry to the fishery ranged from 5.0-7.1 yr in inshore areas and from 3.2-5.1 yr in offshore locations. Estimates of maximum expected weight (W_∞) were derived from length-weight relationships available for several areas. These data indicated that weight is a cubic function of carapace length for lobsters ≥81 mm, justifying the assumption of isometric growth.

The general yield formulation is:

$$Y = \int_{t_p'}^{t_\lambda} F\, N_t W_t dt \qquad (1)$$

where F is the instantaneous rate of fishing mortality, N_t is the number caught at time (t), and W_t is the average weight at time (t).

The Beverton-Holt model assumes a decaying exponential growth function

$$L_t = L_\infty (1-e^{-K(t-t_o)}) \qquad (2)$$

and a cubic relationship between length and weight:

$$W_t = aL_t^3 \qquad (3)$$

or $$W_t = aL_\infty^3 \quad (1-e^{-K(t-t_o)}) \qquad (4)$$

where L_∞ is the asymptotic length, K is the coefficient of catabolism and (a) is a constant.

The expression of yield per recruit is

$$Y/R = FW_\infty e^{-M(t_p'-t_p)} \sum_{n=o}^{3} \frac{U_n e^{-nK(t_p'-t_o)}}{F+M+nK} \; 1-e^{-(F+M+nK)(t_\lambda-t_p')} \qquad (5)$$

where Y is the yield in weight, W_∞ is the asymptotic weight, R is the number of recruits, t_o is the hypothetical age at zero length, t_p is the age at recruitment, t_p' is the age at entry to the exploited phase and t_λ is the maximum expected age.

RESULTS

OPTIMAL FISHING MORTALITY

Fishing mortality rates providing maximum yield per recruit (F_{max}) were initially evaluated at three levels of assumed age at entry to the fishery and natural mortality (Table 1). These analyses

Table 1. Estimated fishing mortality rates providing maximum yield per recruit (F_{max}) of American lobster for selected ages at first harvest for Maine (ME), Massachusetts (MA), Rhode Island (RI), Long Island Sound (LIS), New Jersey (NJ), southern New England offshore (SNE), and Virginia (VA). The superscripts M and F indicate estimates for males and females respectively.[a]

Age at first harvest (t_c)	Natural mortality rate (M)	Inshore						Offshore				Average F over growth equation
		ME	MA	RI^M	RI^F	LIS	NJ	SNE^M	SNE^F	VA^M	VA^F	
4	.1	.14	.09	.09	.11	.16	.20	.14	.10	.15	.20	.14
	.2	.22	.22	.19	.20	.26	.20	.30	.25	.24	.36	.24
	.3	.45	.47	.35	.36	.50	.40	.61	.50	.43	.72	.48
6	.1	.15	.13	.12	.14	.20	.18	.18	.14	.17	.26	.17
	.2	.36	.38	.40	.40	.50	.46	.65	.45	.40	.93	.49
	.3	1.29	1.52	.86	.95	1.82	1.20	.61	.80	>2.00	>2.00	1.30
8	.1	.26	.12	.15	.24	.20	.40	.30	.31	.32	.54	.28
	.2	.71	.75	.60	.90	1.50	2.00	.80	1.21	1.11	>2.00	1.16
	.3	>2.00	>2.00	>2.00	>2.00	>2.00	>2.00	>2.00	>2.00	>2.00	>2.00	>2.00

[a]Source: Lobster Scientific Committee

indicated that for ages at entry ranging from 4-8 yr and with an instantaneous natural mortality rate of M = .10, F_{max} rates were an order of magnitude lower than present estimates of fishing mortality for all areas. Under present minimum size regimes, drastic reductions in fishing mortality would be required to maximize yield per recruit. Taking an assumed instantaneous natural mortality rate of M = .10 and age at entry of 6 yr, estimates of F_{max} ranged from .12-.20 for inshore locations and from .14-.26 for offshore areas (Table 1). Only at unrealistically high levels of assumed natural mortality (M = .30) and an advanced age at entry to the fishery (8 yr) did estimates of optimal fishing mortality approach current levels of instantaneous fishing mortality (Table 1). With assumed natural mortality of M = .10, age at entry levels would have to be raised considerably higher than 8 yr to maximize yield per recruit. Increasing minimum size limits as a compensating mechanism for high levels of fishing mortality would therefore require unrealistically high age at entry levels, given the present structure of the fishery.

Evaluating yield per recruit as a function of fishing mortality indicated that large-scale reductions in F would be required to effect even modest increases in yield for representative data from Maine (Fig. 1) and Rhode Island (Fig. 2). The magnitude of reductions in fishing mortality which might be realistically accomplished through management strategies such as trap limitations or limited entry might be insufficient to substantially improve yield. It may be seen from the Maine data that a decrease in fishing mortality from F = 2.0 to F = 1.0 would result in an approximate increase in yield of 13.0% (Fig. 1); however, it is unlikely that reductions of this magnitude could be reasonably implemented. Similar reductions for Rhode Island waters would result in a 7.5% increase in yield under present minimum size limits and assumed natural mortality of M = .15 (Fig. 2). Only with reductions in fishing mortality to the vicinity of F = 0.2-0.3 would dramatic increases in yield result (Fig. 1). Note that these analyses are extremely sensitive to the value assigned to natural mortality (Fig. 1). At higher rates of natural mortality, the curve approaches an asymptote, reflecting the accelerated decline in stock density due to natural causes.

OPTIMAL AGE AT ENTRY

The age at entry to the fishery providing maximum yield per recruit was initially evaluated at four levels of assumed fishing mortality (F = .2, .4, .6 and .8) and two levels of assumed natural mortality (M = .10, .20) (Table 2). The results of these analyses indicated that, even at relatively low levels of fishing mortality, the optimal age at entry to the fishery was generally higher than current ages at entry for all areas (when M = .10). Again, these analyses were relatively insensitive to the level of fishing mortality (Fig. 3), reinforcing conclusions derived earlier in this report. Representative data from New Jersey and Rhode Island indicated that yield per recruit was typically higher at lower levels of natural mortality; however, the optimal age at entry to the exploited phase was substantially higher at the lower level of natural mortality, particularly with higher fishing mortality rates (Fig. 3, 4 and 5). These data underscore the need for reliable estimates of natural mortality rates for yield assessment purposes.

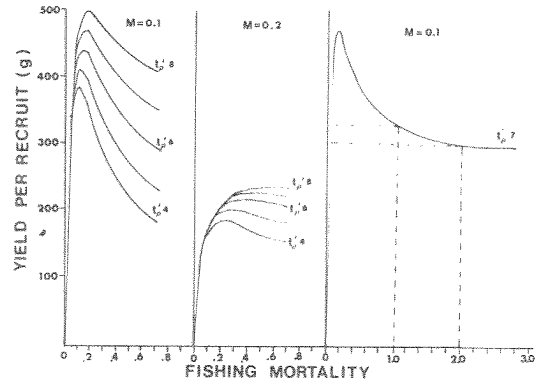


Fig. 1. Relationship between yield per recruit (g) and fishing mortality at two levels of assumed natural mortality and varying age at entry to the fishery for representative Maine data.

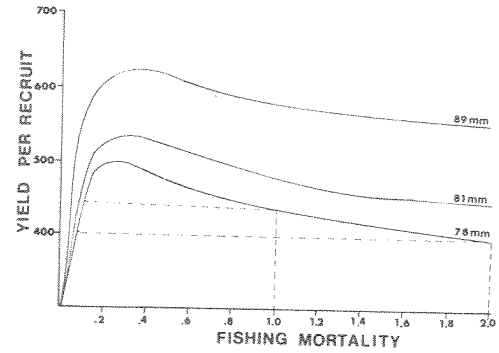


Fig. 2. Relationship between yield per recruit (g) and fishing mortality for three levels of age at entry corresponding to minimum legal size limits of 78, 81, and 89 mm for representative Rhode Island data.

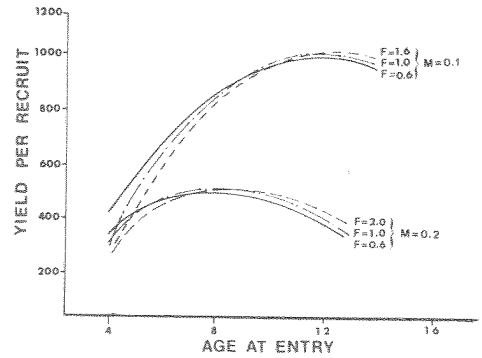


Fig. 3. Relationship between yield per recruit and age at entry at three levels of fishing mortality and two levels of natural mortality for representative New Jersey data.

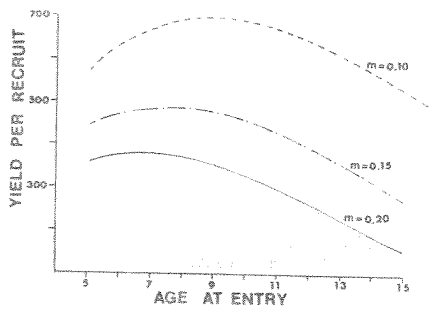


Fig. 4. Relationship between yield per recruit and age at entry to the fishery at three levels of assumed natural mortality and fishing mortality set at F = 0.2 for Rhode Island data.

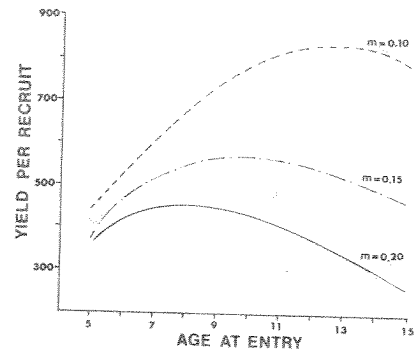


Fig. 5. Relationship between yield per recruit and age at entry to the fishery at three levels of assumed natural mortality and fishing mortality set at F = 0.8 for Rhode Island data.

Table 2. Estimated age at entry to the exploited phase (t_c) providing maximum yield per recruit of the American lobster at selected levels of F. Abbreviations identical to those in Table 1.[a]

Fishing mortality (F)	Natural mortality (M)	ME	MA	RI^M	RI^F	LIS	NJ	SNE^M	SNE^F	VA^M	VA^F	Average t_c providing maximum Y/R over areas
.20	.1	11	10	11	10	10	9	9	10	10	8	9.8
	.2	7	7	7	7	6	6	6	6	7	5	6.4
.40	.1	13	12	13	12	12	11	10	12	12	9	11.6
	.2	8	8	9	8	7	7	7	8	8	6	7.6
.60	.1	14	14	14	13	13	11	11	13	13	10	12.6
	.2	9	9	9	9	8	8	7	8	8	7	8.2
.80	.1	16	14	15	14	13	12	12	13	13	10	13.2
	.2	9	9	10	9	8	8	8	8	9	7	8.5

[a]Source: Lobster Scientific Committee

Yield isopleths constructed for representative data obtained in Maine and Massachusetts demonstrate the relative insensitivity to fishing mortality rate and the advanced age at entry required to maximize yield per recruit (Fig. 6 and 7).

CONCLUSIONS

The results of these analyses clearly indicate that sharp reductions in the level of fishing mortality would benefit the lobster fishery in the United States. Current estimates of the instantaneous rate of fishing mortality are an order of magnitude higher than that which would maximize yield per recruit. Given present levels of fishing mortality, the optimal age at entry to the fishery is far in excess of current entry levels for all areas. The relative magnitude of overexploitation in the lobster fishery raises serious questions as to the future viability of the industry without appropriate management measures.

Effective management strategies must operate within a specific social and economic framework. A successful management program would, therefore, not only contribute to optimal stock production but would minimize any resultant social and economic dislocation. It is unlikely that this fishery could be managed at or near F_{max} levels without major economic disruption at the present time. Similarly, increasing minimum size limits to the range which would provide maximum yield per recruit is impractical at this time. However, significant increases in yield would result with increasing the minimum legal size to 89-mm carapace length on a regional basis as advocated by the Lobster Scientific Committee. In addition, this measure should increase the number of individuals attaining sexual maturity prior to recruitment to the fishery. Although stock-recruitment relationships have not been established for lobster, the anticipated increase in brood stock abundance should tend to stabilize recruitment.

Attempts should be made to develop an effort limitation scheme which would reduce fishing mortality and be generally acceptable to the fishing community. Trap limitations may serve this purpose although a significant enforcement problem might ensue. Acheson (1975) reported acceptance of this proposal in Maine. Broad-scale trap limitations would have the effect of decreasing both fishing mortality and the capital investment associated with fishing large numbers of traps. Clearly, the most effective management strategy would be one which incorporates an increase in the minimum size with an effort limitation technique.

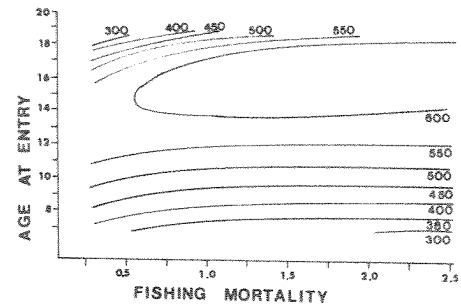


Fig. 6. Yield per recruit as a function of fishing mortality and age at entry to the fishery for representative Maine data.

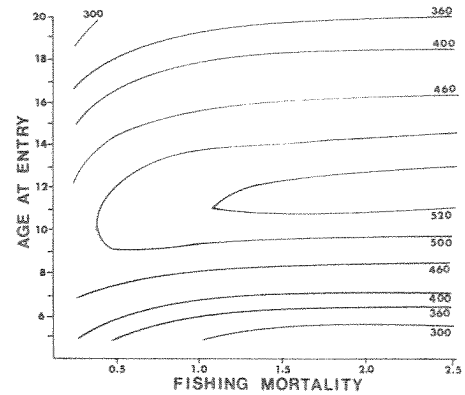


Fig. 7. Yield per recruit as a function of fishing mortality and age at entry to the fishery for representative Massachusetts data.

REFERENCES

Anon. 1977. Report of the Working Group on *Homarus* stocks. Shellfish and Benthos Committee. C.M. 1977/K. International Council for the Exploration of the Sea.

Acheson, J. M. 1975. Fisheries management and social context: the case of the Maine lobster fishery. Trans. Am. Fish. Soc. 104: 653-668.

Bennett, D. B. 1974. Growth of the edible crab, *Cancer pagurus*, off southwest England. J. Mar. Biol. Assoc. U.K. 54: 803-823.

Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. Fish. Invest., Lond., Series 2, 19, 533 p.

Cooper, R. A., and J. R. Uzmann. 1977. Ecology of juvenile and adult clawed lobsters, *Homarus americanus*, *H. gammarus* and *Nephrops norvegicus*. *In* B.F. Phillips and J.S. Cobb (eds.), Workshop on Lobster and Rock Lobster Ecology and Physiology, Div. Fish. Ocean Cir. No. 7. Commonwealth Sci. and Ind. Res. Organ. Australia, p. 187-208.

Fair, J. J. 1977. Lobster investigations in management area I: southern Gulf of Maine. Completion Report of Mass. Div. Mar. Fish. Contract 03-5-043-328. U.S. Dept. Com., NOAA, NMFS.

Halgren, B. A. 1976. Management of the lobster, *Homarus americanus*, resource of the continental shelf, canyons and slope of the northern portion of lobster management area IV. Prog. Rep. New Jersey Contract 03-4-043-359. U.S. Dept. Com., NOAA, NMFS.

Krouse, J. S. 1977. Lobster tagging project. Completion Report of Maine Dept. Mar. Res. Contract No. 3-228-R. Comm. Fish. Res. Dev. Act. NOAA, NMFS.

Mauchline, J. 1976. The Hiatt growth diagram for Crustacea. Mar. Biol. 35: 79-84.

McCaughran, D. A., and G. C. Powell. 1977. Growth model for Alaska king crab (*Paralithodes camtschatica*). J. Fish. Res. Board Can. 34: 989-995.

Marchesseault, G. D., S. B. Saila, and W. F. Palm. 1976. Delayed recruitment models and their application to the American lobster (*Homarus americanus*) fishery. J. Fish. Res. Board Can. 33: 1779-1787.

Morrissey, T. D. (editor). 1976. Review of unpublished lobster growth and mortality data and preliminary assessment of lobster yield per recruit by the Lobster Scientific Committee. File MS. NMFS State-Federal Management Program.

1978. American Lobster Fishery Management Plan. Northeast Marine Fisheries Board.

Russell, H. J., D. V. D. Borden, and M. J. Fogarty. 1978. Management of inshore lobster resources. Completion Report of Rhode Island Div. Fish Wildl. Contract 03-4-043-340. U.S. Dept. Com., NOAA, NMFS.

Thomas, J. C. 1973. An analysis of the commercial lobster (*Homarus americanus*) fishery along the coast of Maine, August 1966 through December December 1970. NOAA Tech. Rep., NMFS SSRF-667, Wash., D.C.

Van Engel, W. A., M. A. Cavell, C. E. Laird, and P. A. Haefner, Jr. 1975. Biology and management of the American lobster. Prog. Rep., VIMS Contract 03-4-043-353. U.S. Dept. Com., NOAA, NMFS.

CANADIAN EFFORTS TO ASSESS YIELD PER RECRUIT IN LOBSTERS

by

G. P. Ennis

Department of Fisheries and Oceans
Research and Resource Services
P.O. Box 5667
St. John's, Newfoundland A1C 5X1

ABSTRACT

Ennis, G. P. 1980. Canadian efforts to assess yield per recruit in lobsters. Can. Tech. Rep. Fish. Aquat. Sci. 932.

In recent years two models have been developed to assess yield per recruit in lobsters. The main feature of both is that the two separate components of lobster growth, molt increment and molt frequency or proportion molting, are used instead of estimates of the parameters of the von Bertalanffy growth equation. One of the models has been used to assess yield per recruit in a number of Newfoundland populations. These assessments have shown that yield per recruit in lobsters is more sensitive to changes in recruitment length (size limit) than to changes in exploitation rate and that yield per recruit can be increased by raising the size limit and lowering exploitation rates.

Yield-per-recruit assessments for lobsters had not been attempted by Canadian workers until quite recently. Robinson (pers. comm.) calculated that a 50% increase in yield per recruit would result by increasing the size limit in District 8 (Northumberland Strait) from 2 1/2 to 3 in. carapace length. Following this initial effort Caddy (1977) prepared a paper for the second ICES *Homarus* Working Group meeting in May 1977 in which he pointed out some of the limitations associated with using the von Bertalanffy equation to describe growth of lobsters as well as the limitations associated with using the dynamic pool model of Beverton and Holt to assess yield per recruit in lobsters. In addition, he presented a simplified yield-per-recruit model for lobsters, which used molt increment and molt frequency as growth functions instead of the von Bertalanffy parameters. Efforts are currently under way to refine and program this model in order to carry out yield-per-recruit assessments on Maritime lobster stocks (Robinson, pers. comm.). Ennis and Akenhead (1978) developed and programmed a lobster yield-per-recruit model which is similar to Caddy's in that it also uses the two separate components of lobster growth (molt increment and proportion molting) instead of estimates of the von Bertalanffy parameters. This program has been used to assess yield per recruit in a number of Newfoundland lobster stocks (Ennis 1978). Yield-per-recruit curves from the assessment for one area are shown in Fig. 1 and 2. The assessments for all areas showed that yield per recruit is more sensitive to changes in recruitment length than to changes in exploitation rate. At an exploitation rate of 80%, yield per recruit would increase 15-20% on the average if the recruitment length is increased from 81 mm to 89 mm, but the increase would be less at an exploitation rate of 60% (Table 1). At the present recruitment length (81 mm) yield per recruit would increase by about 6% on the average if the exploitation rate is decreased from 80 to 60% but the increase would be less at a recruitment length of 89 mm (Table 2).

REFERENCES

Caddy, J. F. 1977. Models of growth in the American lobster, *Homarus americanus* and approaches to a simplified yield model. Fish. Mar. Serv. MS Rep. 1445, 14 p.

Ennis, G. P. MS 1978. Yield per recruit assessments for Newfoundland lobster stocks. CAFSAC Res. Doc. 78/31, 18 p.

Ennis, G. P., and S. A. Akenhead. MS 1978. A model and computer program used to assess yield per recruit in Newfoundland lobster stocks. CAFSAC Res. Doc. 78/30, 9 p.

Table 1. Percentage increase in yield per recruit by increasing recruitment length from 81 to 89 mm (molting data for different years combined).

	Rate of exploitation			
	60%		80%	
	Males	Females	Males	Females
Arnold's Cove	15	13	19	14
St. Chads	16	14	20	16
Comfort Cove	13	14	16	15
Boswarlos	21	14	25	15
Bellburns	16	14	19	16

Table 2. Percentage increase in yield per recruit by decreasing exploitation rate from 80 to 60% (molting data for different years combined).

	Recruitment length			
	81 mm		89 mm	
	Males	Females	Males	Females
Arnold's Cove	5	6	1	4
St. Chads	7	6	3	4
Comfort Cove	4	6	1	4
Boswarlos	13	6	10	5
Bellburns	6	6	2	5

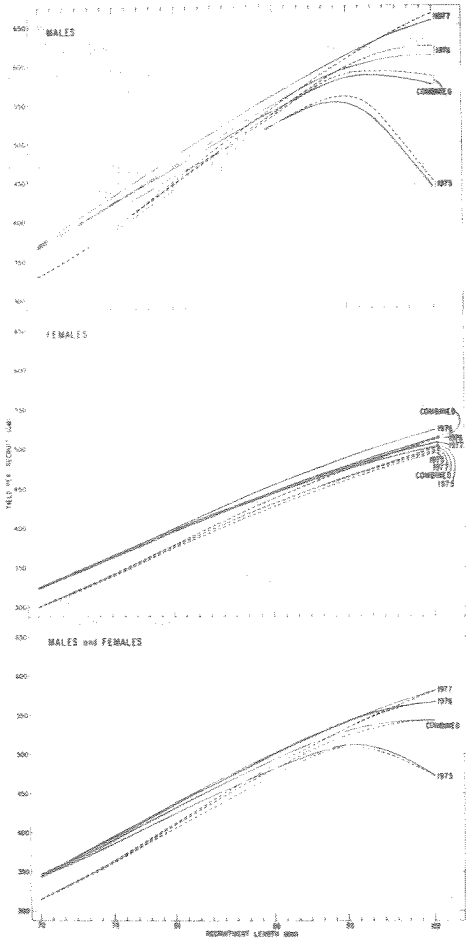


Fig. 1. Curves of yield per recruit against recruitment length for Arnold's Cove using proportions molting data for the years indicated at 60% (————) and 80% (------) rates of exploitation.

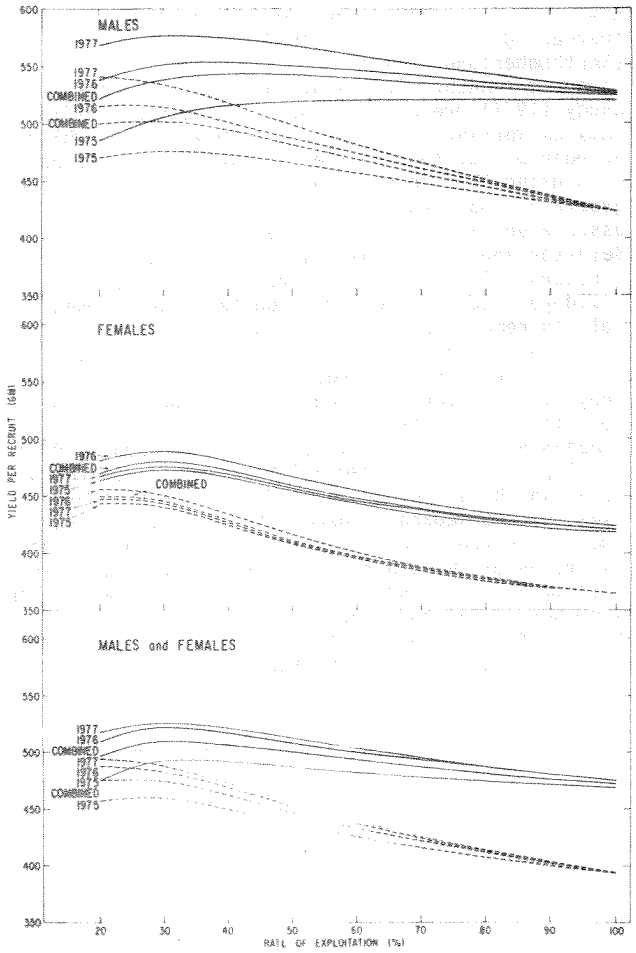


Fig. 2. Curves of yield per recruit against exploitation rate for Arnold's Cove using proportions molting data for the years indicated at 81 mm (------) and 89 mm (————) recruitment lengths.

YIELD PER RECRUIT (D. Bennett, rapporteur)

Anthony: The ICES *Homarus* Working Group used the Beverton and Holt model which, despite the problems with the von Bertalanffy growth curve and the use of constant fishing mortality at all sizes (ages), gave the same conclusions for the Newfoundland stock as Ennis has with his model. Although a decrease in F may not give a large increase in Y/R, it would increase the breeding stock and therefore tend to maintain recruitment.

Ennis: Berried lobsters are found in fairly large numbers below the present minimum size.

Caddy: I have used a model, which is essentially a modification of the Ricker model, employing unequal time intervals, to estimate population egg production per recruit for different input parameters, as well as Y/R. With such high F values, if the size at first capture is below the size of maturity, negligible egg production is possible. With the size at first capture above maturity size, some egg production will always occur whatever the level of F.

Anthony: If the source of recruitment is outside a particular fishery (e.g. offshore), then there may be no need to worry about the breeding stock inshore.

Caddy: In the southern Gulf of St. Lawrence fishermen have increased hoop size so that they are now exploiting large lobsters which may be a main source of recruitment inshore.

Scarratt: In that area, large numbers of stage I larvae have been caught away from fishing grounds, suggesting a reservoir breeding stock.

Anthony: We may speculate that faster growth rates are observed offshore because the faster growers are the first to migrate offshore; this is frequently seen in fish stocks.

Robinson: We should not think in terms of fast growth offshore, slower growth inshore. There are comparable fast growth rates inshore in Canada. There are variations in growth with area.

Fogarty: Cooper concluded that the more stable temperature regime offshore resulted in faster growth.

Morrissey: Did you (Ennis) find that some Newfoundland males showed a decline in Y/R at 95 mm carapace length?

Ennis: Yes, for one year's data in the figure shown. It has occurred in another area but for a different year's data. It is due to lower proportions molting in those years. Normally Y/R increases beyond 95 mm carapace length.

Anthony: The overall conclusion is that the Y/R increases if the size at first capture is increased and the fishing mortality decreased.

Stasko: Offshore, the average size is so high that a small increase in legal size would have little benefit.

Clark: What is the relative effect of use of von Bertalanffy growth parameter estimates with those obtained from other growth models, in yield-per-recruit calculations - for example, how would F_{max} be expected to differ?

Ennis: I used exploitation rates instead of F, but the general conclusion was that fishing mortality is too high, and maximum Y/R would occur at exploitation rates between 20 and 49%.

Caddy: Using the FAO yield tables (Beverton and Holt 1966[1]) for M/K ratios close to 1, you get the same increase in Y/R by a moderate increase in size at first capture as you would achieve from a large reduction in fishing mortality.

Anthony: In Maine there has in recent years been a considerable increase in fishing effort with a reduction in catch. The data fit a Schaefer curve and indicate the need for a significant reduction in fishing effort.

---

[1]Beverton, R. J. H., and S. J. Holt. 1966. Manual of methods for fish stock assessment. Part II - Table of yield functions. FAO Tech. Rep. 38 (Rev. 1), 67 p.

MATURITY AND FECUNDITY IN THE AMERICAN LOBSTER, *Homarus americanus* - A REVIEW[1]

by

W. A. Van Engel

Virginia Institute of Marine Science
School of Marine Science
College of William and Mary
Gloucester Point, Virginia 23062
USA

[1]Contribution No. 938
Virginia Institute of Marine Science

ABSTRACT

Van Engel, W. A. 1980. Maturity and fecundity in the American lobster, *Homarus americanus* - a review. Can. Tech. Rep. Fish. Aquat. Sci. 932.

Several biological features of the American lobster, such as the stage of ovarian development, contents of the male testis and the female seminal receptacle, presence of extruded eggs on the abdomen, and morphometry of the male claw and of the male and female abdomen have been examined for their reliability as criteria of maturity. Evidence is given that the series of processes culminating in the production of viable sperm and a fertilized egg have not been completely described in the lobster. Carapace length at first extrusion of eggs is the best indicator of minimum size at maturity in the female. Minimum age at maturity in the male may or may not be the carapace length at which sperm are first found.

Numbers of extruded eggs carried by females of different sizes, seasonal variations in number and differences due to methods of estimation are given.

INTRODUCTION

Regulations limiting the size at capture of commercial species of crustaceans and fishes often require knowledge of the size at which sexual maturity occurs. A minimus size larger than the size at maturity would, theoretically, permit the animals to reproduce at least once before they are caught.

Several biological features of the American lobster, such as the stage of ovarian development, contents of the male testis and the female seminal receptacle, presence of extruded eggs on the abdomen, and morphometry of the male claw and of the male and female abdomen have been examined for their reliability as criteria of maturity. Each feature is believed to express in some way the degree of readiness of a lobster to reproduce.

OVARIAN DEVELOPMENT

Three stages of development of the ovary, immature, developing and mature, have been assigned from differences in color and ova diameters (Skud and Perkins 1969; Krouse 1973; Thomas 1973; Van Engel et al. 1975; Halgren 1975a, b) (Table 1).

Immature ovaries are white or cream colored, contain ova ≤0.4 mm in diameter and are limited to lobsters ≤89 mm carapace length (CL). They are found in lobsters as small as 39 mm CL caught offshore, i.e., on the edge of the continental shelf and in the canyons (Van Engel et al. 1975). Developing ovaries are yellow and yellow-orange in color, contain ova 0.35-0.8 mm in diameter and are found in lobsters 50-91 mm CL. Mature ovaries are dark green, contain ova ≥0.8 mm in diameter and are found in lobsters >69 mm CL. Size ranges of CL and ova for lobsters with immature and developing ovaries are similar for inshore and offshore lobsters. The CL of lobsters with mature ovaries, >77 mm, is similar in inshore Maine waters (Krouse 1973) and offshore from Oceanographer Canyon to Cape Hatteras (Skud and Perkins 1969; Van Engel et al. 1975). In contrast, the CL of females with mature ovaries in inshore waters of Newfoundland and New Jersey are characteristically small, <78 mm (Templeman and Tibbo 1945; Halgren 1975a). Because of the limit on sizes sampled in New Jersey, females with mature ovaries and CL >78 mm were not observed.

It is apparent that stages of ovarian development do not fall within distinctly separated CL size groups although, in general, the smallest females have immature ovaries and the largest ones are mature.

Further, classifying ovaries as immature, developing or mature may be too simple. Aiken and Waddy (1976) suggest that there is a recurring progression of the ovarian stages from immaturity to maturity at intervals throughout the adult life. If that is true, then the large range of CL, 83-134 mm, of females described as having mature ovaries, from offshore collections (Van Engel et al. 1975), is in error. Apparently color has been overemphasized in determining the state of maturity. Since ripe green ova are retained in the ovary after each egg extrusion, their color masks the true stage of ovarian development. More attention must be given to the number of all sizes of ova in each ovary before an accurate designation of the stage of development can be made.

With our present knowledge, the large overlap of CL between stages does not permit a determination of individual or mean size at sexual maturity. Further use of this technique should be deferred until there is a complete histological study of the ovary over several cycles of growth.

CONDITION OF THE SEMINAL RECEPTACLE

Sperm or a sperm plug in the seminal receptacle of the female indicates that the female was physically and physiologically mature at the time of copulation. Since mating is an event occurring only after maturation and recurring throughout the life span of the female, the most one can learn by probing for sperm is the minimum size at which mating can occur. The minimum size, 63-71 mm CL, is similar for all geographic areas (Templeman 1939; Templeman and Tibbo 1945; Krouse 1973; Lund et al. 1973; Halgren 1975a; Van Engel et al. 1975) (Table 1). The absence of sperm is not evidence that maturity has been delayed in a particular female, for the female may have mated and lost the contents of the seminal receptacle when she molted. Obviously only those females with sperm can extrude fertilized eggs and, since females mate when they are in the soft-shell state, females without sperm must undergo another molt and copulation before they can extrude fertilized eggs.

EXTRUDED EGGS

Numerous investigators have recorded the total length (TL) (where noted) or carapace length (CL) of females with extruded eggs (Templeman 1933, 1935, 1936, 1936, 1944b, in TL; Templeman and Tibbo 1945, in TL; Perkins and Skud 1966; Skud 1966; Skud and Perkins 1969; Squires 1970; Krouse 1973; Lund et al. 1973; Thomas 1973; Russell et al. 1975a, b; Van Engel et al. 1975; Holland and Keefe 1977; Smith 1977). Conversion of TL to CL was made using the equation of Saila et al. (1969): CL mm = 0.62 + 0.3463 TL mm. Alternate equations, not used, are those of Squires (1970): Male TL mm = 2.57 CL mm + 18.94 and female TL mm = 2.77 CL mm + 9.60, for Port au Port Bay, Newfoundland. These regressions of TL on CL are not appropriate for estimating CL from TL, but when used give estimates of CL smaller than those found using the equation of Saila et al. (1969).

The smallest females with extruded eggs occurred in the southern part of the Gulf of St. Lawrence (Pointe du Chene, Northumberland Strait; 61 mm CL) and Long Island Sound (66-67 mm CL). The largest sizes at first occurrence of extruded eggs were 127 mm CL at Seeley's Basin (Bay of Fundy) and 111 mm CL off the southwest coast of Nova Scotia. Templeman (1936) presented evidence that the minimum size at maturity varied regionally and was negatively associated with summer water temperature. He theorized that higher summer temperatures were favorable for growth in length and for ovarian development so that the lobster became mature at an early age. Lower summer temperatures slowed ovarian development without affecting growth in length, and the lobster grew to a large size before becoming mature.

In some studies mean CL at maturity has been reported. Wenner et al. (1974) proposed a method of estimating mean minimum size and standard deviation of the size at onset of maturity with the use of probability paper. Analysis is made of the percentage of females with extruded eggs in a sample

Table 1. Size of female American lobsters, and ova diameters (d), mm, as related to reproductive condition, in inshore and offshore waters, east coast of United States and Canada. Example: range 51-89 mm refers to minimum and maximum carapace length observed.

	White or immature	Yellow or developing	Green or mature	Ovigerous	Sperm or sperm plug	Publications
I. Inshore						
Newfoundland			72[a]	66[a]	69[a]	Templeman (1939) Templeman and Tibbo (1945)
Newfoundland			72	78		Squires (1970)
Northumberland Strait and P.E.I.				61[a]	65[a]	Templeman (1936) Templeman and Tibbo (1945)
Bay of Fundy				127[a]		Templeman (1936)
Atlantic Ocean Coast, Nova Scotia				111[a]		" "
Canada				79-127		Thomas (1973)
Maine				83-127, $\bar{x}$ = 102		Thomas (1973)
Maine	51-89 ≤0.4[d]	69-94 0.5-0.7[d]	77-99 ≥0.8[d]	83-127	65-100	Krouse (1973)
Rhode Island				70-132		Russell et al. (1975a, b)
Long Island Sound				67-116 66-120		Smith (1977) Briggs (1975)
Connecticut				72 ⟶	63-106	Lund et al. (1973)
New Jersey	<69, 69-78	<69, 69-78	69-78	79-125	71 ⟶	Halgren (1975a, 1976a)
II. Offshore						
Georges Bank				90-180 ⟶		Skud (1966)
North Atlantic Slope				88 ⟶		Perkins and Skud (1966)
Canyons						
Corsair				100-200		
Lydonia				90-190		Skud and Perkins (1969)
Oceanographers	76-84	76-91	80-107	80-190		
Veatch	<0.4[d]	0.4-0.8[d]	>0.8[d]	90-170		
Hudson				80-140 $\bar{x}$ = 98		
Washington Canyon to Cape Fear				81-95		Holland and Keefe (1977)
Cape Cod to Cape Hatteras	39-82 0.11-0.35[d]	50-90 0.35-0.51[d]	83-134 0.62-1.02[d]	86-157	64-163	Van Engel et al. (1975)

[a]Minimum carapace length in general geographic area, estimated from total body length, CL mm = 0.62 + 0.3463 TL mm (Saila et al. 1969).

containing the full range of sizes. This method would permit a comparison of the structure of populations spatially separated.

MORPHOMETRY OF THE FEMALE ABDOMEN

An abrupt increase in the rate of growth of the abdomen is associated with attainment of maturity in the female, an alteration enabling the female to carry a large number of eggs on the pleopods.

The relative rate of change of the width of the second abdominal segment (AW), expressed as AW/CL, is curvilinear, decreases with an increase in CL, and has been described from female lobsters from inshore and offshore areas from Canada to Virginia: Templeman (1933, 1935, 1944b); Templeman and Tibbo (1945); Perkins and Skud (1966); Skud and Perkins (1969); Krouse (1973); Halgren (1975a, b, 1976a, b); Van Engel et al. (1975). Three inflection points on the curves have been described: minimum CL at maturity; CL at which one-half of the females are mature; CL at which all females are mature.

The location of the first inflection on the regression of AW/CL on CL for any geographic region agrees in general with the minimum CL at which a female becomes mature. No data exist to verify inferences of the CL at which either one-half or all females are mature. Templeman (1944b, p. 286-288), using data from Cape Traverse, P.E.I. (Knight, in Templeman 1944b), arbitrarily assumed that only when TL ≥12 in. (105 mm CL) were all females mature. Since 25.3% of those large females had extruded eggs (berried), he assumed that when 12.5% of the females were berried that one-half the females were mature. Further, he estimated that the AW/TL ratio would be 0.235 when one-half the females were mature [AW/CL = 0.684, using equations of Saila et al. 1969]. After calculating the AW/TL ratio for female lobsters from Newfoundland, Northumberland Strait and Nova Scotian waters, Templeman (1944b) and Templeman and Tibbo (1945) estimated the TL at which, presumably, one-half of the females become mature. No measurements of large numbers of females, including berried females, for any other Canadian locality than Cape Traverse are available for review.

An estimate of the CL at which all females are mature was made by Skud and Perkins (1969) from data from a large collection of lobsters from offshore New England. The regression was described as cubic, with an asymptote at 100 mm CL. In addition, they examined the relationship between ova diameter and CL and between ova diameter and AW, from a relatively small sample of lobsters. They concluded that all females with CL >100 mm or with AW >60 mm, or both, were mature. These conclusions cannot be accepted since it was assumed that diameters of ova from the surface of the ovary are representative of all the ova and that they accurately describe the stage of ovarian development.

DEVELOPMENT OF THE TESTIS

Less attention has been given to criteria for maturity in the male lobster than in the female. Using the presence of sperm in the vas deferens or testis as evidence of maturity, Krouse (1973) observed that some Maine lobsters mature at 41 mm CL and about 50% of them at 44 mm CL, which is about one-half the minimum CL of females with extruded eggs. Minimum size at maturity in males is 48-51 mm CL (reported as 14-15 cm TL) in Newfoundland (Templeman and Tibbo 1945), 49 mm CL offshore between Cape Cod and Cape Hatteras (Van Engel et al. 1975), and 60 mm CL in inshore New Jersey (Halgren 1975a).

MORPHOMETRY OF THE MALE ABDOMEN, CARAPACE AND CLAW

No significant change in the AW/CL ratio occurs with an increase in CL in males, in contrast to the condition in females, in inshore Canadian waters or offshore between Cape Cod and Cape Hatteras (Templeman 1935; Van Engel et al. 1975). The relative length of the carapace, expressed as a percentage of the total length, CL/TL, increases sharply when Newfoundland males reach 69 mm CL (200 mm TL) whereas the relative length of the female carapace remains constant (Templeman 1939, 1944a). Similarly, the regression of relative claw length on total length in males is curvilinear but varies geographically in lobsters from 69-76 mm CL (200-220 mm TL) in Northumberland Strait and eastern Nova Scotia to 103-114 mm CL (300-330 mm TL) in the Bay of Fundy (Templeman 1933, 1935). These increases in relative size are not related to the minimum CL at which sperm are found but to the CL, about 68 mm, at which all the males had sperm, excluding lobsters from the Bay of Fundy and western Nova Scotia (Templeman and Tibbo 1945).

Since maturation of the male gonad occurs at a small CL, it would appear that the number of pre-recruit males would not be a limiting factor in ensuring that all females in reproductive readiness would be provided a mate. Early evidence suggested that males were unable to mate with considerably larger females (Templeman 1934), but more recently males were found able to mate with females twice their weight (Hughes, in Aiken and Waddy 1976).

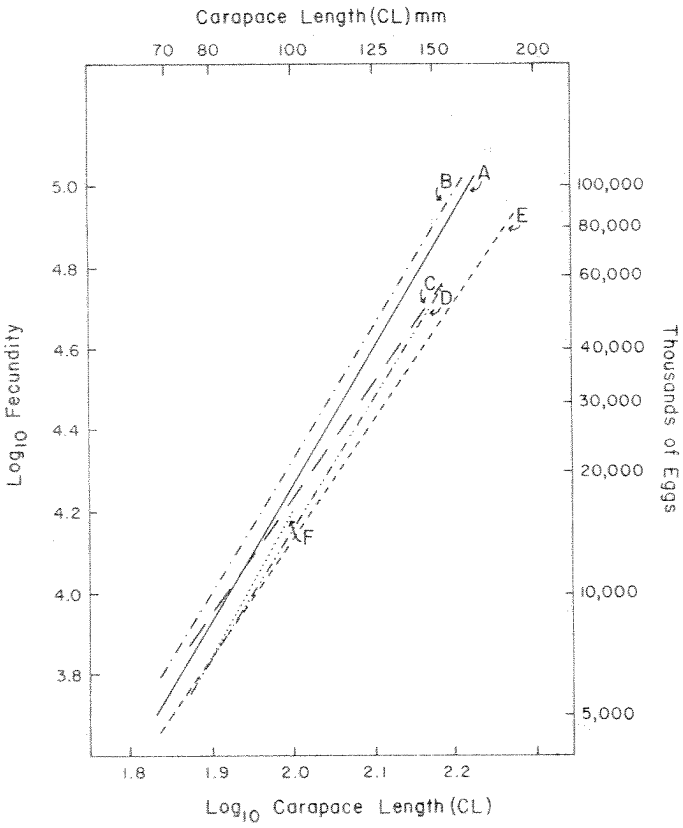
Minimum CL size limits for legal capture are the same for both sexes, although the limits are not the same in all states and in Canada. Since the relative length of the carapace is larger in males than females, and presuming the lobsters are of the same age, equal minimum size limits permit the capture of males at a younger age than females. However, any shortage of recruit or larger-sized males would be offset by the large number of pre-recruit-sized mature males.

DISCUSSION ON CRITERIA FOR MATURITY

The series of processes that culminate in the production of viable sperm and a fertilized egg have not been completely described in the lobster.

Sperm in males appear when the lobsters are of relatively small size, 40-50 mm CL, in all geographic areas. However, abrupt changes in the relative length of the carapace and of claw length at 69-76 mm CL suggest that visceral changes precede external modifications. Possibly the male gonad undergoes stages of development similar to those seen in the female gonad. Annual or seasonal cycles of the male gonad have not been suggested but should not be ruled out until investigated.

For the female, strong evidence exists that there are cycles of development in the ovary. It is obvious that there is no prerequisite that the female possesses mature ovaries prior to mating. At least one exogenous factor, high summer temperature, is believed to be favorable for body growth in length and for ovarian development, with the effect that maturity, physiological and morphological, of the female is attained at an early age. Lower summer temperatures slow ovarian growth without



A. Herrick	$\text{Log}_{10}\ F = -2.4505 + 3.3542\ \text{Log}_{10}\ CL$
B. Perkins (October)	$\text{Log}_{10}\ F = -2.1802 + 3.2499\ \text{Log}_{10}\ CL$
C. Perkins (April)	$\text{Log}_{10}\ F = -1.4019 + 2.8132\ \text{Log}_{10}\ CL$
D. Perkins (June)	$\text{Log}_{10}\ F = -2.1815 + 3.1569\ \text{Log}_{10}\ CL$
E. Saila et al.	$\text{Log}_{10}\ F = -1.6017 + 2.8647\ \text{Log}_{10}\ CL$
F. Squires	$F = -21746.4 + 379.6\ CL$

Fig. 1. Fecundity - carapace length relationship.

affecting growth in length; females grow to a large size before becoming mature (Templeman 1936).

Another factor not yet isolated establishes an apparent antagonism between vitellogenesis in the female gonad and the molt cycle. Vitellogenesis occurs in two stages, separated by a winter, and is inhibited during premolt (Aiken and Waddy 1976).

The existence of cycles of ovarian development has not been recognized in most studies that attempt to determine the size at which maturity is attained by a fraction or all female lobsters.

FECUNDITY

The number of recruits to the fishable stock is of most interest in lobster production estimates. Of particular concern is the effect of stock density on recruitment; this relationship is not known. An initial step in a study of the relationship between the size of the parent stock and of the recruits is an estimate of the intensity of reproduction, determined by the mean number of eggs per female and the frequency of egg extrusion. Fecundity is defined as the mean number of eggs; it may be used as an index of parental stock size.

It is generally assumed that egg extrusion occurs every other year. However, factors altering the molt cycle may suppress ovarian development and delay egg extrusion (Aiken and Waddy 1976).

Counts of the number of extruded eggs carried by females of different sizes have been made by Herrick (1909), Taylor (1947), Saila et al. (1969), Squires (1970), and Perkins (1971) (Fig. 1). Saila et al. (1969), comparing their data from inshore lobsters with those of Herrick (1909), demonstrated that differences in the methods of estimation resulted in different estimates of total number. Seasonal variation in number, believed by Perkins (1971) to represent egg loss during incubation, was observed in lobsters from offshore New England. Number of eggs ranged from 5,000-10,000 for females with 70-90 mm CL, to 60,000-100,000 for females with 140-190 mm CL, approximately. Regressions of egg number on CL are curvilinear; Saila et al. (1969) and Perkins (1971) used logarithmic transformations for their statistical analyses. All data have been converted to common logarithms to make comparisons easier. The paper by Taylor (1947) was not reviewed. Smith (1977) has shown that a substantial portion of the female lobsters in Long Island Sound (2-14%) carry fewer than 150 eggs.

REFERENCES

Aiken, D. E., and S. L. Waddy. 1976. Controlling growth and reproduction in the American lobster, p. 415-430. *In* J. W. Avault, Jr. [ed.] Proceedings of the seventh annual meeting of the World Mariculture Society, San Diego, Calif., Jan. 25-29, 1976.

Briggs, P. T. 1975. Aspects of the American lobster in Long Island Sound, N.Y. Ann. Rep., April 1, 1974-March 31, 1975, Comm. Fish. Res. Dev. Act, Contract 3-212-R-1, New York State Dept. Environ. Cons. Text 7 p., 4 tables, 5 fig.

Halgren, B. A. 1975a. Management of the lobster, *Homarus americanus* resources of the continental shelf, canyons and slope of the northern portion of Lobster Management Area IV. Second Quarterly Rep., May 1-June 30, 1975, New Jersey Contract 03-4-043-359, U.S. Dept. Com., NOAA, NMFS. Text 3 p., 5 tables, 2 fig.

1975b. Management of the lobster, *Homarus americanus* resources of the continental shelf, canyons and slope of the northern portion of lobster management area IV. Third Quarterly Rep., July 1-Sept. 30, 1975, New Jersey Contract 03-4-043-359, U.S. Dept. Com., NOAA, NMFS, 3 p., table, 8 fig.

1976a. Management of the lobster, *Homarus americanus* resources of the continental shelf, canyons and slope of the northern portion of lobster management area IV. Fourth Quarterly Rep., Oct. 1-Dec. 31, 1975, New Jersey Contract 03-4-043-359, U.S. Dept. Com., NOAA, NMFS, 2 p., 6 tables, 3 fig.

1976b. Management of the lobster, *Homarus americanus* resources of the continental shelf, canyons and slope of the northern portion of lobster management area IV. Sixth Quarterly Rep., Apr.-June 1976, New Jersey Contract 03-4-043-359, U.S. Dept. Com., NOAA, NMFS, 3 p., 10 tables, 6 fig.

Herrick, F. H. 1909. Natural history of the American lobster. Bull. (U.S.) Bur. Fish. 29: 149-408.

Holland, B. F., Jr., and S. G. Keefe. 1977. A summary of American lobster (*Homarus americanus*) investigations offshore North Carolina and Virginia from 1968-1972. North Carolina Dept. Nat. Econ. Resour., Div. Mar. Fish., Morehead City, North Carolina. Mimeo, 45 p.

Krouse, J. S. 1973. Maturity, sex ratio, and size composition of the natural population of American lobster, *Homarus americanus*, along the Maine coast. Fish. Bull. 71: 165-173.

Lund, W. A., Jr., L. L. Stewart, and C. J. Rathbun. 1973. Investigation of the lobster. Comm. Fish. Res. Dev. Act, Contract 3-130R, Univ. Conn. Mar. Res. Lab., 189 p.

Perkins, H. C. 1971. Egg loss during incubation from offshore northern lobsters (Decapoda: Homaridae). Fish. Bull. 69: 451-453.

Perkins, H. C., and B. E. Skud. 1966. Body proportions and maturity of female lobsters. Abstract. Amer. Zool. 6: 615.

Russell, H. J., Jr., D. V. Borden, and E. W. Walter. 1975a. Management studies of inshore lobster resources. Third Quarterly Rep., Jan. 1-March 31, 1975, Rhode Island Contract 03-4-043-360, U.S. Dept. Comm., NOAA, NMFS. Text 13 p., 6 tables, 16 fig.

Russell, H. J., Jr., D. V. Borden, and E. W. Yoder. 1975b. Management studies of inshore lobster resources. Segment Completion Rep., June 24, 1974-June 30, 1975, Rhode Island Contract 03-4-043-360, U.S. Dept. Com., NOAA, NMFS. Text 17 p., 7 tables, 17 fig.

Saila, S. B., J. M. Flowers, and J. T. Hughes. 1969. Fecundity of the American lobster, *Homarus americanus*. Trans. Am. Fish. Soc. 98: 537-539.

Skud, B. E. 1966. Size composition, sex ratio and maturity of offshore lobsters. Abstract. Amer. Zool. 6: 362-363.

Skud, B. E., and H. C. Perkins. 1969. Size composition, sex ratio, and size at maturity of offshore northern lobsters. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 598, 10 p.

Smith, E. M. 1977. Some aspects of catch/effort, biology, and the economics of the Long Island Sound lobster fishery during 1976. Final Rep., Jan. 9, 1976-Apr. 28, 1977, Comm. Fish. Res. Dev. Act, Contract 3-253-R-1, Conn. Dept. Environ. Prot., 97 p.

Squires, H. J. 1970. Lobster (*Homarus americanus*) fishery and ecology in Port au Port Bay, Newfoundland, 1960-65. Proc. Nat. Shellfish. Assoc. 60: 22-39.

Taylor, C. C. 1947. Some observations on the weight and number of eggs of female lobsters. Maine Dept. Sea Shore Fish. Circ. 1, 3 p.

Templeman, W. 1933. Investigators summaries. Ann. Rep. Biol. Board Can. 1932: 38-41.

1934. Mating in the American lobster. Contrib. Can. Biol. Fish., New Ser. 8: 421-432.

1935. Local differences in the body proportions of the lobster, *Homarus americanus*. J. Biol. Board Can. 1: 213-226.

1936. Local differences in the life history of the lobster (*Homarus americanus*) on the coast of the maritime provinces of Canada. J. Biol. Board Can. 2: 41-88.

1939. Investigations into the life history of the lobster *Homarus americanus* on the west coast of Newfoundland, 1938. Newfoundland Dept. Nat. Resour. Res. Bull. 7(Fish.), 53 p.

1944a. Sexual dimorphism in the lobster (*Homarus americanus*). J. Fish. Res. Board Can. 6: 228-232.

1944b. Abdominal width and sexual maturity of female lobsters on the Canadian Atlantic coast. J. Fish. Res. Board Can. 6: 281-290.

Templeman, W., and S. N. Tibbo. 1945. Lobster investigations in Newfoundland 1938 to 1941. Newfoundland Dept. Nat. Resour. Res. Bull. 16(Fish.), 98 p.

Thomas, J. C. 1973. An analysis of the commercial lobster (*Homarus americanus*) fishery along the coast of Maine, August 1966 through December 1970. NOAA Tech. Rep. NMFS SSRF-667, 57 p.

Van Engel, W. A., M. A. Cavell, C. E. Laird, and P. A. Haefner, Jr. 1975. Biology and management of the American lobster. First annual report, June 24, 1974-June 23, 1975, Virginia Contract 03-4-043-353, U.S. Dept. Com., NOAA, NMFS, 44 p.

Wenner, A. M., C. Fusaro, and A. Oater. 1974. Size at onset of sexual maturity and growth rate in crustacean populations. Can. J. Zool. 52: 1095-1106.

MATURITY AND REPRODUCTION IN THE AMERICAN LOBSTER

by

D. E. Aiken and S. L. Waddy

Department of Fisheries and Oceans
Biological Station
St. Andrews, New Brunswick EOG 2XO

ABSTRACT

Aiken, D. E., and S. L. Waddy. 1980. Maturity and reproduction in the American lobster. Can. Tech. Rep. Fish. Aquat. Sci. 932.

The biology of lobster reproduction is poorly understood; we have little ability to predict or control responses, and many established concepts are now being questioned.

Two criteria can be used to estimate male maturity: relative weight of the vasa deferentia and relative volume of the crusher cheliped. Female maturity can be estimated from relative abdomen width, cement gland development, ovary development, and size at oviposition. Smallest size at maturity occurs in western Long Island Sound and the southern Gulf of St. Lawrence; largest size at maturity occurs in the Bay of Fundy and areas along the continental slope.

Female lobsters can mate in the hardshell condition but most successful mating occurs in the hours immediately following the female molt. Fecundity increases logarithmically with size, but there appears to be considerable variation between individuals. Unfertilized eggs seldom attach properly, and approximately one-third of properly attached eggs are lost before hatching. Females appear to follow a 2-yr oviposition cycle throughout most of their reproductive lives, and two fertile extrusions have been documented from a single mating.

INTRODUCTION

In most areas of biological study the information base is built up in two stages: an initial descriptive phase, in which observations are catalogued, and an experimental phase, in which hypotheses are tested and principles evolved. It is indicative of how little we know about lobster reproductive biology that our present knowledge is based almost entirely on descriptive information, that we have very little grasp of how and why things happen, and only limited ability to predict or control responses. Fortunately, the situation is changing. The combined needs of fisheries management and lobster culture are focusing attention on our primitive understanding of reproductive biology and providing incentive for the necessary long-term studies and detailed experimental work.

Some well established "facts" about lobster reproductive biology will be questioned in this review because new information has cast doubt on old assumptions and offered explanations for facts that have been difficult to understand with established concepts. For example, it is widely accepted that fertilization occurs externally, the eggs being fertilized as they pass over the seminal receptacle enroute to attachment on the pleopods (see Wilder 1957, 1973), but it is also well known that the seminal receptacle contains a sperm plug which forms an apparently impenetrable barrier between the spermatozoa and the external environment, and this sperm plug appears little changed after oviposition and fertilization. How then do the spermatozoa get to the outside? What manner of sperm plug transmutation makes this possible? Farmer (1974) suggested the spermatozoa of *Homarus* never do reach the outside, that shortly before oviposition a pair of transitory ducts are formed for the specific purpose of conducting spermatozoa from the seminal receptacle to the oviducts for *internal* fertilization. If this is indeed the case, the mechanism of fertilization in lobsters would be similar to that in some crabs, and some perplexing questions concerning lobster fertilization would be answered.

Some field techniques for the study of lobster reproduction have been in use for years but the methodology now varies from one investigator to another, making comparison of data impossible. Other techniques are relatively new and should be more widely used. Still others are tentative, but if used in conjunction with established criteria can yield meaningful results. One of the objectives of this review is to make current techniques more widely known and encourage the standardization of procedures.

Finally, the information presented here is not restricted to the lobster in Canadian waters; we have drawn freely on all relevant information on *Homarus* in order to provide perspective on a subject about which too little is known.

MALE REPRODUCTION

A male lobster is physiologically mature when capable of producing mature spermatozoa, but is not *functionally* mature until capable of mating with and inseminating a female. Male lobsters of only 40-45 mm CL produce mature spermatozoa (Briggs 1976; Krouse 1973), but males of this size are well below the smallest sizes at onset of maturity in females. Templeman (1935) conducted mating experiments with lobsters from the southern Gulf of St. Lawrence and found that males between 60 and 65 mm CL were unable to mate. We conducted similar mating experiments with five males from the same area, ranging in size from 50-65 mm CL and found that, although all had mature spermatozoa in the vasa deferentia, none was interested in mating. Since male maturity has been equated with presence of spermatozoa (Briggs 1976; Krouse 1973; Templeman 1936b), the difference between physiological and functional maturity must be borne in mind.

INDICATORS OF MATURITY

Vas deferens weight

If a "vas deferens factor" (VD_f) is derived from the combined weight of both vasa deferentia and the cube of the carapace length,

$$VD_f = \frac{\text{Vasa Deferentia (mg)}}{(\text{carapace length in cm})^3} \times 100$$

and plotted against carapace length the vasa deferentia can be seen to increase rapidly in weight relative to carapace length. Data from the two extremes in Canadian waters - the Bay of Fundy and the southern Gulf of St. Lawrence - show that a given VD_f occurs at a different carapace length in the two areas. A VD_f of 100, for example, occurs at a carapace length of 67 mm in the southern Gulf, and at approximately 122 mm in the Bay of Fundy.

Cheliped size

Templeman (1935) expressed cheliped propus length as a percentage of total body length and plotted this against total length. He found that male chelipeds increased in relative length more rapidly after maturity and this fact could be used to identify size at onset of male maturity in different areas. Unfortunately, total body length is seldom recorded in modern studies because it is notoriously unreliable, and Templeman's cheliped measurement as a percentage of carapace length produces a useless scatter of points when plotted against CL. Furthermore, Templeman's Figure 2 (p. 215) for the crusher cheliped of Grand Manan males shows a considerable spread of values and an ill-defined inflection, indicating even Templeman's original method may have required very large samples for meaningful results. When cheliped length alone is plotted against carapace length the fit of the data is much improved but the inflection is obscure, making the technique useless for detecting onset of maturity.

Recently P.A.M. Anderson, working at this laboratory, recognized that volume or mass of the crusher propus was much greater in mature males, and he devised an index of volume based on the product of length, width and thickness of the crusher propus divided by carapace length. When plotted against CL for a range of male sizes this "Anderson cheliped index" produces a clear inflection corresponding to approximate size at onset of maturity. This is demonstrated in Fig. 1, where crusher propus length and the Anderson index are independently applied to the same set of data for males from Grand Manan.

The equation for the Anderson cheliped index can be written as:

$$CPV = \frac{L \times W \times D}{CL} \times 10$$

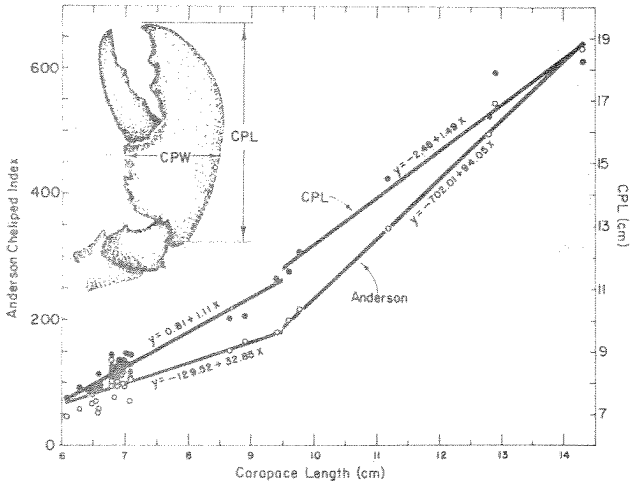


Fig. 1. Anderson cheliped index compared to a simple plot of crusher propus length against carapace length. Note the Anderson index flattens the immature phase, accentuates the mature phase and makes the inflection apparent even with a relatively small sample. Regression of CPL on CL obscures the inflection and could be interpreted as a straight line.

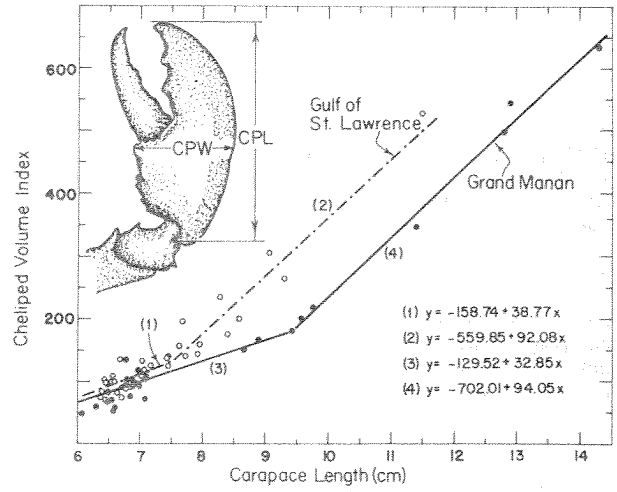


Fig. 2. Anderson cheliped index plotted against carapace length for male lobsters from Grand Manan and the southern Gulf of St. Lawrence. Note similarity in slopes of mature and immature regression lines for the two areas, but different carapace lengths at inflection (75 mm vs. 95 mm).

where CPV is the crusher propus volume
L is crusher propus length (CPL) from posterior articulation to the most anterior point down the midline (Fig. 1)
W is width across the palm (CPW)
D is maximum thickness, or depth (CPD) measured at approximately the location of the CPW symbol in Fig. 1
CL is carapace length.

All measurements are in centimeters.

Drawing on actual data, a Grand Manan male of 8.9 cm CL might have an Anderson index of only 168:

$$\frac{10.5 \times 4.99 \times 2.86}{8.90} \times 10 = 168$$

whereas a male of comparable size from the Gulf of St. Lawrence could have an Anderson index as large as 304:

$$\frac{11.96 \times 6.34 \times 3.62}{9.04} \times 10 = 304$$

indicating earlier maturity in the male from the Gulf of St. Lawrence. Regressions of Anderson index on CL for a sample of males from each area are shown in Fig. 2. The slopes of immature and mature phases for the different areas are remarkably similar, but the inflection for Gulf males occurs at 7.5 cm CL compared to 9.3 cm CL for Grand Manan males. It should be pointed out that the relationship between this inflection and functional maturity is not yet established, and these are small samples so additional data will undoubtedly shift these points somewhat. However, the available information does demonstrate the potential of the Anderson index for assessing male maturity in different areas.

MATING BEHAVIOR

Although the mating of hard-shell females is known to occur (Dunham and Skinner-Jacobs 1978; Waddy unpublished), most successful matings occur less than 3 h after the female completes ecdysis. Behavior of the male at this time suggests the release of a pheromone by the female, and the intensity of attraction decreases with time. According to Templeman (1934), if a male is transferred to a tank containing a female that molted within the last 12 h, mating will usually occur, but this seldom happens if more than 2 d have elapsed. Our experiences extend Templeman's conclusions somewhat: we have found that mating usually occurs in the first 24 h, and occasionally as much as 2 d after the molt (see Templeman 1936b).

A male that has successfully mated with one female is capable of mating with another a few hours later (Hughes and Matthiessen 1962; Templeman 1934), and although males both smaller and larger than the molted female may mate successfully, we agree with Templeman (1936b) that the greatest incidence of successful mating occurs when the male is slightly larger than the female. Comparable size may also be necessary for successful sperm transfer; a female mated to a smaller male will often attempt to mate a second time if a larger male becomes available, whereas this seldom happens after a successful mating with a large male (Easton 1976). The observations of Atema et al. (1977) indicate the opportunity for multiple paternity would be reduced by the presence of the protective male, yet Nelson and Hedgecock (1977) give electrophoretic evidence of multiple paternity in wild lobsters. Opportunities for multiple paternity are limited by both size and time. A much larger male could easily displace a smaller male for possession of a female, but males

that are too large for a given female show little interest in her. On the other hand, a male that is too small is unable to turn the female over, even though he has the inclination to do so. Finally, the gelatinous matrix of the spermatophoric mass hardens in the seminal receptacle of a mated female and after 9 or 10 h is sufficiently hard to prevent penetration by another male (Templeman 1934), a fact that complicates the reports of Dunham and Skinner-Jacobs (1978) concerning intermolt mating of previously inseminated females.

FEMALE REPRODUCTION

A female lobster can be considered mature when capable of extruding eggs, but since this capability is difficult to assess through external examination, size at onset of maturity is often estimated from the size of ovigerous females in the population. For example, Wenner et al. (1974) plotted sizes of ovigerous female crabs on probability paper and from the resulting straight line obtained an instantaneous estimation of mean minimum size at onset of sexual maturity and a standard deviation about the mean.

Unfortunately, maturity estimates based on incidence of ovigerous females overlook the large number of mature females removed from the population by intensive fisheries in areas where the legal minimum size is below the mean minimum size at onset of egg production. Lobsters molting to maturity in summer are removed from the population by intensive fall or spring fisheries before they have the opportunity to extrude eggs. The few that do survive to extrude eggs appear as a much smaller proportion than they represent. In our opinion the best way to avoid this bias and obtain an accurate indication of proportion maturing at a given size is to examine gonadal development in conjunction with other maturity criteria.

INDICATORS OF MATURITY

Relative abdomen width

Templeman (1935) observed that relative width of the second abdominal segment increased with approach of maturity and suggested (1944) it could be used both for comparing sizes at which females from different localities began carrying eggs, and for determining the size at which a certain percentage becomes mature.

Squires (1970) stated that egg laying often precedes relative increase in abdomen width, but we have never observed this. On the contrary, relative increase in abdomen width usually commences three or more molts before first oviposition (Fig. 3).

As described by Templeman (1935), abdominal width was measured between the pleural spurs as maximum *inside* width, and this measurement has been used by most who have applied the method since. However, our measurements, and those of Briggs (1976), are based on maximum *outside* width of the second abdominal segment because in our opinion this is a more rapid and accurate measurement under field conditions. For convenience we express abdomen width as a percentage of carapace length and refer to it as a "maturity index".

Krouse's (1973) data on abdomen width include lobsters as small as 30-35 mm CL, and show that

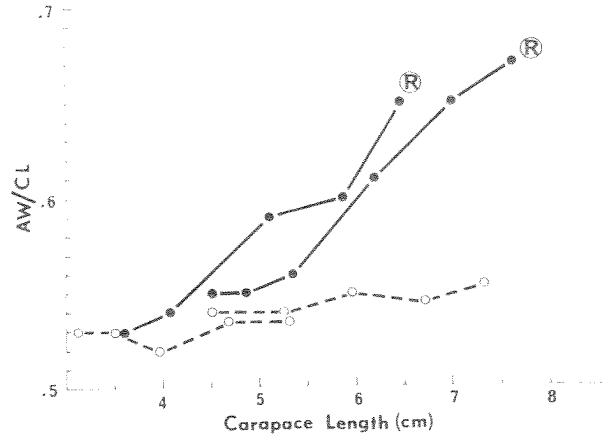


Fig. 3. Change in relationship between abdomen width (AW) and carapace length (CL) of juvenile lobsters over successive molts. Two females (solid lines) and two males (broken lines) demonstrate change. Each point represents one molt. In females relative abdomen width increased over 3 or 4 molts to maturity, indicated by ovary reabsorption (R) at an AW/CL of 0.65 and 0.67.

initial separation of male and female AW/CL occurs between 35 and 45 mm CL (Fig. 4). Our observations on rate of AW/CL change in laboratory reared juveniles substantiate this (Fig. 3). Krouse's data for inshore Boothbay Harbor lobsters show an inflection at a larger CL than that obtained for offshore lobsters by Skud and Perkins (1969) suggesting the inshore lobsters mature at a larger size than their counterparts in the canyons of the continental slope.

Thus AW/CL and the relationship of AW/CL to CL can be used as an indication of maturity within a defined geographical area, and can also be used to compare size at maturity in different areas, provided the relationship between ovary development and abdomen width is first defined for each area through direct observation. In the Gulf of St. Lawrence, for example, 97% of females with an AW/CL of 0.67 (maturity index of 67) or greater will be potentially mature.[1] This also appears to be the case for Grand Manan females, but this may not be true in all areas.

Cement glands

The cement glands on the endopodite of the pleopod can be used as an indicator of maturity. These glands wax and wane with ovarian development, and the presence of well developed cement glands on a non-ovigerous female is evidence of impending oviposition and, therefore, of maturity. When used in conjunction with other criteria the cement glands can be especially useful for detecting maturity in females prior to the spawning season. However, caution is advised in the application of this technique because the exact relationship between cement gland and ovarian development is not yet

[1] It should be borne in mind that females with an AW/CL considerably less than 0.67 can also be mature.

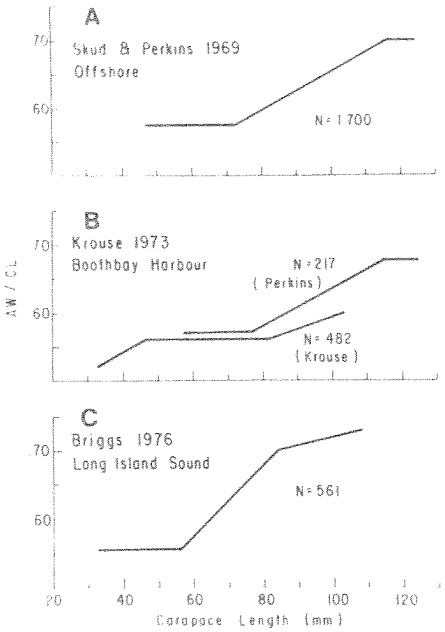


Fig. 4. Relationship between carapace length and width of the second abdominal segment of female *Homarus americanus* from different localities: A- offshore canyons of southern New England continental shelf; B- inshore areas near Boothbay Harbor, Maine; C- Long Island Sound. Curves are stylized and not identical to those fitted by the authors.

known. For example, some cement gland development does occur in prepubertal females and can be detected by microscopic examination of the pleopods. Cement gland development associated with late vitellogenesis (and therefore maturity) is readily apparent on gross examination of the pleopod, and we are now compiling a photographic record of cement gland development at all stages of the reproductive cycle, from which we hope to develop criteria for estimating ovary development and predicting time of oviposition.

Spermatophoric mass

Females from Grand Manan and the southern Gulf of St. Lawrence almost always have spermatophores in the seminal receptacle if they have developing or mature ovaries, and seldom do if their ovaries are completely immature. There are, however, enough exceptions to make presence or absence of a spermatophore an unreliable indicator of maturity. For example, Krouse (1973) found a surprising number of inshore Maine lobsters with developing or mature ovaries that lacked spermatophores in the seminal receptacle.

Oviduct color

It can be extremely useful to know what proportion of mature females in a given locality actually survive to produce a second brood, and body size is of no value in this determination. However, the distal portion of the oviduct can assist in this determination. In an immature female this distal portion is clear, but in females known to have extruded eggs this portion is a distinct yellow. While presence of the yellow color is a good indication of previous oviposition, absence of yellow color is not proof that no previous oviposition has occurred. The yellow coloration gradually fades with time and may be difficult to identify after 2 yr.

SIZE AT MATURITY

Smallest size at maturity apparently occurs in western Long Island Sound, where females only 55-59 mm CL may be ovigerous (Briggs 1976), and 50% maturity occurs at approximately 70-74 mm CL (Fig. 5). The Bay of Fundy-Grand Manan area has the largest size at onset of maturity for "inshore" lobsters, comparable to that for lobsters from the

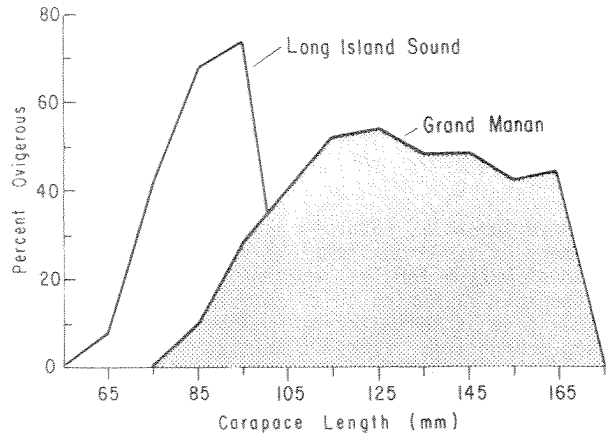


Fig. 5. Size of ovigerous females from two physiological extremes in the range of *Homarus americanus*. Carapace lengths indicated are midpoints in 10-mm size groups. Data for Long Island Sound from Briggs (1976), and for Grand Manan from Groom (1977).

offshore canyons of southern Georges Bank (Perkins and Skud 1966). The smallest ovigerous females from the Bay of Fundy are close to 90 mm CL (Groom 1977; McLeese and Wilder 1964; Templeman 1936a), and Groom's (1977) data indicate 50% maturity is not reached at Grand Manan until 110-120 mm CL (Fig. 5). These data indicate Grand Manan is one area where a *maximum* size limit might make sense in terms of preserving reproductive potential. For example, in the Seal Cove area of southern Grand Manan, an area of considerable productivity, over 99% of landed females are completely immature.

In the southern Gulf of St. Lawrence lobsters as small as 59 mm CL are found with eggs (Templeman 1936a, 1944) and in Newfoundland, the smallest ovigerous females are between 69 mm (Ennis 1971) and 76 mm (Squires 1970). Minimum size at maturity increases in a southerly direction along the eastern shore of Nova Scotia from Cape Breton to southwest Nova Scotia, and reaches a maximum in the vicinity of Grand Manan.

Several hypotheses have been advanced to explain why lobsters mature at different sizes in different areas. It has been suggested that high exploitation rates in the fishery combined with size limits below mean minimum size at maturity exert genetic pressure for maturation at a smaller size. It has also been suggested that exposure to the

continental slope results in larger minimum size at maturity because of genetic influence from offshore stocks, both through larval drift and directed movement of adults. However, the most plausible explanation appears to be that first advanced by Templeman (1936a), who contended that high summer temperature favors early maturity whereas consistently colder water retards maturation. He noted that bottom temperature at the western end of Northumberland Strait could be 17°C while at a comparable depth the eastern end was only 8.4°C, and that the smallest berried females also occurred at the western end, whereas those along the northeast and southeast coasts of Prince Edward Island, including the eastern end of Northumberland Strait, were 1-3 cm longer in total length. These conclusions are substantiated by Smith (1977), who reported a progressive decrease in mean size of ovigerous females from the eastern (coldest) end toward the western (warmest) end of Long Island Sound (Fig. 6).

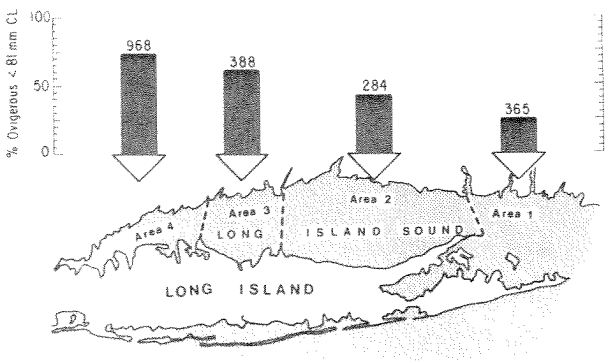


Fig. 6. Relationship between locality and size of ovigerous females in Long Island Sound during 1976. Vertical bars show percentage of berried females smaller than 81 mm CL in each of four sampling areas indicated on map below each bar. Number examined in each area indicated above bar. Data from Smith (1977).

Although the Gulf of St. Lawrence and western Long Island Sound are both areas of high lobster density and small size at maturity (lending support to the density-exploitation hypothesis), there are also areas of high density where maturity occurs at a large size (southern end of Grand Manan, for example). The only factor consistently associated with small size at maturity appears to be relatively high summer temperature, and laboratory rearing experiments also support this.

OVARY DEVELOPMENT

The ovary goes through changes in color and size during development, and the ovary of a large female contains relatively more ova than a smaller one at a given stage of development. To reflect this, and to compensate for length:volume relationships, we use an ovary factor (O_f):

$$O_f = \frac{\text{ovary weight (mg)}}{(\text{carapace length in cm})^3} \times 10.$$

When used in combination with ovary color and ova diameter, the ovary factor is useful for expressing comparative ovary development over the full range of sizes (Table 1). The criteria used by other authors to distinguish ovary categories are given in Table 2.

Table 1. Stages and morphological criteria used to classify ovary development in the American lobster *Homarus americanus*.

Stage 1: Immature
Ovary white
Oocytes <0.5 mm
O_f <100

Stage 2: Immature Developing
Yellow, beige, pale green
Oocytes <0.8 mm
O_f <100

Stage 3: Developing
Light to medium green
Oocytes <1.0 mm
O_f <200

Stage 4: Developing
Medium to dark green
Ooctyes 0.1-1.6 mm
O_f <325

Stage 5: Developing
Dark green
Oocytes 1.0-1.6 mm
O_f >325

Stage 6: Ripe
Dark green
Oocytes 1.4-1.6 mm
and free in the ovary
O_f >400

Stage 6A: Oocytes free

Spent or Reabsorbing
White or yellow with
dark green residual ova
Flaccid in early stages

OVIPOSITION AND EGG ATTACHMENT

Egg laying occurs in different months in different geographical areas, starting as early as May and ending as late as October. The period June through September encompasses most spawning activity, but in cold water areas like the Bay of Fundy and Grand Manan it can occur well into October. Oviposition in each area occurs within a fairly narrow time period and often as two distinct peaks, possibly associated with different age-classes.

Relationship between mating and oviposition

These two events are completely independent in the American lobster, and oviposition may follow mating by as little as 1 mo or more than a year, and will occur even if the female has not mated or been in contact with a male since the previous molt. The difference is that unfertilized eggs are seldom carried for more than a few weeks and usually are lighter in color.

Since only part of the stored spermatozoa is used when eggs are extruded (Bumpus 1891; Krouse 1973; Templeman 1936b) it is possible for at least

Table 2. Comparison of criteria used to define ovary categories for *Homarus americanus*.

Category	Mean size of ova (mm)			Color of ovary				Ovary factor[b]
	Skud and Perkins (1969)	Squires[a] (1970)	Krouse (1973)	Skud and Perkins (1969)	Krouse (1973)	Byard (1975)	Waddy (unpubl.)	Byard (1975)
Immature	<0.4	-	≲0.4	white	translucent white	white, creamy	white	9-120
Developing	0.4-0.8	-	0.5-0.7	yellow	yellow-orange	light to dark green	beige, gold, orange, yellow, light to med. green	127-320
Mature	>0.8	1.3-1.5	≳0.8	green	dark green	dark green	dark green	>320

[a]Squires (1970) used only two categories. Ova from 1.3-1.5 mm were considered "potentially mature."

[b]Ovary factor = $O_f = \frac{\text{ovary weight (mg)}}{(\text{CL in cm})^3} \times 10$

two successive batches of eggs to be fertilized from a single mating, a phenomenon we have observed in the laboratory. Without the capability for multiple extrusion the relative contribution of larvae by large females might be reduced in spite of their greater fecundity because mating usually occurs only in the freshly molted condition and large females may go several years without molting. The capability of fertilizing two broods from a single mating changes that situation, as a female need molt and mate only every fourth or fifth year to continue fertilizing eggs biennially.

Fecundity

Herrick (1909) used the volumetric method to estimate fecundity of lobsters from Vineyard Sound and produced a relationship based on total length. Saila et al. (1969) used an electronic counter to estimate fecundity of lobsters from waters off Rhode Island and Massachusetts as well as from the Gulf of St. Lawrence, and found a logarithmic relationship with carapace length. They concluded Herrick overestimated fecundity at all lengths.[2] Perkins (1971) applied a similar electronic counting method to lobsters from the canyons of the continental shelf off southern New England, and obtained fecundity values similar to those of Saila et al. However, Squires (1970) used the volumetric method to estimate fecundity of females at Port au Port Bay, Newfoundland, and his counts were close to those of Herrick for the sizes examined (74-103 mm CL). These various fecundity estimates are summarized in Table 3 and Fig. 7.

The differences in these various estimates may be due to methodology or geography. Saila et al. and Perkins used electronic counters; Herrick and

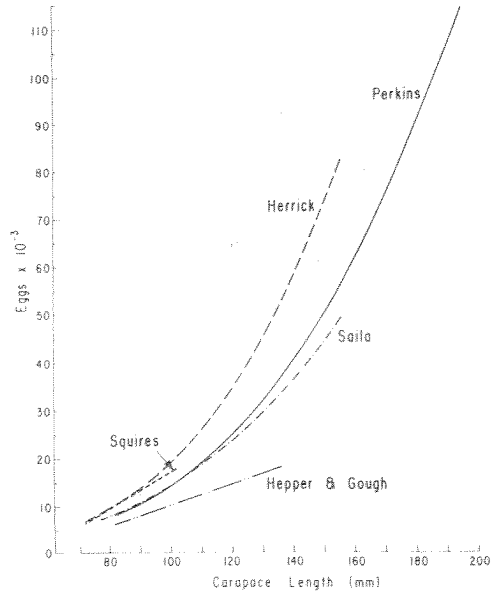


Fig. 7. Regression lines for fecundity of *Homarus* as reported by different authors. The lowest line (Hepper-Gough) is for *H. gammarus*; all others are for *H. americanus*. See text for elaboration.

Squires estimated volumetrically. Yet Squires validated his estimates by actual counts on 25% of the lobsters and found the error to be less than 2%, compared with a maximum error of ±2% reported by Perkins for electronic counting, so the higher values obtained by Squires and Herrick probably are not due to counting technique.

Squires noted great individual variation in fecundity, and this is also obvious in the descriptions of Herrick and Perkins, so small samples

[2]The regression equation in Saila et al. (1969) is incorrectly written without the negative sign (-1.6017), and most of the fecundity values in their Table 2 are incorrect for Herrick's data as well as their own.

Table 3. Fecundity of *Homarus* (as eggs close to hatching) calculated for 5-mm increments in carapace length from regression equations supplied by the various authors.

Carapace length	Herrick (1909)	Squires (1970)	Perkins (1971)	Saila et al. (1969)	Hepper & Gough[a] (1978)
72	6017	5585		5236	
77	7536	7483		6346	
82	9307	9381	7248	7600	5364
87	11351	11279	8737	9004	6453
92	13691	13177	10423	10567	7542
97	16350	15075	12318	12297	8630
102	19353	16973	14436	14202	9719
107	22723		16790	16288	10809
112	26484		19394	18565	11897
117	30663		22261	21039	12985
122	35283		25405	23719	14079
127	40372		28840	26611	15163
132	45955		32579	29724	16251
137	52058		36636	33065	17340
142	58709		41025	36640	
147	65935		45761	40459	
152	73763		50858	44527	
157	82222		56329	48853	
162			62189		
167			68452		
172			75134		
177			82247		
182			89808		
187			97830		
192			106328		
197			115318		

[a]For *Homarus gammarus*. All others for *Homarus americanus*.

could be misleading. Yet, sample sizes among three of these four are comparable to the largest, and presumably least-biased sample - the 4645 examined by Herrick.

Time of year in which the samples are taken is also important. According to Perkins egg loss between extrusion and hatching averages 36%, so counts on new eggs would be higher than on eggs about to hatch. However, the samples by Herrick, Perkins, Squires, and Saila et al. were all taken about the same time of year.

Squires felt that fecundity at a given size can vary from one locality to another. This possible source of variation among the different fecundity estimates cannot be discounted because the investigators obtained their lobsters from quite different areas. Standardized egg counts from different areas would clarify the question of geographic variation and we feel that until those are available, or other more explicit studies are conducted, Herrick's fecundity estimates should not be dismissed.

The fecundity estimate of Hepper and Gough (1978) indicates the European lobster, *Homarus gammarus*, carries considerably fewer eggs than its American counterpart at a given carapace length (Table 2). In their opinion, the relationship between fecundity and body length in *H. gammarus* is linear rather than logarithmic as it appears to be in *H. americanus* (Fig. 7). This may be a difference between species or merely a reflection of small sample size, limited range of sizes sampled, and individual variation in fecundity.

As can be seen in Table 3, doubling the carapace length in the American lobster can increase the brood size by 8 or 9 times. Assuming they produce broods biennially, as do smaller mature females, the potential contribution (relative fecundity) of very large females then becomes a function of their relative frequency in the population. In some areas fishermen are beginning to exploit previously untouched stocks of very large lobsters (150-200 mm CL). If the relative fecundity of these jumbos is significant, their loss could seriously depress recruitment for many years to come, so it would seem an accurate estimate of their relative fecundity is very important.

Egg attachment and egg loss

Fertilized eggs usually attach successfully but unfertilized eggs often do not. Unfertilized eggs may be lost soon after oviposition (Knight 1918), but it is not unusual for a fair number to remain for several weeks. Although infertility is one cause of poor egg attachment it is not the only one; there are different degrees of egg adhesion, and probably as many reasons for them. It is often stated that a rough substrate and at least 45 cm water depth are essential for proper attachment, but we routinely obtain successful attachment in smooth bottom tanks with only 25 cm water depth, and have had successful attachment in only 14 cm of water.

It is fairly common for eggs that have been fertilized and attached to suffer attrition in succeeding months. There probably are many causes for excessive attrition, although disease, parasitism and unfavorable social conditions are most commonly cited. We have, for example, noted a high incidence of egg loss associated with infestations by the nemertine *Carcinonemertes* sp. Although we have no evidence this worm does any damage directly, it lays its own eggs on the stalks of lobster eggs and the presence of a large number of worms and worm eggs may be sufficiently irritating to cause the female to remove her own eggs as part of the cleaning process. In addition, normal activity, capture and release from traps and similar factors occurring over the long incubation period account for natural attrition estimated at 36% (Perkins 1971).

Abnormally colored eggs (red, yellow, and pale green) are fairly common in the laboratory and may be caused by diet. These can be fertile and will hatch normally. Orange and yellow eggs are occasionally found on wild lobsters as well, but the cause of this is not known.

ANNUAL REPRODUCTIVE CYCLE

Although there has been uncertainty, it now appears the 2-yr ovary cycle continues throughout the reproductive life of the lobster, and that molt and reproductive cycles are differentially controlled by temperature so that conflict between the two is minimized. The presence of eggs on the pleopods does not appear to inhibit premolt development as it has been reported to do in crayfish. Females in berry progress through premolt at what appears to be a normal rate, and occasionally will be in mid to late premolt when the eggs hatch. Females do molt while carrying eggs, but this is by no means common. There are several instances involving laboratory specimens exposed to unusual temperature or photoperiod cycles, but one wild-caught female was brought into this laboratory with a full complement of eggs at a late stage of development, and she completed a normal molt within days. Without question, she would have molted in the wild.

There are indications the transition from C_4 ("intermolt") to D_0 (premolt) is delayed when the ovary is either maturing or mature, as the female is almost always in C_4 at the time of oviposition. This ensures the molt and reproductive cycles are synchronized so that the eggs will develop and hatch before the female can complete premolt at the temperatures normally experienced in the wild. There is also some indication that final ovary maturation may be disrupted if it coincides with middle to late premolt (Fig. 8). Having the ovary reabsorbed due to an impending molt would ensure the conservation of energy committed to the ovary, and might serve to re-synchronize the molt and reproductive cycles so oviposition could occur the following summer when the female would not be molting.

Reproductive events for a typical female American lobster over a 7-yr period are summarized in Fig. 9. First mating occurs at the pubertal molt (occasionally at the prepubertal molt), when primary vitellogenesis is under way. Vitellogenesis is reduced during the winter but secondary vitellogenesis commences in the spring. At this time the ovary matures, cement glands become engorged and eggs are extruded (Adult-I year). The eggs are

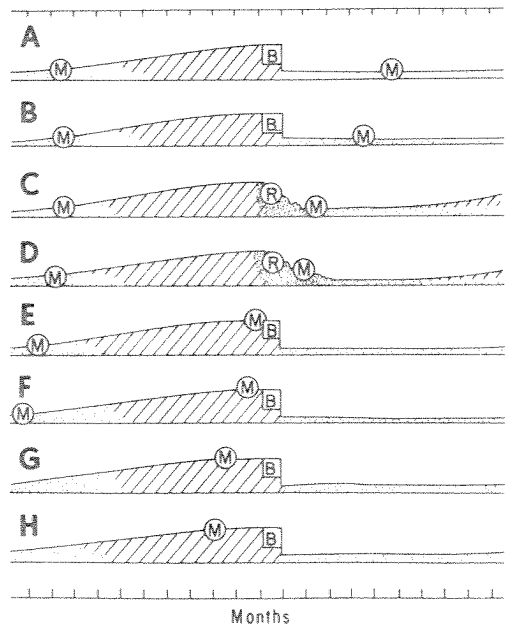


Fig. 8. Molt (M), oviposition (B) and ovary reabsorption (R) in females held at 15°C for 6 summer months in a 9-mo year. Ovary reabsorption occurred only when the molt and reproductive cycles coincided so that molt would occur shortly after oviposition. Adapted from Aiken and Waddy (1976).

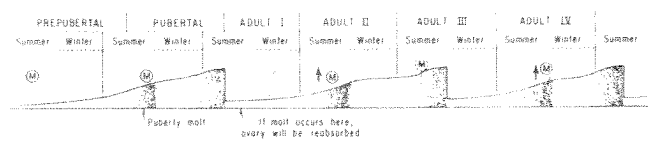


Fig. 9. Reproductive cycles for typical female *Homarus americanus* over a 7-yr period. Ovary growth and vitellogenesis (intensity indicated by stippling) occurs in two stages, the second of which terminates in oviposition, indicated by a vertical drop in the line. Hatching (arrow) and molt (M) usually occur in one summer and oviposition in the next but occasionally, especially in warm water areas, molt and oviposition will occur in the same summer. Adapted from Aiken and Waddy (1976).

carried through that summer and the succeeding winter, and hatch the following summer (Adult-II year). Molt and mating normally occur the same summer the eggs hatch. A significant percentage of females from the southern Gulf of St. Lawrence molt in late summer and extrude eggs about a month later (Aiken and Waddy 1976; Byard 1975). The warm summer temperatures in the Gulf of St. Lawrence may be the cause of this and, if so, it probably occurs in other areas as well (western Long Island Sound, for example). Although molt frequency decreases with age or size, existing evidence indicates the 2-yr ovarian cycle continues throughout most of the reproductive life of the lobster.

REFERENCES

Aiken, D. E., and S. L. Waddy. 1976. Controlling growth and reproduction in the American lobster. Proc. World Maricul. Soc. 7: 415-430.

Atema, J., S. Jacobson, and L. Stein. 1977. Pair formation and mating behavior in the lobster, . In: Workshop on lobster and rock lobster ecology and physiology (B.F. Phillips and J.S. Cobb, eds.), p. 19. CSIRO Div. Fish. Oceanogr. Circ. 7: 300 p.

Briggs, P. T. 1976. Aspects of the American lobster in Long Island Sound, New York. NOAA, NMFS, Comm. Fish. Res. Dev. Act, Job Completion Rep., New York Project 3-212-R, 37 p.

Bumpus, H. C. 1891. The embryology of the American lobster. J. Morph. 5: 215-262.

Byard, E. H. 1975. Female specific protein and reproduction in the lobster. Ph.D. Thesis, Univ. West. Ont.

Dunham, P. J., and D. Skinner-Jacobs. 1978. Intermolt mating in the lobster (*Homarus americanus*). Mar. Behav. Physiol. 5: 209-214.

Easton, M. D. L. 1976. Lobster population modelling. In: Ann. Rep. Fish. Mar. Serv. Biol. Sta., St. John's, Newfoundland, p. 14.

Ennis, G. P. 1971. Lobster (*Homarus americanus*) fishery and biology in Bonavista Bay, Newfoundland 1966-70. Fish. Res. Board Can. Tech. Rep. 289: 17-46.

Farmer, A. S. 1974. Reproduction in *Nephrops norvegicus* (Decapoda: Nephropidae). J. Zool., Lond. 174: 161-183.

Groom, W. 1977. Lobster project, 1977, Grand Manan Island. In: "Fish'N'Ships" (W. Groom, ed.) p. 1-10. N.B. Dept. Fish. Inform. Notice Bay of Fundy Fishermen 1, 12 p.

Hepper, B. T., and C. J. Gough. 1978. Fecundity and rate of embryonic development of the lobster, *Homarus gammarus* (L), off the coast of North Wales. J. Cons. Int. Explor. Mer 38: 54-57.

Herrick, F. H. 1909. Natural history of the American lobster. Bull. Bur. Fish. 29: 149-408.

Hughes, J. T., and G. C. Matthiessen. 1962. Observations on the biology of the American lobster *Homarus americanus*. Limnol. Oceanogr. 7: 414-421.

Knight, A. P. 1918. Lobster investigations at Long Beach Pond, N.S. Contrib. Can. Biol. 1917-1918: 53-71.

Krouse, J. S. 1973. Maturity, sex ratio and size composition of a natural population of American lobster, *Homarus americanus*, along the Maine coast. Fish. Bull. 71: 165-173.

McLeese, D. W., and D. G. Wilder. 1964. Lobster storage and shipment. Fish. Res. Board Can. Bull. 147, 69 p.

Nelson, K., and D. Hedgecock. 1977. Electrophoretic evidence of multiple paternity in lobster *Homarus americanus* (Milne-Edwards). Am. Natur. 111: 361-365.

Perkins, H. C. 1971. Egg loss during incubation from offshore northern lobsters (Decapoda: Homaridae). Fish. Bull. 69: 451-453.

Perkins, H. C., and B. E. Skud. 1966. Body proportions and maturity of female lobsters. Amer. Zool. 6: 615 (abstract).

Saila, S. B., J. M. Flowers, and J. T. Hughes. 1969. Fecundity of the American lobster, *Homarus americanus*. Trans. Am. Fish. Soc. 98: 537-539.

Skud, B. E., and H. C. Perkins. 1969. Size composition, sex ratio and size at maturity of offshore northern lobster. U.S. Dept. Int., Fish. Wildl. Serv. Spec. Sci. Rep. 598, 10 p.

Smith, E. M. 1977. Some aspects of catch/effort, biology, and the economics of the Long Island Sound lobster fishery during 1976. NOAA, NMFS, Comm. Fish. Res. Dev. Act, Final Rep. Connecticut Project No. 3-253-R-1: 97 p.

Squires, H. J. 1970. Lobster (*Homarus americanus*) fishery and ecology in Port au Port Bay, Newfoundland, 1960-65. Proc. Nat. Shellfish. Assoc. 60: 22-39.

Templeman, W. 1934. Mating in the American lobster. Contrib. Can. Biol. Fish. N.S. 8: 423-432.

1935. Local differences in the body proportions of the lobster, *Homarus americanus*. J. Biol. Board Can. 1: 213.

1936a. Local differences in the life history of the lobster (*Homarus americanus*) on the coast of the Maritime Provinces of Canada. J. Biol. Board Can. 2: 41-88.

1936b. Further contributions to mating in the American lobster. J. Biol. Board Can. 2: 223.

1944. Abdominal width and sexual maturity of female lobsters on Canadian Atlantic coast. J. Fish. Res. Board Can. 6: 281-290.

Wenner, A. M., C. Fusaro, and A. Oaten. 1974. Size at onset of sexual maturity and growth rate in crustacean populations. Can. J. Zool. 52: 1095-1106.

Wilder, D. G. 1957. Canada's lobster fishery. Can. Geogr. J., Sept.

1973. The American lobster. Environment Canada FMS Fisheries Fact Sheet No. 5: 8 p.

MATURITY AND FECUNDITY (R. Harris, rapporteur)

Smith: Did Squires use counts or volumetric method for fecundity estimates?

Waddy: Squires used the volumetric method, but also did counts which were within 2% of the volumetric fecundity estimates, so he felt the volumetric technique was valid.

Smith: So Herrick's volumetric method may be relatively more accurate than we would have thought?

Waddy: Yes.

Robinson?: Are you saying that Saila's values are wrong?

Waddy: No. But he felt that Herrick's fecundity estimates are too high. I feel that we should not discount Herrick's data.

Stasko: How about geographic differences in fecundity estimates?

Waddy: There may be geographic differences in fecundity estimates.

Caddy: We do not have such fecundity curves for Canadian lobster stocks?

Waddy: We have Squires' fecundity curve which covered a very limited size range and gave a straight line relationship. This would probably not be a straight line over a larger size range.

Caddy: I would like to ask about multiple egg laying. There are major implications if a fertilized female can lay fertilized eggs twice in succession after only one mating. Also, do not the pleopods have to be clean?

Waddy: Yes. She cleans them off very well.

Anthony: Are you saying that multiple broods do occur?

Waddy: Yes, they have occurred.

Anthony: How frequently? Are you saying the female lobster receives enough sperm in order to lay two batches of eggs without an intervening molt?

Waddy: Yes. Generally the female is on a 2-yr reproductive cycle regardless of molting and mating. If she is of a size class that molts every second year, she will molt, mate and then lay eggs. A larger female lobster that may molt only every 3-5 yr is probably on a 2-yr reproductive cycle, laying eggs every second year.

Stasko: Do you have any evidence for that? A 2-yr cycle for the smaller females is based on one year of energy for egg production and the next for molting. If you do not have the molting in the bigger females, then why is there still the 2-yr reproductive cycle?

Waddy: It takes that long for the ovaries to develop.

Anthony: I assume that if she has no sperm, she does not lay eggs but resorbs them.

Waddy: Whether or not she has sperm makes no difference in egg-laying. If she molts and is not fertilized, she will still lay eggs; it doesn't cause resorption of the ovary.

Robinson: Is the female on the 2-yr reproductive cycle with respect to the temperature at which these observations were made?

Waddy: That is with respect to the temperatures we find in this area. Females from the two extremes of Prince Edward Island and Bay of Fundy are on this cycle. For example, she may lay eggs in 1976, and hatch those eggs in 1977. At the time of hatching the ovary is not developed enough to produce another batch of eggs that year; she will then lay eggs again in 1978.

Robinson: What you are saying is that you have identified a crustacean physiological function for which temperature is not a rate determinant.

Waddy: Temperature has quite an effect on the reproductive cycle. It probably determines the size at maturity as well as the length of time the eggs are carried on the pleopods before hatching. In some areas eggs may be carried 11-12 mo and in another they may be carried 9-10 mo because of temperature difference. But even so, the ovary during that time will not have had enough time to develop to extrude eggs. They do not seem to ever hatch and extrude eggs the same year. The only time I have had that happen is in the lab when I have accelerated their hatching time and had them hatch in April and then gotten another egg-laying in the fall.

Morrissey: I have verifications of that from a tag return, tagged in April with a sphyrion tag. The lobster had mature ova and was recaptured the following summer. She was on a cycle of hatching eggs in one summer and extruding eggs in the latter part of the following summer. No data were recorded from this lobster to determine if molt had occurred.

Stasko: Susan, you have mentioned that the female will extrude eggs even if not fertilized. Are these eggs identifiable as unfertilized?

Waddy: Often the unfertilized eggs in the lab are medium green in color. The fertilized eggs are generally black-green.

Easton: We have had similar results in our studies. Females seem to have a 2-yr reproductive cycle. Approximately 10% of females berry twice without molting in a size range of 86-101 mm CL.

Caddy: In the case of females which lay eggs in the fall several months after mating, does the 2-yr cycle still apply?

Waddy: Yes, for example, she may molt in July, extrude eggs in October, hatch the following July, and then possibly molt the same year.

Van Engel: Molting and reproductive growth are antagonistic to each other in most crustaceans, so it is very reasonable that one is suppressed when the other is imminent. The lobster seems to be anomalous to most other crustaceans in that this long-term development does not fit what I think is the normal picture. The reproductive strategy would demand that the ovary recover very quickly after the eggs are extruded. What is the ovarian cycle?

Waddy: Once the female extrudes her eggs the ovary goes through a fairly quick recovery. She goes through primary vitellogenesis while carrying the eggs. The ovary is uniformly medium green but is not nearly mature when the eggs are hatched. Ova development is completed after hatching and molting.

Anthony: Is the reproductive cycle normal even if mating does not occur?

Waddy: Mating has no effect on the reproductive cycle. In my laboratory studies, the reproductive cycle for unmated lobsters was the same as for their fertilized counterparts. Also, in lab studies unfertilized females generally drop their eggs after a few weeks. Studies in P.E.I. have shown that the incidence of insemination is approximately 99%, so unfertilized mature females in this area are not a common occurrence.

Bennett: Should there be conservation of a breeding stock of males? Is a 1:1 sex ratio necessary?

Waddy: Yes, it is necessary to conserve mature males as well as mature females. It appears from our studies that males are "functionally" mature at the same size or even larger than females.

Easton: Small male lobsters have difficulty mating with large females.

Waddy: Successful mating can still occur when the male weighs approximately twice as much as the female.

Caddy: Minimum size limit of lobsters in Canada is usually below or close to size at first maturity. Maybe there should be a uniform size limit close to 50% maturity.

RECENT U.S. LOBSTER TRAP GEAR RESEARCH: APPLICATIONS AND IMPLICATIONS

by

R. J. Smolowitz and F. M. Serchuk

U.S. Dept. of Commerce
National Marine Fisheries Service
Woods Hole, Massachusetts 02543

ABSTRACT

Smolowitz, R. J., and F. M. Serchuk. 1980. Recent U.S. lobster trap gear research: applications and implications. Can. Tech. Rep. Fish. Aquat. Sci. 932.

In the United States, in regards to the lobster fishery, development is sponsored by the commercial sector and conservation engineering by state and federal governments. In recent years, there have been four major studies on trap selectivity and escapement, all results being supportive of each other. This is leading to acceptance by industry of sublegal escape vents as a management tool; however, the optimum size escape vent may not yet be in use.

INTRODUCTION

Fishing gear research is generally guided by two major objectives: development and conservation engineering. Development most often involves exploratory fishing and/or new gear trials, while conservation engineering is directed towards existing gear refinement to improve size and/or species selectivity, or gear-related harvest efficiency. In this paper, recent USA lobster trap research in both development and conservation engineering is reviewed and assessed.

DEVELOPMENT

The most recent USA lobster gear development efforts have been the offshore lobster explorations accomplished in the late 1960's and early 1970's. In these trials, a wide variety of trap types, handling systems, and exploitation strategies were tested and evaluated (USFWS 1968a, 1968b; NMFS 1971). Initial government successes were rapidly followed by industrial technological refinements of both gear and fishing techniques. The efficacy of these developments has resulted in the current USA offshore lobster fishery averaging over 4 million landed pounds annually and supporting 150 fishing vessels.

Current developmental research is mostly industry-sponsored and emphasizes new trap type and material testing. Lobstermen often add several new traps to their regular strings to informally compare yield and efficiency. Both manufacturers and lobstermen have recently expressed increased interest in new materials capable of extending trap longevity. Impetus for this may be a consequence of the ready availability of low-interest government loans to replace traps lost by "natural disaster" or foreign fishing activity. Lobstermen resultingly can now afford the more expensive but "maintenance-free" trap.

CONSERVATION ENGINEERING

Selectivity - Studies of gear selectivity often serve two main purposes: (1) knowledge of selectivity may permit catch to serve as an index of population changes; and (2) selectivity data may be integrated into management regimes to attain goals such as bycatch reduction and increased yield.

In recent years, most USA federal and state conservation engineering lobster trap research has been on size selectivity, in particular the reduction of the quantity of undersized individuals retained using escape vents. Results of these investigations (Krouse 1976, 1978; Krouse and Thomas 1975; Fair and Estrella 1976; Fogarty and Borden 1978; Smolowitz 1978a, 1978b; Pecci et al. 1978; Nulk 1978) have alerted New England fishermen and management personnel to the benefits of vents for sublegal-sized lobsters (sublegal escape vents).

Both the USA studies and past Canadian research (Templeman 1958) indicate that, for a carapace length of 81 mm, retention of legal-sized lobsters and release of undersized individuals (shorts) are maximized with a 45-mm wide escape vent. Additionally, if retention of marketable-sized *Cancer* crabs (≥90 mm) is desired, a circular vent of 58-mm diameter is most effective.

Escape vent size is a critical dimension. Small changes often result in major changes in catch. This is one reason why lath spacing regulations of the past did not work well. Escape vents should be fabricated to close tolerances.

The main emphasis of current sublegal escape vent research has been directed towards 100% retention of legal-sized lobsters. Using a 45-mm wide vent, however, would allow only about a 70% escapement of shorts (Nulk 1978). If a 47-mm vent is employed, greater than 90% escapement of shorts occurs accompanied by a 90% retention of the legals. While a small reduction in immediate yield is ensured with the 47-mm vent compared to the 45-mm vent, short- and long-term ghost fishing is significantly reduced as well as other forms of trap-related mortality and injury. Hence, longer-term benefits to yield and yield per recruit may be substantial.

Commercial adoption of escape vents in the lobster fishery will alter the size (length) selectivity of the trap and hence the length-frequency distribution of the catch towards larger lobsters. Since catch size composition may have shifted to smaller-sized individuals during the switch from wood laths to wire mesh, the use of escape vents would reverse this trend. Furthermore, various research studies indicated that use of a vented trap may result in increased efficiency. This situation has an analogue in otter trawl gear; trawls possessing larger codend meshes tend to be more efficient in retaining larger fish (Beverton and Holt 1957). The presumption here is that higher efficiency results from increased water flow through the larger meshes and/or less blockage of water flow by small fish. Although hypotheses for increased lobster trap efficiency have been advanced in relation to saturation effects or other behavioral aspects (Smolowitz 1978b; Fogarty and Borden 1978), the basic question of why a lobster enters a crowded trap needs further resolution.

Ghost fishing - The second major research area in New England conservation engineering studies has been ghost fishing of lobster traps. Ghost fishing is a regular occurrence (Sheldon and Dow 1975; Pecci et al. 1978), and may result in substantial economic losses, especially in a fishery comprised of 2 million traps (Smolowitz 1978b).

Present research data indicate that the effects of long-term cumulative ghost fishing can be easily mitigated by incorporation of a wooden lath into the trap.

Deterioration of wood laths is currently under investigation by Carl Berg, Marine Biological Laboratory in Woods Hole, in a study of marine borers, partially aimed at evaluating different types and thicknesses of wood for resistance to borer damage.

More difficult to resolve is a solution to the short-term ghost fishing problem due to a dearth of data to make a decision that is primarily economic in nature; the contrasting trade-off is damage and mortality rates versus cost of degradable section or link replacement. Adoption of a sublegal escape vent that affords 90-95% escapement of shorts will probably remedy the problem to insignificance or, at least ameliorate it to acceptable levels.

Promising efforts are in progress by Frank Ansuini, Lexington, Massachusetts, in developing a short-term degradable link that maintains full strength for a designated period and then rapidly deteriorates in a few days. The material can now be developed to last for any reasonable time period, although the cost may be about 25¢ each. Cheaper approaches are available but these still have problems (Blott 1978).

In summation, when determining sublegal escape vent size the goal should be to release 90-95% of the shorts instead of trying to retain 100% of the legals. Besides the benefits in long-term yields that may accrue, this seems the best way to address the short-term ghost fishing problem.

If a minimum size is established that offers a fair degree of spawning stock protection, this type of escape vent becomes an ideal management tool.

REFERENCES

Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. Fish. Invest., London, Ser. 2, 19, 533 p.

Blott, A. J. 1978. A preliminary study of timed release mechanisms for lobster traps. Mar. Fish. Rev. 40: 44-49.

Fair, J. J., and B. Estrella. 1976. A study on the effects of sublegal escape vents on the catch of lobster traps in five coastal areas of Massachusetts. Mass. Div. Mar. Fish. #9276-10-26-10-76-CR, 8 p.

Fogarty, M. J., and D. V. D. Borden. 1978. Assessment of lobster trap vent incorporation on lobster escapement and by-catch. R.I. Div. Fish Wildl. #03-6-043-35132, 81 p.

Krouse, J. S. 1976. Incidence of cull lobsters, *Homarus americanus*, in commercial and research catches off the Maine coast. Fish. Bull. U.S. 74: 719-724.

1978. Effectiveness of escape vent shape in traps for catching legal-sized lobster, *Homarus americanus*, and harvestable-sized crabs, *Cancer borealis* and *Cancer irroratus*. Fish. Bull. U.S. 76: 425-432.

Krouse, J. S., and J. C. Thomas. 1975. Effects of trap selectivity and some population parameters on size composition of the American lobster, *Homarus americanus*, catch along the Maine coast. Fish. Bull. U.S. 73: 862-871.

National Marine Fisheries Service. 1971. Exploratory fishing and gear research base. Shellfish resource assessment. Cruise Rep. M/V Delaware II 70-8. U.S. Dept. Com., NOAA, NMFS, Woods Hole, Mass., 10 p.

Nulk, V. E. 1978. The effects of different escape vents on the selectivity of lobster traps. Mar. Fish. Rev. 40: 50-58.

Pecci, K. J., R. A. Cooper, C. D. Newell, R. A. Clifford, and R. J. Smolowitz. 1978. Ghost fishing of vented and unvented lobster, *Homarus americanus*, traps. Mar. Fish. Rev. 40: 9-43.

Sheldon, W. W., and R. L. Dow. 1975. Trap contributions to losses in the American lobster fishery. Fish. Bull. U.S. 73: 449-451.

Smolowitz, R. J. 1978a. Trap design and ghost fishing: An overview. Mar. Fish. Rev. 50: 2-8.

1978b. Trap design and ghost fishing: Discussion. Mar. Fish. Rev. 40: 59-67.

Templeman, W. 1958. Lath-spacing in lobster traps. Fish. Res. Board Can. Prog. Rep. Atl. Coast Sta. 69: 22-28.

U.S. Fish and Wildlife Service. 1968a. Exploratory fishing and gear research base. Lobster explorations on the continental shelf and shelf with pot (trap) fishing gear. Cruise Rep. M/V Delaware 68-3. U.S. Dept. Int., Bur. Com., Fish., Glouster, Mass., 8 p.

1968b. Exploratory fishing and gear research base. Lobster explorations with pot (trap) gear. Cruise Rep. M/V Delaware 68-5. U.S. Dept. Int., Bur. Com., Fish., Glouster, Mass., 7 p.

LOBSTER GEAR SELECTIVITY - A CANADIAN OVERVIEW

by

R. W. Elner

Department of Fisheries and Oceans
Biological Station
St. Andrews, New Brunswick EOG 2XO

ABSTRACT

Elner, R. W. 1980. Lobster gear selectivity - a Canadian overview. Can. Tech. Rep. Fish. Aquat. Sci. 932.

Ongoing and past Canadian research on lobster gear design and trap selectivity is reviewed. Despite extensive research into alternative designs and materials, softwood traps, as used by the inshore fishery, have remained essentially unchanged for almost a century. The more recent Canadian offshore fishery utilizes large hardwood (oak) traps. Minimum size of lobster retained within a trap is dependent on the maximum size of the vent in the trap's lath or mesh spacing. Provision of adequate trap escape vents has been shown to decrease catches of sublegal-sized lobsters and increase commercial catches, probably by reducing inter- and intraspecific competition. The upper size of lobster trapped is controlled by the size of trap entrance. Some inshore fishermen are now using giant traps with large entrances, specifically to exploit 'jumbo' lobsters. The lobster trap is compared to other lobster population survey and collection techniques. Physiological and behavioral factors affecting trap selectivity, efficiency, and catch-rate are discussed. Lost lobster traps are liable to continue fishing, causing losses to the fishery, until they degrade. Research into alternative baiting techniques could result in a more efficient trap.

INTRODUCTION

In a trap fishery the trap itself provides a natural and logical focus for conservation, regulation, and management. Through the properties of 'prey' size selectivity inherent in the trap design, size limits can, in theory, be set and to some extent remotely enforced. Likewise, through imposing a limit to the absolute number of traps allowed in a fishery total catch and effort can be regulated. The marked mechanical size-selective properties of lobster traps, although varying on a regional basis, are mainly functions of the maximum lath, or mesh, spacing (controlling the minimum size of animal retained) and entrance, fishing ring, diameter (controlling the maximum size of animal able to enter the trap and to some extent the trap efficiency in terms of animals retained after entry).

In addition to mechanical considerations, the fishing characteristics of a trap depend to a large extent on poorly understood and inadequately quantified physiological and behavioral influences. Caddy (1977) has summarized the main factors affecting the trap capture process (Table 1).

From a fisheries viewpoint, achieving optimal trap characteristics requires careful balancing of the critical factors in that the maximum yield of legal-sized lobsters must be achieved whilst sublegal-sized ('short') lobsters must be allowed free exit. From an enforcement viewpoint the fisherman should be aware that he is not being deprived of a portion of his catch and is indeed benefiting by any increased trap selectivity imposed.

PREVIOUS RESEARCH AND BACKGROUND

In terms of basic gear type the Canadian lobster fishery can be broadly classed into 'inshore' and 'offshore' categories. The familiar inshore wood and mesh lobster trap, with separate 'parlor' and 'kitchen', has remained essentially unchanged in general shape and fishing principle since the late 1800's when it replaced the hoop net as a more efficient method of exploiting lobster stocks (Doliber 1973). Rutherford et al. (1967) discuss lobster fishing techniques and different trap designs around the Maritime Provinces. The Canadian offshore fishery, operating on Georges and Browns Banks, has, however, passed through two major trap stages since its inception in 1971: the fishery started off with a modified mesh on conical steel Japanese red crab traps which were quickly superseded by large hardwood traps. Deepwater lobster fishermen around eastern Grand Manan in the Bay of Fundy have also recently switched from large softwood traps to offshore-type hardwood traps after trials between large softwood, hardwood, and plastic-coated steel traps (Groom 1977, 1978).

Despite a long history of evaluation trials by Provincial and Federal Fisheries Departments on alternative lobster trap designs and materials, no outright superior alternative to the present inshore trap has been found. Wilder (1956) carried out extensive tests on various designs of metal and plastic traps in an attempt to discover an equally efficient but more durable replacement to the wooden trap. Although the results were inconclusive and none of the designs were adopted, Wilder did demonstrate that some steel traps were not significantly different from wooden ones in their ability to catch lobsters. Nova Scotia Department of Fisheries has recently tested plastic, steel, and plastic-coated steel lobster traps (Smith, unpubl. data). Steel traps were markedly more durable than conventional wooden traps, although they caught consistently fewer lobsters. In general, plastic-coated steel traps proved inferior to wooden traps in their ability to catch 'markets', although they were also inferior in catching sublegal-sized lobsters). There was no significant difference between number and weight of 'market' lobsters caught in wooden and plastic traps, although the plastic traps unaccountably caught significantly more 'shorts' than wooden traps.

Table 1. Main factors affecting the trap capture process (from Caddy 1977, based on Bennett and Brown 1976).

Process	Contributing factors
Bait/trap attraction:	(- type size, freshness bait (- appetite (food availability, molt condition) (- sheltering response ? (- diurnal, tidal feeding rhythms (- reproductive condition
Locating trap:	(- response time (- random, directed walk (gear conflict ?) (- effects of temperature on locomotory speed (- soak time
Entry to trap:	(- inter-, intraspecific attraction, avoidance, (competition (predation, cannibalism) (- dimension of entry port (upper size limit ?) (+ trap size (- number of individuals in trap (gear saturation)
Escape from trap:	(- size of mesh, lath spacing, presence of (escape ports (- self-destruct panels to prevent ghost fishing (of lost traps ?

A large amount of Canadian research on lobster gear has been concerned with providing adequate escape openings, in terms of lath spacing, for sublegal-sized lobsters. Lath spacing remains uncontrolled in all the Maritime Provinces except Newfoundland where a 1 3/4-in. (45-mm) lath spacing regulation has been enforced since 1937 (Templeman 1958; Wilder 1965). Around the remainder of the Maritimes lath spacing varies between approximately 1 and 1 5/8 in. (25-41 mm), depending on whether the particular fishery is 'canner'- or 'market'-sized lobster orientated. These unrestricted lath spacings are generally considered too small, from a conservation viewpoint, as they entrap large numbers of sublegal lobsters. Over most of the fishery the lobster stock is heavily exploited with the result that a high proportion of the catch is below legal size. Even at the start of the season 50-60% of the catch may be 'shorts', a proportion that can rise in excess of 80% towards the end of the season when most of the legal-sized lobsters have been caught (Anon. 1975; Stasko 1978). Such high catches of 'shorts' can have an adverse effect on the future years' fishery: handling and exposure of 'shorts' on deck frequently results in direct injuries and mortality and, at best, trauma to the animal leading to decreased growth; dumping 'shorts' back into the sea exposes them to fish predation on their way down to the bottom; once landed on the sea bottom the 'shorts' are susceptible to further predation and stress if adequate cover and food are not present. By providing traps with escape openings that allow sublegal-sized lobsters free exit the aforementioned causes of loss are negated, the fisherman is saved the extra labor of removing large numbers of unwanted animals from his gear and is spared the temptation to utilize 'shorts' illegally. Adequate escape openings also allow fish, crabs, and other animals that might otherwise be retained, and have to be removed manually, more chance to escape. In addition, large numbers of 'shorts' retained in a trap can rapidly saturate the gear reducing the catch of commercially sized lobsters. Similar gear saturation effects caused by interspecific interactions with competitive species such as rock crabs, *Cancer irroratus*, are similarly reduced by adequate lath spacing.

Studies by Wilder (1943, 1945) in New Brunswick, Prince Edward Island, and Nova Scotia, and Templeman (1939) in Newfoundland, clearly demonstrated the effectiveness and feasibility of adequate lath spacing for sharply reducing the numbers of 'shorts' brought to the surface. Wilder (1943, 1945, 1949) found that traps with lath spaces of 1 3/8 in. (35 mm) between the two lowest side laths would permit the escape of up to 90% of 'short' lobsters below the legal minimum size of 7 in. (178 mm) total length that would have been caught by 1-in. (25-mm) lath spacing. This result was achieved without reducing the total catch of legal-sized lobsters. Similarly, in areas where a 3 1/8-in. (79-mm) carapace length size regulation was in effect, Wilder (1948) found that a 1 3/4-in. (45-mm) inter-lath space, compared with a 1 1/4-in. (32-mm) space, allowed 75% of the sublegal lobsters to escape yet caught the same weight of legal-sized animals. Templeman (1939) compared the size selectivity of traps with 1 3/4-in. (45-mm) and 1 1/3-in. (34-mm) lath spacings: in the subsequent catch of 1,500 lobsters the wider-spaced traps retained less than 20% as many 'short' lobsters below the legal minimum total length of 9 in. (152 mm) as the narrower-spaced traps. Moreover, the wider lath spaced traps actually caught more legal lobsters than the traps with smaller spaces. This latter finding is, however, in contrast to Vézina (unpublished data) who surveyed the efficiency and selectivity of an assortment of lobster traps with differing escape characteristics in the Northumberland Strait. Here, the fishing power in terms of 'catch per unit effort' (C.P.U.E.), both in numbers and weight of legal lobsters caught, was found to be higher for the unmodified regular traps than for the traps with increased or decreased escape size characteristics, despite the fact that the unmodified traps retained large numbers of 'shorts'.

As a result of Wilder's investigations, 1 1/4-in. (32-mm) and 1 5/8-in. (41-mm) lath spacing regulations were introduced for the Maritime Provinces in 1949. However, these regulations were rescinded in 1955 due to opposition from the fishermen and difficulties involved in enforcement (Templeman 1958; Wilder 1965). The fishermen's major complaints were as follows: 1) the effort involved in modifying large numbers of traps (despite the facts that wider lath spaced designs required less ballast, were consequently easier to haul, lasted longer and probably fished better on wave-disturbed bottom than conventional narrow lath spaced traps); 2) the belief that large numbers of lobsters were damaging legs and chelipeds due to the wider laths, with a subsequent financial loss to the fishermen; 3) the belief that bait disappeared more quickly in wider-lathed traps; 4) the argument that some legal-sized lobsters were escaping through the wider lath spaces (despite the fact that the wide lath spaced traps appeared to catch more legal-sized lobsters); 5) the argument that the laths on the wider lath spaced traps were liable to chewing and wearing by the lobsters resulting in the escape of more legal-sized animals. All of these arguments and beliefs are convincingly challenged by Templeman (1958).

A viable and possibly less controversial alternative to lath spacing, although working on the same principles, is the introduction of 'escape vent panels' into traps; recent Canadian management research has been directed at this alternative as a sublegal lobster protection method. The Departments of Fisheries for New Brunswick (Henry, unpublished data), Nova Scotia (Cadegan, pers. comm.) and Prince Edward Island (Lewis 1978) have carried out field trials of lobster traps with various sized escape vents drilled into wooden side-panels. These panels easily and efficiently provide the traps with accurately sized escape openings without radically altering the trap itself. In Prince Edward Island, Lewis (1978) found that traps equipped with a wooden panel containing three circular escape vents, 45 mm in diameter, caught up to 12% more legal-sized lobsters and released 60% of short lobsters caught by conventional traps. Lewis (1978) also compared plastic vent panels to wooden ones and found that there was no significant difference between the two materials in their ability to release short lobsters but there was a trend for the wooden panels to retain more legal-sized lobsters. It was felt that the plastic panels might be as acceptable as the wooden ones when factors such as ease of manufacture were taken into consideration. This information has been made available to Prince Edward Island fishermen to encourage the voluntary use of escape panels.

To enable a crab fishery to be pursued during the lobster closed season, Stasko (1975) and Stasko and Graham (unpubl. data) conducted laboratory and field trials on lobster traps fitted with various

sizes of rectangular fishing head designed to capture rock crabs and exclude lobsters. For use as escape vents in the trap itself round openings were found to be more effective than square ones in allowing lobsters to escape while retaining commercial-sized crabs.

There has also been a need for research traps specifically to catch sublegal-sized lobsters so that future recruitment into the fishery can be estimated. Designing such a trap, able to capture very small juvenile lobsters, has proved difficult. Modified lobster traps fished by Mackay (1920) caught juvenile lobsters down to 2-1/2 in. (64-mm) total length (20.1-mm carapace length) in Malpeque Bay, Prince Edward Island. Similar traps fished in the Northumberland Strait (Dawson 1920) failed to catch lobsters smaller than 4 in. (102 mm) total length (33.8-mm carapace length). In 1977, Stasko (1978) fished small traps, with 3-in. (76-mm) entrance rings designed to retain 'shorts' down to about 30-mm carapace length, alongside normal offshore hardwood traps on Browns Bank, but failed to catch any sublegal lobsters. Groom (1978) fished the same small traps without success alongside hardwood traps in a project to assess the lobster population off Grand Manan. Elner (unpubl. data) fished the same traps again in Malpeque Bay, Prince Edward Island, and caught lobsters down to 46.7-mm carapace length, although a diver survey revealed the presence of large numbers of small lobsters down to 28.0-mm carapace length.

There have been relatively few studies validating the lobster trap as a survey technique by comparing its selectivity and efficiency against that of other lobster sampling methods, such as Scuba and submersible diving, trawling, and dragging. Vézina (unpubl. data) has made direct comparisons between lobster catches by various types of traps and the population as ascertained by Scuba divers. The actual selectivity of the traps proved very marked, with retention increasing from 0 to 100% over 10-mm carapace length. Ennis (1978) compared diver- and trap-caught lobster samples in northern Placentia Bay, Newfoundland, and found a greater proportion of new-shelled lobsters in the diver-caught samples. Scarratt (1971, 1973), researching the effects of irish moss raking on lobsters around Prince Edward Island, made effective lobster population surveys using Scuba divers to search laid-down quadrats of known area. The results were compared with the size frequency of lobsters brought up in irish moss rakes. Scarratt (1968) used a similar technique to ascertain lobster populations in an artificial reef experiment. Caddy and Watson (1969) used a submersible to survey lobsters on an artificial reef. Scarratt (1975) used Scuba divers again to survey the lobster population on scallop grounds near Pictou, Nova Scotia. Lobsters are frequently brought up in gear such as otter trawls and scallop drags; however, in Canada there have been no studies to date to cross-correlate catch statistics with pot-caught animals over the same ground.

The effective area over which a trap attracts lobsters is related to the animal's olfactory response threshold. Caddy (1977), working from data presented by McLeese (1973a) on lobster olfactory response, obtained a value for 'effective area fished' by a trap of a similar order of magnitude as that calculated by Miller (1975) for snow crabs, *Chionoecetes opilio*. Naturally this estimate is affected by factors such as currents, soak time, response time, and proportion of population responding to bait (this latter factor may be expected to decline with distance approximately according to the inverse square law).

McLeese and Wilder (1958) experimentally determined linear relationships between walking rate and catchability of lobsters with temperature. The slope of the catchability line was found to be dependent on stock density. With these relationships, as well as catch and effort data collected by Wilder, Paloheimo (1963) used data on the catchability of lobsters, by trapping, at various temperatures to estimate population size. In addition to marked temperature effects, Paloheimo found variations in catchability between different areas and tagged and untagged lobsters within areas. These variations were attributed to differences in relative densities as well as to aggregation of lobsters and fishing. Certain low values of estimated catchability seemed to be inversely related to fishing effort, a relationship which suggests negative interactions between units of gear not predicted by the customary catch and effort relationships.

Skud (1976) investigated the effect of soak time in relation to C.P.U.E. for offshore lobsters and found that a trap's catch does not increase linearly with time in the water but rises towards an asymptote (a widely recognized effect also reviewed by Caddy (1977)). Stasko (unpublished), also in a study of the offshore fishery, found that catch per trap haul remains effectively constant and independent of soak time due to asymptotal levels being attained relatively rapidly. For this reason Stasko used catch per trap haul as a measure of effort, rather than the catch per trap haul per unit soak time recommended by Skud (1976). Several factors may explain these observed decreases in efficiency per soaking day: higher densities of lobsters in a pot may be a physical deterrent to other lobsters (i.e. a trap saturation effect is achieved); or perhaps the bait may be sufficiently consumed over longer soaking periods to fail to attract other trap entrants; behavioral interactions as well as escapement and trap size could also affect saturation levels and daily catch rate.

McLeese (1970, 1973b) and McLeese et al. (1977) document the existence of lobster sex and other pheromones acting as intraspecific attractants amongst lobsters. McLeese (1973c, d) tested the chemosensory response and orientation of lobsters to various food and chemical solutions. Caddy (1977) has reviewed these and other behavioral and physiological considerations that might be involved in the attraction of lobsters to traps, and could have short-term or constant effects on catchability.

PRESENT RESEARCH AND CONCERNS

There is continued concern regarding the protection of 'short' lobsters and a research program into plastic escape panels, based on the panel currently compulsory in Maine, is being developed by A. Campbell at St. Andrews.

There has been relatively little work on fishing ring size and its effect on the upper sizes of lobster caught and trap selectivity. The majority of Maritime fishermen use wood or plastic rings; the remainder use metal or no ring at all (this latter practice is believed to prevent groundfish from entering the trap). Stasko (1975)

reported that the smallest opening a crab or lobster could be pushed through was also the smallest opening that it passed through unaided, and related crab and lobster size to the minimum entrance they could fit through. Currently, the size of inshore trap fishing ring varies around the Maritimes from about 4 to 5 in. (102-127 mm) in diameter. In the offshore traps the fishing ring has been reduced to 7 in. (178 mm), from the original 10 in. (254 mm) when the fishery started (Pye, pers. comm.). However, some inshore fishermen have recently been increasing the size of their fishing rings to enable them to trap larger, 'jumbo-sized' lobsters that have previously been immune to the conventional traps (this practice is in spite of the belief that large ring sizes lower the retaining properties of the trap for smaller sizes of lobster). Indeed, numbers of fishermen, especially around Grand Manan, the central Northumberland Strait, and the eastern Atlantic coast of Nova Scotia, have recently introduced relatively massive enclosed wooden traps, approximating 4 x 4 x 2 ft (1.2 x 1.2 x 0.6 m) with large fishing rings specifically designed to exploit the previously unfished jumbo lobsters. This practice is currently causing concern because of the contribution that the jumbo lobsters could well be making to the fishery as brood stock. D. G. Robinson of St. Andrews, is at present investigating the effect of fishing-ring size on trap selectivity. Preliminary results suggest that larger rings catch larger lobsters and achieve a greater C.P.U.E., in terms of catch weight, than the smaller rings. In contrast, traps with smaller rings appear slightly more efficient in retaining their catch than larger ringed traps, and achieve a marginally greater C.P.U.E. in terms of number of animals caught.

Studies on efficiency of retention for lobster traps are almost totally lacking. Recent work by Miller (unpubl. data) on trapping of the crabs *Cancer productus* and *C. magister* and trap saturation has revealed that rates of escape with these particular species are significant. Intraspecific behavioral interactions around various designs of crab trap and the behavior of crabs at the trap (Miller 1978) clearly demonstrate the constraints behavior can have on trap efficiency and saturation level. Miller (pers. comm.) is now postulating that trap saturation is due to released odor from crabs in traps. Equivalent studies on lobster are almost totally lacking and should certainly be a priority when considering trap efficiency and design in the future. Stasko (1975) and Stasko and Graham (unpublished data) noted that unmodified lobster traps caught fewer crabs than traps specifically designed to fish crabs; presumably this was due to interspecific agonistic behavior. Work currently in progress by R. W. Elner, St. Andrews, also suggests that rock crabs and lobsters will actively exclude the other species from traps and shelter. M. D. Easton of Newfoundland has developed a one-way valve for lobster traps with which to study trapping behavior. One-way trap doors have already been tested in the snow crab fishery but, although they achieved better retention than unmodified traps, they caught less crabs (Anon. 1969).

Although present snow crab fishing regulations call for biodegradable panels, no real consideration has yet been given by Canadian lobster researchers to 'ghost traps' and the effect that continued fishing by these lost traps might have on the fishery. It is believed, however, given adequate lath spacing and the fact that both inshore and offshore traps are now built largely of biodegradable materials, that the effects of 'ghost fishing' on the lobster fishery are probably not critical.

There have been repeated, largely unsuccessful, attempts to introduce artificial and improved types of bait into the lobster fishery to replace the common fish baits. Fishermen in some areas use bait bags or cans designed to make more efficient use of bait. Easton (pers. comm.) has recently developed a bait bag for use by the Newfoundland fisheries. Similar bait bags are being researched by the Nova Scotia Department of Fisheries (Smith, pers. comm.). Studies by Hancock (1974) and McLeese (1970, 1973b, c) present the possibilities for a bait that will attract only desired species to traps and repel unwanted species thereby reducing interspecies interactions, conserving bait and increasing trap selectivity and overall efficiency.

REFERENCES

Anon. 1969. Proceedings meetings on Atlantic crab fishery development. Fredericton, N.B., March 4-5, 1969. Canadian Fisheries Reports 13, 208 p.

1975. Lobster fishery task force. Final Report, Fish. Environ., Halifax, 180 p.

Bennett, D. B., and C. G. Brown. 1976. The problems of pot immersion time in recording and analyzing catch-effort data from a trap fishery. ICES Special Meeting on Population Assessments of Shellfish Stock Contr. No. 6, 12 p.

Caddy, J. F. 1977. Some considerations underlying definitions of catchability and fishing effort in shellfish fisheries, and their relevance for stock assessment purposes. ICES Shellfish and Benthos Committee C.M.1977/K:18, 22 p.

Caddy, J. F., and J. Watson. 1969. Submersibles for fisheries research. Hydrospace, March 1969, 5 p.

Dawson, A. B. 1920. The distribution of small lobsters in and about Egmont Bay, Prince Edward Island. Biol. Board Can. MS Rep. 50, 7 p.

Doliber, E. 1973. Lobstering inshore and offshore. International Marine Publishing Co., Camden, Maine, 108 p.

Ennis, G. P. MS 1978. Growth curves for Newfoundland lobsters from data on molt increment and proportion molting. CAFSAC Res. Doc. 78/29, 11 p.

Groom, W. 1977. Lobster project, 1977, Grand Manan Island. Fish 'n' Ships. N.B. Dept. Fish. Information Notice for Bay of Fundy Fishermen 1: 1-10.

1978. Lobster Report. Results of research on Grand Manan's lobster population. Research and Development Branch, New Brunswick Department of Fisheries, Fredericton, N.B., 69 p.

Hancock, D. A. 1974. Attraction and avoidance in marine invertebrates - their role in developing an artificial bait. J. Cons. Int. Explor. Mer 35: 328-331.

Lewis, B. 1978. Escape mechanisms. The Lighthouse, Prince Edward Island Department of Fisheries 7, 3 p.

Mackay, D. A. 1920. Report upon yearling and two year old lobsters in Richmond Bay, P.E.I. for 1920. Biol. Board Can. MS Rep. Biol. Sta. 49, 14 p.

McLeese, D. W. 1970. Detection of dissolved substances by the American lobster (*Homarus americanus*) and olfactory attraction between lobsters. J. Fish. Res. Board Can. 27: 1371-1378.

1973a. Olfactory responses of lobsters (*Homarus americanus*) to solutions from prey species and to seawater extracts and chemical fractions of fish muscle and effects of antennule ablation. Mar. Behav. Physiol. 2: 237-249.

1973b. Chemical communication among lobsters (*Homarus americanus*). J. Fish. Res. Board Can. 30: 775-778.

1973c. Orientation of lobsters (*Homarus americanus*) to odor. J. Fish. Res. Board Can. 30: 838-840.

1973d. Response of lobsters *Homarus americanus* to odor solution in the presence of bleached kraft mill effluent. J. Fish. Res. Board Can. 30: 279-282.

McLeese, D. W., R. L. Spraggins, A. K. Bose, and B. N. Pramanik. 1977. Chemical and behavioral studies of the sex attractant of the lobster (*Homarus americanus*). Mar. Behav. Physiol. 4: 219-232.

McLeese, D. W., and D. G. Wilder. 1958. The activity and catchability of the lobster (*Homarus americanus*) in relation to temperature. J. Fish. Res. Board Can. 15: 1345-1354.

Miller, R. J. 1975. Density of the commercial spider crab, *Chionoecetes opilio*, and calibration of effective area fished per trap using bottom photography. J. Fish. Res. Board Can. 32: 761-768.

1978. Crab (*Cancer irroratus* and *Hyas araneus*). Ease of entry into baited traps. Fish. Mar. Serv. Tech. Rep. 771, 8 p.

Paloheimo, J. E. 1963. Estimation of catchability and population sizes of lobsters. J. Fish. Res. Board Can. 20: 59-88.

Rutherford, J. B., D. G. Wilder, and H. C. Frick. 1967. An economic appraisal of the Canadian lobster fishery. Fish. Res. Board Can. Bull. 157, 126 p.

Scarratt, D. J. 1968. An artificial reef for lobsters (*Homarus americanus*). J. Fish. Res. Board Can. 25: 2683-2690.

1971. Investigation into the effects of irish moss raking on lobsters. Fish. Res. Board Can. MS Rep. 1105: 1-36.

1973. The effects of raking irish moss (*Chondrus crispus*) on lobsters in Prince Edward Island. Helgoländer wiss. Meeresunters. 24: 415-424.

1975. Observations on lobsters and scallops near Pictou, N.S. Fish. Mar. Serv. Res. Dev. Tech. Rep. 532, 6 p.

Skud, B. E. 1976. Soak-time and the catch per pot in an offshore fishery for lobsters (*Homarus americanus*). ICES Special Meeting on Population Assessments of Shellfish Stocks Paper No. 8, 20 p.

Stasko, A. B. 1975. Modified lobster traps for catching crabs and keeping lobsters out. J. Fish. Res. Board Can. 32: 2515-2520.

MS 1978. Inshore-offshore lobster stock interaction: a hypothesis. CAFSAC Res. Doc. 78/37, 9 p.

Templeman, W. 1939. Investigations into the life history of the lobster (*Homarus americanus*) on the west coast of Newfoundland, 1938. Newfoundland Dept. Nat. Resour., Res. Bull. (Fish.) 7, 52 p.

1958. Lath-spacing in lobster traps. Fish. Res. Board Can., Prog. Rep. Atl. Coast Sta. 69: 22-29.

Wilder, D. G. 1943. The effect of lath spacing and size of fishing ring on the catch of lobster traps. Fish. Res. Board Can., Prog. Rep. Atl. Coast Sta. 34: 22-24.

1945. Wider lath spaces protect short lobsters. Fish. Res. Board Can., Atl. Biol. Sta., Circ. G-4, 1 p.

1948. The protection of short lobsters in the market lobster areas. Fish. Res. Board Can., Gen. Ser. Circ. 11, 1 p.

1949. Protect short lobsters by widening lath spaces. Fish. Res. Board Can., Gen. Ser. Circ. 14, 1 p.

1956. Experiments to improve lobster traps. Fish. Res. Board Can. MS Rep. 608, 51 p.

1965. Lobster conservation in Canada. Rapp. Cons. Explor. Mer 156: 21-29.

PROBLEMS OF GEAR SELECTIVITY (J. Fair Jr., rapporteur)

Smolowitz: No one knows what the true selectivity of lobster traps is (editor's note: i.e., the proportion of the population entering at size that is retained). Maine and Massachusetts currently require 1 3/4-in. rectangular or 58-mm round escape vents. Rhode Island requires a 1 5/8-in. vent because of their smaller minimum size.

Stasko: Do these laws apply to offshore traps?

Fair: No. The state regulations only apply to state waters (within 3 mi).

Caddy: Is there any concern about the increased use of large entrance rings?

Scarratt: In the Pictou area, we are concerned that the increasing use of large entrance rings may deplete the population of large lobsters, thereby reducing recruitment. There are basically two ways to eliminate the capture of large lobsters: a maximum size limit as in Maine, or the imposition of gear regulations, such as a maximum ring size, resulting in making the gear inefficient in capturing lobsters above a certain size.

Stasko: It is interesting that the U.S. is trying to eliminate maximum size restrictions while in the Maritimes we are now thinking about this as a temporary measure to discourage extension of the inshore fishery to previously unfished "brood stock" areas.

Caddy: Have there been any attempts at developing a trap to catch very small lobsters?

Stasko: Various attempts at designing such traps have not been successful. (It was the consensus that the behavior of juvenile lobsters is such that trapping is virtually impossible in most cases.)

Bennett: If escape vents increase the efficiency of the traps and increase F, should not trap limits accompany escape vent regulations?

Briggs: The enforcement of trap limits is a problem. In addition, because of the nature of the fishery and the competitiveness of the fishermen, imposed trap limits become a goal by which those below the set limit increase their traps to the limit. As a result, by setting trap limits, you can actually increase effort.

Smolowitz: Instead of trying to achieve 100% retention of legals, we should adjust escape vent size to allow 95% escapement of shorts. This still results in 90% retention of legals.

Caddy: Have there been any studies on the mortality rate of discards?

Scarratt: We have made some attempts to define the mortality of discards through tagging studies. In general, the practice was thought to be wasteful, especially in areas where predators such as catfish were abundant.

Smolowitz: Escape vents should also help to alleviate the problem of culls (editor's note: a cull is a lobster in which claw loss or other major damage eliminates it from the "market" category) in the fishery, which is probably trap-related. We noted 10% new damage to lobsters present in surface-hauled pots in our study in Buzzard's Bay, Mass.

Krouse: Similar problems were noted in Maine.

Morrissey: Has any difference in the incidence of culls been noted in Newfoundland where lath spacing has been in effect for a relatively long period?

Ennis: We haven't made any attempts to investigate this problem.

Anthony: Is there any doubt that handling causes lobster damage? (no disagreement).

Caddy: Let us move on to the question of ghost fishing.

Scarratt: This may be more of a problem in offshore areas; Scuba surveys indicate that inshore pots are broken up by storms. There is some tendency toward the use of plastic traps in SW Nova Scotia, which are equally as efficient and more rugged than wooden traps. This may increase ghost fishing.

Caddy: Does anyone have any information on trawl selectivity?

Morrissey: There is some information to suggest that otter trawls are selective of large berried females in the offshore areas. This may have serious implications.

Burns: Our data show that trawls are selective of larger lobsters than the traps in the offshore fishery. The upper limit in the traps is in the range of 170 mm CL, while in the trawls it is up to 240 mm CL. The ratio of females to males is in the range of 60:40.

Robinson: There has been a lot of work done in Europe on the *Nephrops* beam trawl fishery.

Bennett: The selectivity relationships in that fishery are not clear, due mainly to the spiny carapace of the animal, which tends to hang up in the net.

Fogarty: A current study in Rhode Island is designed to assess damage and mortality in trawls, but only one mesh size has been used.

(It was the general opinion of the group that the otter trawl is relatively inefficient as a method of capture for lobster.)

MEASURES OF EFFORT

by

J. Thomas

Department of Marine Resources
West Boothbay Harbor, Maine

ABSTRACT

Thomas, J. 1980. Measures of effort. Can. Tech. Rep. Fish. Aquat. Sci. 932.

Historically, effort was measured by either attempts at physical counts or some type of intuitive estimate of the total number of traps fished for a year. Recently, effort has been measured by either lobstermen maintaining log-books issued by a state agency or by a direct interview technique as the fishermen land their lobster catches. Both procedures enable us to collect information for such heretofore unrecorded effort categories as, (1) trap-hauls with the number of days these traps were set-over, (2) boat-days or trips, (3) man-days and hours. All of these categories show an increasing trend in effort with, usually, a concurrent decrease in landings of lobsters.

Historically, the collection of annual catches in pounds of lobsters was given a higher priority than the tabulation of the effective effort that produced these catches. Nevertheless, in many areas of the American lobster fishery, some attempts were made at getting estimates or actual counts of traps fished. Despite the omissions and inadequacies of the data, it is obvious that effective management regulations are needed in this fishery (Fig. 1). During the recent decade, and with the inception of P.L. 94-265 (the "200-mile-limit bill"), the importance of collecting accurate catch and effort statistics has become apparent (i.e., the optimum yield concept with one of its major components of maximum sustainable yield).

Since August 1966, the Maine Department of Marine Resources has been collecting detailed catch and effort information on the lobster fishery by sampling the commercial catch and interviewing lobstermen as they land their catches. More recently, Connecticut and Rhode Island have initiated a mandatory daily log-book reporting system on their fisheries, particularly for lobsters. The log-books, maintained by each fisherman, contain such categories as area fished, number of traps hauled for a day, number of days these traps were set-over, pounds and numbers of legal lobsters caught.

The two procedures described above should be adequate for determining the condition of these particular lobster resources. Over time, this information will give us an adequate data base for evaluating most cause-and-effect relationships, should any recommended management regulations be enacted.

In the Maine lobster fishery, probability sampling enables us to collect catch and effort data from the defined sampling units of 153 dealers. We are then able to estimate such quantities as total trap-hauls for a given year simply by dividing the catch in pounds, as given in "Maine Landings" (the official total landings as reported in Fish Statistics of the U.S.), by our survey estimate of catch in pounds per trap-haul (Table 1). This procedure gives us the means for determining total effort in the Maine lobster fishery for such categories as boat-days and hours, man-days and hours, trap-hauls, and trap-haul-set-over-days, none of which is reported in "Maine Landings."

To determine the recent trends in effort in the Maine lobster fishery, we have plotted a series of sample-effort categories by year from 1968 through 1977 (Fig. 2). The trend lines associated with each effort category indicate a coincident increase in the number of (1) boat-days or trips, (2) traps fished, (3) trap-hauls, and (4) trap-haul-set-over-days. Because of previous misunderstanding, we have included definitions of each of the effort categories as follows:

(1) Boat-days: the sum of the individual boat trips that we sampled in each year.

(2) Traps-set-out: the sum of all those traps that each fisherman stated he was fishing at the time of the interview; understandably, some traps could be counted more than once during the course of each sample year. In addition, it is difficult for each fisherman to recall how many months he fished a set number of traps, confounded even more by the loss or replacement of traps during this period of time.

(3) Trap-hauls: the sum of the number of traps hauled for the daily catch by the crew of each boat.

(4) Trap-haul-set-over-days: the total number of traps hauled for each sample-day by the crew of each boat multiplied by the lapsed number of days since these same traps were last hauled.

We are in the process of determining whether or not further standardization of effort is needed, and we are calculating catchability coefficients on a seasonal basis in order to establish the relationship of fishing mortality (F) to effort.

There are other ancillary uses for the effort categories tabulated in Table 1. For instance, we made an estimate of 34.9 million trap-hauls in the Maine lobster fishery for 1977. We estimate that approximately 1.5 lb of bait are used per trap-haul, which leads to a total estimate of 52.3 million lb of bait used in the Maine lobster fishery for 1977. Another example would be the characterization of revenues. The average landed value of lobsters per boat-day for 1977 was $148.75. Therefore, if the typical fisherman used his boat for 150 d in that year, his gross earnings were $22,312.50. A final example is shown by the array of the percentage of boats that fished categorized numbers of traps (Fig. 3). On a coastwide basis, 70% of the lobstermen report that they fish less than 400 traps per year. When we employ this same procedure for Casco Bay, Maine, however, we find that 62% of the lobstermen there use well over 400 traps per year. Therefore, the biological and socio-economic arguments for a limit on the number of traps per vessel will have to be studied carefully. This type of regulation seems to be gaining in popularity among the fishermen (especially if they fish fewer than the proposed number of traps). Such a proposal may not bring about the desired conservation of lobster stocks. Canada has had 250-400 trap limits by district since 1967. Not surprisingly, these limits have not led to a significant reduction in fishing mortality D. G. Robinson, pers. comm.).

Table 1. Total catches in pounds of lobsters are reported in "Maine landings" with corresponding total division estimates from sample-survey data, 1967 through 1977.

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Catch in pounds	16,491,195	10,506,500	19,838,385	18,175,815	17,560,620	16,259,670	17,046,855	16,460,325	17,017,411	19,001,053	18,487,138
Catch in numbers	13,975,589	17,232,353	16,531,987	15,273,794	14,633,850	13,549,725	14,325,088	13,492,070	14,300,345	16,102,587	15,535,410
Total value	13,247,026	14,696,325	15,935,752	16,943,556	17,235,424	16,784,175	21,782,093	22,666,677	27,568,206	27,888,643	29,024,807
Total trap hauls	27,034,746	34,177,500	32,521,943	30,806,466	32,519,667	26,225,274	31,568,250	26,984,139	34,034,822	30,646,860	34,881,392
Total boat days	194,429	215,216	240,430	183,051	208,104	157,793	180,462	165,182	187,595	187,763	195,342
Total man days	240,396	262,030	290,800	227,881	261,397	206,708	234,257	227,730	245,031	263,757	266,500
Total man hours	1,764,595	1,875,120	2,018,558	1,735,658	1,948,582	1,502,187	1,857,988	1,641,371	1,894,085	1,928,454	2,027,098

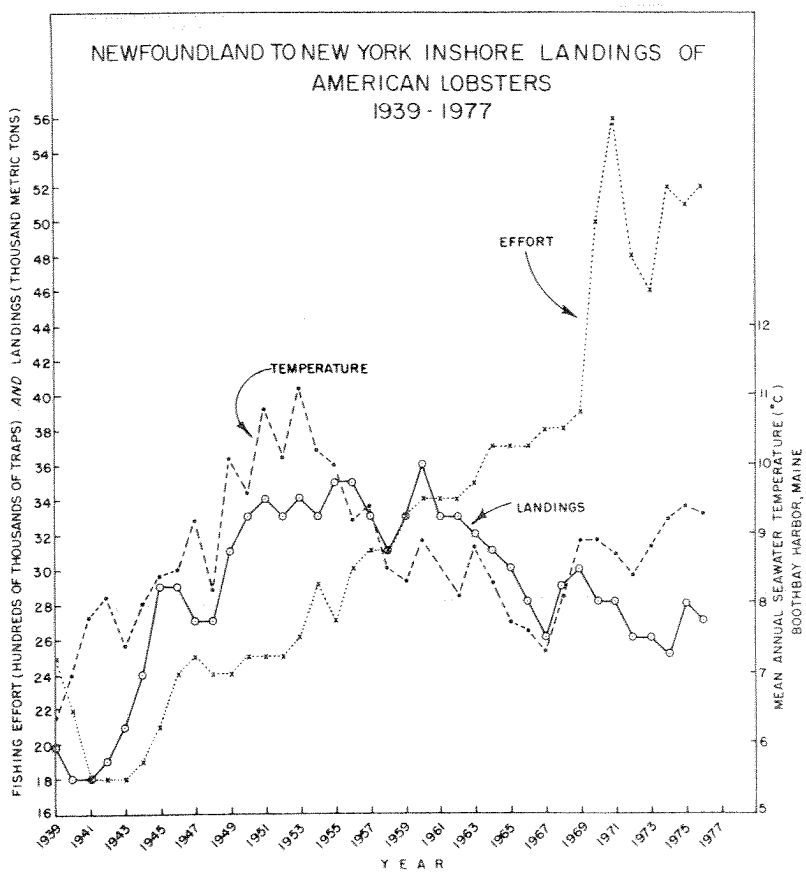


Fig. 1. Annual landings in metric tons with estimates of number of traps fished and surface water temperature from 1939 through 1977, combined for the area from Newfoundland to New York (compiled by Robert L. Dow).

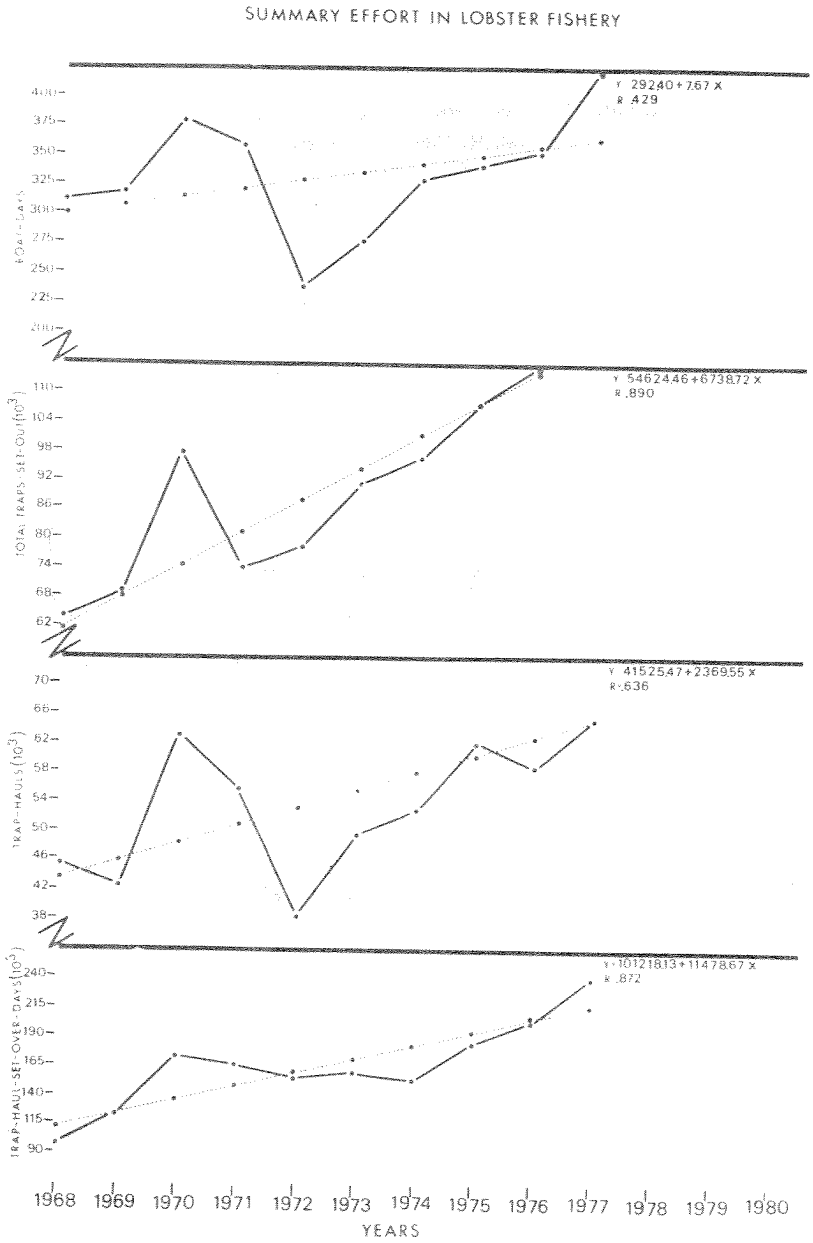


Fig. 2. Several categories of effort with calculated trend lines compiled from sampling the commercial lobster catch in Maine, 1968 through 1977.

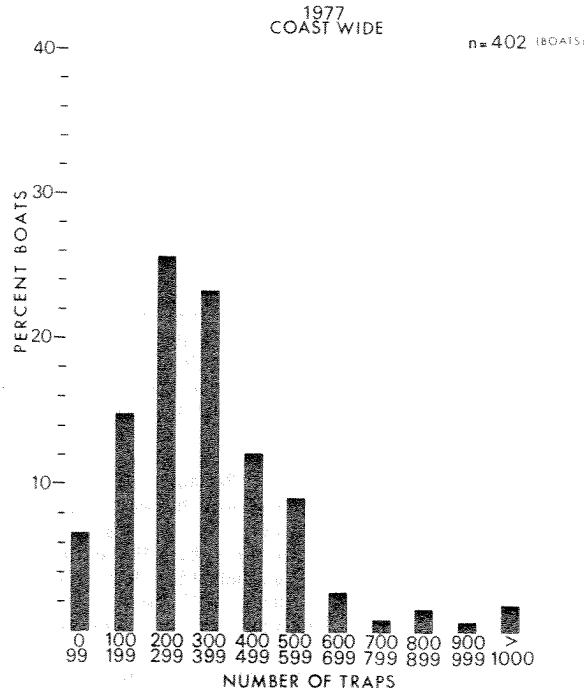


Fig. 3. The percentage of boats fishing the demarcated number of traps in the State of Maine during 1977.

MEASURES OF EFFORT (P. Briggs, rapporteur)

Caddy: What measures of effort should we use?

Stasko: The lobster seasons in Canada determine the impact of a given fleet size on the population - if they changed, it might drastically change effective effort.

Anthony: Could we have Jim Thomas demonstrate the differences between catch per trap haul, catch per trap haul set-over-days, and catch per trap?

Thomas: Catch in numbers per trap haul set-over-days dramatically reduces the variability of the data when compared to other catch-per-unit-of-effort values.

Anthony: Catch per trap overestimates declines. This is less marked with catch per trap haul set-over-days. We should adjust catch per trap haul set-over-days for seasonal effects: long sets are more common in winter, short sets more common in summer.

Smith: You should eliminate any long set-overs in winter and early spring (say, 10 d or more) because other factors (escapement, diminished attraction of bait) are influencing these catch-per-unit-of-effort values.

Clark: Do seasonal catch-effort differences relate to differences in distribution or behavior?

Briggs: There are fewer full-time fishermen around Long Island in the winter season. Some have pots out there just to save a space for them to fish during the summer months.

Van Engel: We plotted catch per trap haul set-over-days from the commercial catch data and found seasonal differences in four areas.

Stasko: We have carried out some preliminary analysis of seasonal data from the offshore fishery and found no consistent trends in catch-per-unit-of-effort values for different seasons, depths, and areas. Activity of offshore lobsters may not change seasonally.

Robinson: Measures of effort do not show seasonal effects and have not dealt with the effects of different baits, etc. We do not know the effect on survival to maturity at a given level of effort. Size frequency or other direct measures of effort are also important.

Caddy: It is still important to find out what types of measures should be used. I question whether catch per trap haul set-over-days is best. Perhaps it is better to adjust total effort to a standard number of days soak time.

Stasko: In the Canadian offshore fishery, after 2 set-over-days, there is little change in catch per trap haul up to 20 set-over-days.

Anthony: Trap haul set-over-days, in effect, do standardize effort; this technique reduces these values to 1 set-over-day.

Van Engel: This procedure promotes good public relations with fishermen. We use THSOD to help fishermen decide the most economical number of days for them to set-over their traps.

Russell: Catchability may decline by saturation.

Burns: Establish a standard trap haul set-over-day and adjust other data to this.

Robinson: If F varies over time then trap-haul-set-over data may relate to economics, but we have trouble using catch per trap to determine what happens biologically.

Anthony: Catch per trap haul set-over-day is better. This leads to the question - How much better than the other measures?

Caddy: We may not be in the position to evaluate this without independent experimental data.

Campbell: We have some data to determine if there are differences between pounds per trap haul and pounds per trap haul set-over-days. There seems to be little relationship when traps are set-over a week or more because then it is difficult to separate escapement from catchability.

Caddy: Size of gear and saturation are factors confounding the problem of effort definition.

Fogarty: In order to evaluate this situation, we could use Rothchild's approach to the Alaskan king crab fishery; i.e., evaluate the coefficients determining the curve of gear saturation with time.

Caddy: If we can quantify the effects of temperature on catchability, we could begin to define seasonal factors. Any information on changing fishermen's efficiency (sounders, better boats, haulers, etc.) would also be helpful.

Thomas: We are in the process of compiling past license application data. Several questions on the application forms relate to improved efficiency of operation in recent years; for example, by 1967 most Maine fishermen had converted to hydraulic haulers resulting in a dramatic increase in the number of traps used.

Anthony: Because of gear interactions, catch per trap may be masking increases in mortality.

Campbell: In Port Maitland fishermen usually use a 2-day set. There are temperature effects on catchability but unadjusted trap hauls may work quite well here.

Anthony: You must evaluate which is better for your problems.

Smolowitz: The overall number of offshore traps and vessels has been stable but fishermen efficiency has improved. Catch per trap haul set-over-days may not be adequate here.

Anthony: If they stayed in one area, you would see catch per trap haul set-over-days drop sharply.

Scarratt: Irrespective of limiting fishermen or traps, there has been an increase in effort. Should we use inefficiency as a management tool? Limitations on such things as pot haulers, boat size, automatic baiting machines, radios...

Caddy: I don't think fishermen will accept such a concept.

Anthony: We need to decrease effort rather than keep the status quo. It is already too high in most areas. Trap limits, for example, can be counterproductive.

Scarratt: Perhaps we should only consider the trap itself. Should we place restrictions on all non-wood traps?

Stasko: We have data that indicate that the larger traps are more efficient in deeper water at least. In some nearshore locations, some fishermen are starting to use larger traps.

CATCH-EFFORT TRENDS AND ESTIMATES OF MAXIMUM SUSTAINABLE YIELD IN THE U.S. LOBSTER FISHERY

by

B. A. Halgren

Department of Environmental Protection
Trenton, New Jersey 08625

ABSTRACT

Halgren, R. A. 1980. Catch-effort trends and estimates of maximum sustainable yield in the U.S. lobster fishery. Can. Tech. Rep. Fish. Aquat. Sci. 932.

Catch and effort in the modern U.S. lobster fishery increased gradually for about 25 yr until the beginning of the 1970's when effort doubled in a 4-yr period and landings decreased by over 2,000 metric tons (MT). Maximum sustainable yield (MSY) for the U.S. fishery has been estimated at approximately 16,280 MT. Landings in 1976, which were the highest since 1971, totaled 14,316 MT or about 12% less than the estimated MSY. Estimates of optimal levels of effort indicate that the current numbers of traps in use in many areas are far greater than required to achieve MSY. These data indicate that the U.S. lobster fishery is overcapitalized and that the resource is probably being overfished.

The commercial lobster fishery in the United States developed in the early 1800's to supply the New York and Boston markets. From its humble beginnings in several locations in Connecticut and Massachusetts, the fishery rapidly expanded and by the middle of the century extended from Maine to New Jersey. By the late 1800's more than 3,700 people were engaged in the fishery, over 200,000 lobster pots were in use and landings reached as high as 11,000 MT.

The early 1900's saw a major decline in the U.S. lobster landings. Despite an increase in effort, as measured by the number of traps fished to 344,000 traps, the 1939 landings totaled only about 5,425 MT. During the 1940's, however, the fishery turned around again. In response to an almost doubling of the level of effort from 344,000 to 612,000 traps, the landings more than doubled to a total of 11,160 MT in 1949. The next 20 yr (1949-69) saw a gradual and steady increase in effort which, in 1969, surpassed the 1 million trap level (Table 1, Fig. 1). This increase of about 450,000 traps was accompanied by a modest increase in harvest of slightly over 4,000 MT to a 1969 total of approximately 15,191 MT.

The start of the 1970's marked a period of very rapid escalation of effort. During a 4-yr period, from 1969 through 1973, the number of traps being fished increased by over 1 million while the landings decreased by over 2,000 MT. Figure 2 illustrates that, although the catch per unit of effort in the U.S. lobster fishery has been declining since the early 1950's, the most dramatic reduction occurred during this 4-yr time span. From 1973 to 1976 effort remained fairly constant with some recovery in the landings to 14,316 MT in 1976.

In contrast to the dominant inshore portion of the U.S. lobster fishery, the offshore portion is relatively new with landings first being reported in 1950 (136 MT), primarily as a bycatch in otter trawl fin-fisheries. As a directed otter trawl fishery for lobster expanded, offshore landings increased to 544 MT in 1960 and to a peak of 3,983 MT by 1972. An offshore trap fishery started in 1969 and very rapidly expanded to a peak harvest of 2,890 MT in 1972. Although effort levels continued to grow to a high of about 74,000 traps by 1976, landings had decreased to 1,914 MT. Otter trawl landings reached a high of 3,199 MT in 1970, then declined rapidly to only 598 MT in 1976 as the otter trawl fishery was being replaced by the offshore pot fishery.

The lobster fishery in Maine has always been extremely important, amounting to 80-85% of the total U.S. catch in the early years and about 60% in recent years. The decline in the relative importance of the Maine catch is partly due to a downward trend in Maine landings and the increased offshore landings from the southern New England/mid-Atlantic areas discussed above. Generally, however, catch and effort patterns in Maine followed (or set) the national pattern of fairly constant increase from the late 1930's until 1959 when the effort level had reached about 750,000 traps. At this point effort in the Maine fishery deviated from the national pattern and remained virtually static for 11 yr (1959-69). Although landings did drop off toward the end of this period, the 11-yr average was a very healthy 9,828 MT. By 1975, however, the number of lobster pots fished in Maine had jumped to about 1.7 million and landings had dropped to 8,619 MT. The dramatic increase in effort that occurred during the 1970's was dominated by the 900,000 trap increase in Maine along with the development of the 74,000 trap offshore fishery.

Maximum sustainable yield (MSY) for the Maine inshore lobster fishery has been estimated by Dow (pers. comm.) at 10,000 MT with an optimal level of effort of 800,000 traps (Fig. 3). This estimate was based upon historical catch and effort data employing the method described by Pinhorn and Halliday (1975) and indicates that the Maine fishery was operating very near MSY and optimal effort from 1959 through 1969.

Smith (pers. comm.) also used the Pinhorn and Halliday method to estimate an MSY of 340 MT and an optimal level of effort of approximately 60,000 traps for the Connecticut fishery in the Long Island Sound. Fair (pers. comm.) estimated an MSY of 1,746 MT and an optimal level of effort of 140,000 traps for the Massachusetts inshore fishery using the Schaefer model and a slightly more conservative MSY estimate of 1,708 MT and an optimal level of effort of 130,000 traps by fitting the same data with a fourth degree polynomial regression. Marchesseault and Saila (1976) added a delay term to the instantaneous Schaefer model which they felt produced a more dynamically responsive model for the lobster fishery with its unique incremental recruitment pattern. Fitting this model to historical catch effort data (Table 3) they estimated a maximum equilibrium yield of approximately 237 MT and an optimum equilibrium effort of 24,500 traps for the inshore Rhode Island fishery (Fig. 4). Burns (1977) reported two preliminary estimates of MSY for the offshore area (12 mi) to 3,345 and 3,991 MT using the Schaefer model. These were calculated independently by gear using the commercial offshore lobster trap and otter trawl abundance indices respectively.

The areas for which estimates of maximum sustainable yield have been calculated and mentioned above account for 96% of the total U.S. landings. Adding the lowest estimates of MSY for each of these areas yields a total of 15,629 MT. Expanding this figure to include those areas that make up the other 4% of the total U.S. landings, where estimates of MSY are not readily available, yields an estimated total maximum sustainable yield for the U.S. of 16,280 MT. Actual total U.S. landings in 1976 were 14,316 MT, approximately 12% less than the estimated MSY.

Levels of effort which currently exist in many of the above discussed areas are far in excess of the estimated levels of optimum effort. For example, in 1976 Maine and Massachusetts, the two leading lobster producing states, had inshore trap levels of approximately 1,757,000 and 222,000 respectively. In contrast to this, optimal levels of effort for these areas were estimated to be 800,000 and 120,000 traps respectively, or about half the current levels of effort. Dow (1976) examined yield trends with increased fishing effort in Maine and calculated that, for years in which annual water temperature has been the same (1958-73), declines in the Maine landings have been associated with increased fishing effort at the rate of 1,000 tons decrease in landings for each increase of 175,000 traps. Burns (1977) suggested the present levels of effort even in the relatively new offshore trap fishery are greater than required to achieve MSY.

The definitely declining trend in catch per unit of effort, the fact that current levels of effort in most areas are well above the estimated

optimal levels of effort and that current harvest is well below theoretical levels of maximum sustainable yield indicate that the U.S. lobster fishery is overcapitalized and that the resource is being overfished.

REFERENCES

Burns, T. 1977. Offshore lobster assessment. NMFS, Northeast Fisheries Center, Woods Hole, June 28, 1977, 9 p.

Dow, R. L. 1976. Yield trends of the American lobster resource with increased fishing effort. MTS Journal 10: 17-25.

Marchesseault, G. D., and S. B. Saila. 1976. Delayed recruitment models and their application to the American lobster (*Homarus americanus*) fishery. J. Fish. Res. Board Can. 33: 1779-1787.

Pinhorn, A. T., and R. G. Halliday. 1975. Resources 1975 - current status of Atlantic offshore groundfish stocks and fisheries. Fish. Mar. Serv. Res. Dev. Tech. Rep. 526, 49 p.

Table 1. Catch-effort data for the U.S. lobster fishery: 1939-76.

Year	Effort (pots x 10^3)	Catch MT	Year	Effort (pots x 10^3)	Catch MT
1939	344	5,425	1958	754	12,350
1940	343	5,324	1959	857	13,153
1941	343	5,324	1960	844	14,094
1942	278	5,569	1961	895	12,667
1943	304	7,394	1962	909	13,340
1944	326	8,115	1963	867	13,692
1945	478	10,287	1964	904	13,999
1946	587	10,989	1965	944	13,669
1947	674	10,830	1966	947	13,354
1948	617	9,499	1967	908	12,007
1949	612	11,160	1968	966	14,671
1950	579	10,499	1969	1,062	15,191
1951	513	11,743	1970	1,453	15,343
1952	545	11,329	1971	1,558	15,130
1953	569	12,720	1972	1,785	14,185
1954	628	12,433	1973	2,178	13,021
1955	675	13,100	1974	2,125	12,779
1956	667	12,000	1975	2,084	13,131
1957	689	13,648	1976	2,203	14,316

Source: Fishery Statistics of the United States
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service and Predecessors
STATISTICAL DIGESTS 1-70

Table 2. Catch per unit of effort in the U.S. lobster fishery: 1939-76.

Year	MT (per thousand pots)	Year	MT (per thousand pots)
1939	15.8	1958	16.4
1940	15.5	1959	15.3
1941	15.5	1960	16.7
1942	20.0	1961	14.2
1943	24.3	1962	14.7
1944	24.9	1963	15.8
1945	21.5	1964	15.5
1946	18.7	1965	14.5
1947	16.1	1966	14.1
1948	15.4	1967	13.2
1949	18.2	1968	15.2
1950	18.1	1969	14.3
1951	22.9	1970	10.6
1952	20.8	1971	9.7
1953	22.4	1972	7.9
1954	19.8	1973	6.0
1955	19.4	1974	6.0
1956	18.0	1975	6.3
1957	19.8	1976	6.5

Source: Fishery Statistics of the United States
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service and Predecessors

STATISTICAL DIGESTS 1-70

Table 3. Catch and effort data for the Rhode Island inshore lobster fishery: 1930-67 (data obtained from Rhode Island landings).

Year	Catch MT	Effort (pots x 10^3)	Year	Catch MT	Effort (pots x 10^3)
1930	613.7	39.2	1949	160.8	17.4
1931	571.2	40.8	1950	113.4	13.4
1932	570.3	42.1	1951	95.8	8.8
1933	321.2	53.6	1952	41.4	4.6
1934	-	-	1953	55.1	5.6
1935	280.7	25.3	1954	86.4	8.0
1936	314.5	27.3	1955	100.5	7.9
1937	350.9	29.3	1956	90.9	8.2
1938	321.8	29.0	1957	118.3	7.0
1939	288.4	25.5	1958	135.9	9.4
1940	123.7	20.1	1959	185.1	12.3
1941	176.9	16.0	1960	206.1	10.6
1942	196.3	11.5	1961	175.6	9.5
1943	132.6	11.2	1962	117.8	7.3
1944	106.2	11.1	1963	76.0	7.7
1945	121.0	10.2	1964	90.6	7.0
1946	163.2	14.3	1965	172.6	8.5
1947	178.1	14.8	1966	230.7	11.8
1948	173.6	15.4	1967	231.8	13.2

Source: Marchesseault and Saila (1976)

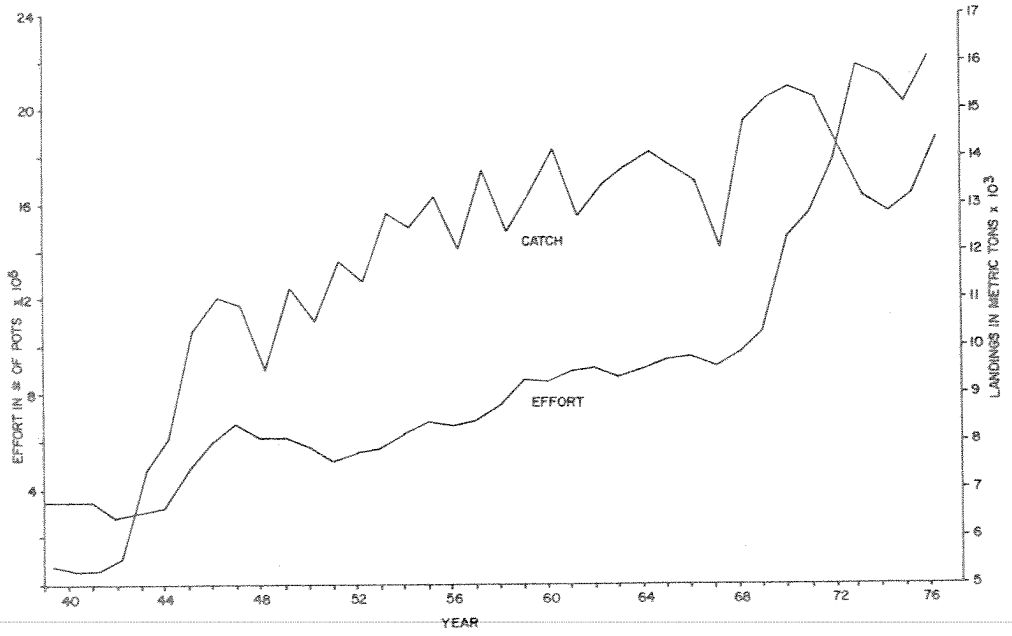


Fig. 1. Catch-effort data of the U.S. lobster fishery: 1939-76.

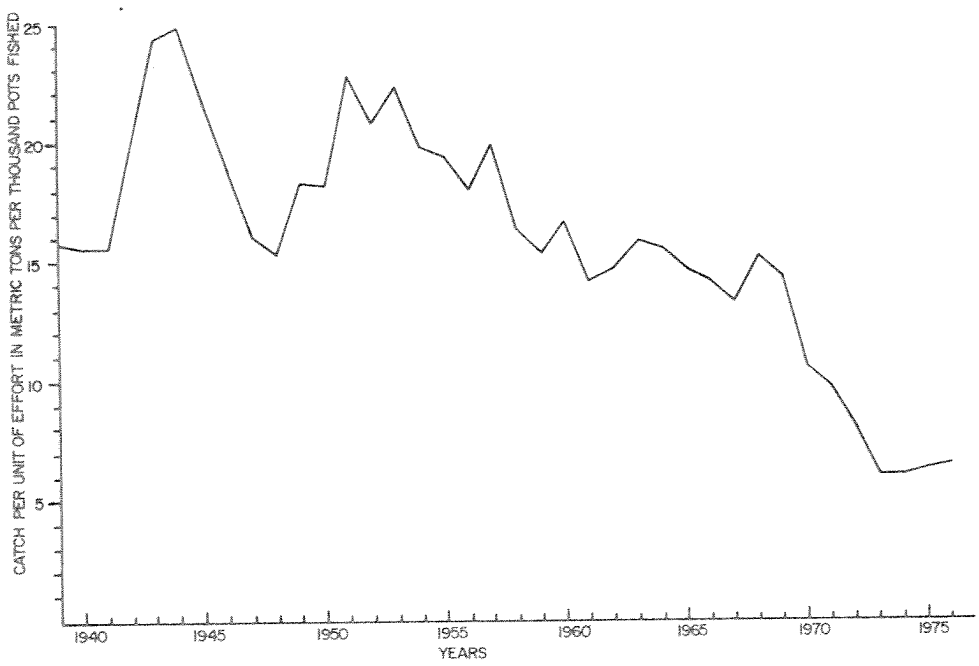


Fig. 2. Trends of catch per unit of effort in U.S. lobster fishery: 1939-76.

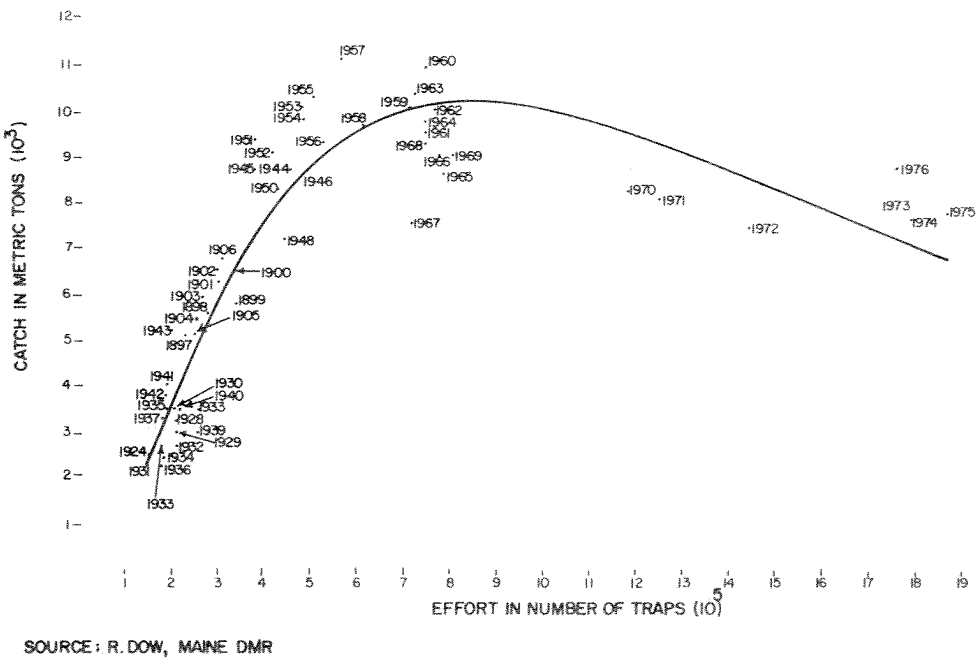


Fig. 3. Lobster catch-effort, Maine 1897-1976.

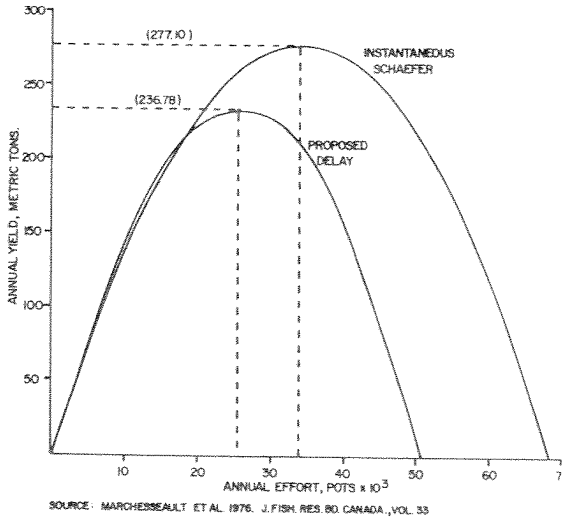


Fig. 4. Predicted values of annual yield with annual effort for the Rhode Island inshore lobster fishery given by the proposed delay and instantaneous Schaefer models.

CATCH-EFFORT TRENDS AND ESTIMATES OF MAXIMUM SUSTAINABLE YIELD (G. P. Ennis, rapporteur)

- opened with a question from Morrissey as to whether or not there had been an increase in the abundance of sublegal lobsters at St. Paul Is. in the years following the 10-yr closure to fishing. Robinson presented graphs showing a very significant shift to the left in size-frequency distributions in years immediately following the reopening of the fishery there, and a size-frequency distribution from a nearby area for the same period which was even farther to the left.

- Robinson referred to a figure presented towards the end of his talk showing Canadian landings since the fishery started. Following the development of the fishery and peak landings around 1885, landings remained at the 90 million lb level for some time before declining sharply to around 30 million lb by mid-1920. Over the past 60 yr, landings were reasonably stable at around the 40 ± 10 million lb level. The suggestion is that the Canadian MSY could be close to 90 million lb at larger size limits than currently in effect.

- referring to the production curve presented by Halgren for Maine, Caddy pointed out that the low variation in catches at given levels of effort indicates that temperature has little effect on landings. Anthony responded by referring again to the graph of landings, effort, and temperature over time for Maine. This illustrated clear positive correlations between temperature and landings and a clear indication that in recent years of the fishery, despite a dramatic increase in effort, landings have generally declined.

- Campbell referred to his preliminary analyses of data from the Port Maitland fishery which gave a better correlation between catch and effort than between catch and temperature but concluded that, as a general trend, catch and temperature were related. Stasko indicated that in these analyses, a time lag had not been used and it was pointed out by Anthony and Scarratt that temperature can be affecting catches in the current year because of its effect on growth, catchability, survival, etc.

- conclusions were summarized as follows: MSY for the entire U.S. fishery has been estimated to be 36 million lb at an optimum effort level of 1.2 million traps - this is around 4 million lb above current landings. The suggestion was made by Halgren that this MSY would not be attained unless the effort level was first reduced below the optimum level. In the Canadian fishery, it was suggested that MSY was probably double current landings of around 40 million lb. It was obvious that the level of effort in the Canadian fishery was far to the right (on a production curve) of the optimum level, and had been for so long that there were little data to indicate what the optimum level would be.

- Robinson touched on the subject of subsidies in the fishery and indicated that the real cost (i.e. cost to society) of conducting this fishery was far greater than the actual cost to the fishermen and suggested that subsidies tend to be counter-productive.

- Caddy suggested that subsidies (such as the lost-trap compensation scheme in the U.S.) are disrupting the normal predator-prey relationship between lobsters and fishermen in this fishery and suggested that, if direct or indirect forms of subsidy were eliminated, effort would drop to more reasonable levels without further interaction.

Points of discussion raised during presentation

- Robinson indicated that Y/R analyses show that the estimated MSY for the U.S. would be higher at a larger size limit. Anthony pointed out that any estimate of MSY applied to current conditions of size limit, unit of effort, etc., in the fishery and that if changes in these take place the MSY would be different.

- Robinson suggested that changes in catch tend to reflect changes in recruitment rather than changes in Y/R as a result of effort changes. He referred to differences between landings in SW Nova Scotia, Maine, and Charlotte County in relation to long-term temperature changes which indicated that factors other than temperature were involved in influencing changes in catch.

- Following a 10-yr closure of the fishery at St. Paul Is., Robinson estimated that landings in the first year that the fishery reopened were 57,300 lb, 29,640 lb in the second year and 5,300 lb in the third. The total area of lobster grounds around the Island is about 1.5 sq mi. Adjacent grounds under continuous exploitation were yielding about 2,000-3,000 lb/mi^2/yr. These figures are a clear indication that the carrying capacity of lobster grounds generally is far in excess of current standing stocks and that increases in standing stocks that would result from size limit increases through improved Y/R would be well within the carrying capacity of the grounds.

STATISTICAL REPORTING SYSTEMS

by

E. M. Smith

Department of Environmental Protection
Marine Region, P.O. Box 248
Waterford, CT 06385

ABSTRACT

Smith, E. M. 1980. Statistical reporting systems. Can. Tech. Rep. Fish. Aquat. Sci. 932.

Three categories of reporting systems are used by the ten U.S. lobster producing states. These are 1) trip landing reports through dealers, 2) annual reports by fishermen, and 3) trip reports by fishermen. The categories used by the different states are summarized, some advantages and disadvantages of each are discussed, and an evaluation of the most recent method of collecting trip data (logbook approach) is presented. A potential misuse of the logbook systems in fisheries management is discussed briefly.

INTRODUCTION

Lobster reporting systems in the U.S. may be reduced to three broad categories although no two are truly alike. The primary objective of any of the systems is undoubtedly to provide a consistent, timely summary of landings and fishing effort over a period of several years. I would like to discuss briefly the methods by which the several lobster producing regions south of New Brunswick are satisfying this objective (Table 1). Three categories of systems were referred to. These are 1) trip landing reports through dealers, 2) annual reports by fishermen, and 3) trip reports by fishermen. Virtually all states use a combination of two of these three. Disadvantages to this non-standardized approach include lack of uniformity in reporting, data handling, and calculations, and the resultant duplications in collecting effort and in compilation of regional statistics.

DESCRIPTION OF REPORTING SYSTEMS

Six of the states depend primarily on category "1", a cooperative arrangement with the U.S. National Marine Fisheries Service to record vessel landings and value by trip at the landing site (i.e., a dealer weighout system). Trip tickets are collected either daily or monthly and processed at the Northeast Fishery Center at Woods Hole. Landings appear as monthly summaries, or daily in the "green" or "blue" sheets and also as annual compilations in the Fishery Statistics of the United States. At the present time, this system is the most uniform approach throughout the region and has been conducted for the greatest number of years. However, some serious disadvantages include the fact that it only samples major dealers rather than all landings, and it makes collection of fishing effort and location data dependent on relatively infrequent, random samples of docking vessels. The lack of fishing effort data related directly to the catch made with that effort is probably the principal drawback to the system. However, as an accurate landings approximator over a period of time, for those vessels sampled, it may be no worse than any other system.

The second approach, annual reporting, is used by three states either as a supplement to the dealer weighout system (Mass. and New York) or solely as a foundation for their lobster reporting systems (New Hampshire). This approach is probably the least accurate of the three types although it does have a distinct advantage over the weighout system in that, theoretically at least, all lobstermen report. Thus, mathematical expansion of sample data is unnecessary. Also, the annual method is the least expensive of the two to operate.

The annual method allows for a rudimentary collection of effort information, generally expressed as the number of traps fished by month or year. Therefore, it is prone to disadvantages in the tabulation of precise statistics relative to catch in the specified time period. All of the annual methods require information on fishing location either by a coded map or prominent geographical location.

The system ultimately depends on recollection of either monthly or annual catches by fishermen at the end of the season. This allows an unintentional bias caused by memory lapses, and in some cases, probably an intentional one prompted by a groundless fear that their records will be used for taxation. One final disadvantage is that the information is

Table 1. Landings and the types of reporting systems used by the major U.S. lobster producing regions.

State	Magnitude of landings (MT)	Type of report & period of reporting[a] (fishermen)	(dealer)
Maine	7,000-9,000	NONE[b]	Trip/daily**
New Hampshire	200-300	Annual/Annually	---
Massachusetts	2,000-3,000	Annual/Annually	Trip/daily**
Rhode Island	1,000-2,500	Trip/month	Trip/daily**
Connecticut	200-400	Trip/month	Trip/monthly[c]
New York	200-800	Annual/Annually	Trip/monthly**
New Jersey	300-800	NONE	Trip/monthly**
Delaware	<15	---	---
Maryland	<50	---	---
Virginia	30-120	NONE	Trip/monthly**
North Carolina	---	---	---

[a]A/B A = type of report (i.e. by trip)
B = period for which report is submitted (i.e. monthly, annually)
[b]Dockside sampling program administered by Maine collects individual vessel data.
[c]Connecticut administers the dealer reporting system

**NMFS "weighout" system - dealer records landings by trip, port agent collects tickets either daily or monthly. Port agent makes random vessel samples for fishing effort (dockside).

always about a year old when it is analyzed, and present thinking appears to suggest that this is an unsatisfactory time lag.

The third category of system is the most recent, most expensive, most complicated, and in many ways the most frustrating method of compiling marine fishery statistics. For 4 yr, the State of Connecticut has operated a computer-generated logbook reporting system for lobster. More recently, Rhode Island has adopted the same approach for generation of their statistics. Both systems rely on daily record keeping by lobstermen. The log books are submitted to the licensing agency at monthly intervals at which time they are edited and processed. A monthly printout of catch by area, landings by port, and various different catch and catch-per-unit-of-effort statistics can then be summoned from the computer. In Connecticut, we now also include all of our recreational landings by use of a separate software program.

This system satisfies many of the requirements for a comprehensive statistical reporting system. It is flexible in the sense that, depending on your programming budget, you can re-analyze your data in a variety of ways. The time lag between submission of data and generation of reports is short. All data, including effort, are recorded daily. Therefore, of all the present reporting systems, the logbook approach alone allows creation of an accurate catch and effort data base for the entire fishery over very short time intervals.

Considerable criticism has been leveled at the logbook or "creel census" approach for collection of fisheries data. Perhaps some of the criticism is justified. In both Connecticut and Rhode Island the law says lobstermen must report. Still, in practice it is more like a voluntary system because we simply do not have the the manpower to check every fisherman regularly. Therefore, the accuracy of the system, as in the annual reporting approach, ultimately depends on the cooperation of the fishermen. As an adjunct to a biological sampling program, Connecticut spent a year verifying the reliability of the system as an estimator of catch per unit of effort. Our findings indicate that the sytsem output does reflect catch per unit of effort (LB/THSOD) as it is observed in the field. This system may be more accurate than the annual approach since a man may not be inclined to under-report 50% each day but, at the end of the year, he may decide his total catch is twice as large as he ought to be telling anyone.

There are disadvantages to the logbook approach. As mentioned, it is relatively expensive. The Connecticut system has cost an average of $25,000 per year for the 4 yr of operation and an additional $30,000 to initiate the entire program. Perhaps this is not expensive compared to other equally comprehensive sampling programs but it can be a substantial portion of one's budget and thus provide a major roadblock to expansion or change in other programs since, once you have such a system, you do not want to give it up if a more important short-term objective needs to be addressed.

A discussion of some of the early developmental problems in the Connecticut system may be of assistance to others contemplating similar programs. It is essential, at minimum, to have a data entry operator, programmer, and data entry terminal directly under the control of the program supervisor and preferably, under one roof. This is the approach that Rhode Island has taken and Connecticut is in the final stages of converting to this method. Having operated under a variety of situations, including contracted work and partial subsidy to other divisions of our department for various services, we find these approaches all have problems ranging from programmers with other priorities to union strikes by keypunchers and administrative delays in processing contract funds. All of these problems yield one result, namely, a backlog of data to be entered and an unnecessarily lengthy time lag between submission of data by the fishermen and generation of statistical summaries for that month.

A third drawback is that one will never get totally "clean" data from the fishermen. Our program is designed to sum identifiable data from incomplete books; however, our statistics are computed only from trips with complete fishing data. Many fishermen send books omitting fishing location codes but with a written description of the location in the margin of the book. They may also record set-over days as two or more numbers which correspond to different sets of gear, assuming we will average them. No amount of instruction has changed this behavior. As a result, we spend a certain amount of time each month editing books to correct or "clean up" their raw data. Of course, this is not a problem if you have total control over your keypuncher and he or she is fully trained to make these editorial changes as the data are entered.

In the early years of the system we had several problems with the Postal System related to handling massive amounts of prepaid business return mail. This is probably an unavoidable growing pain in implementing such a system but some advance planning can prevent unnecessary delays.

It is probably fair to estimate that, until recently, time formerly spent computing statistics has simply been transferred to time spent administering the system. Upon completion of our final equipment changes, it is expected that time spent on the project will be almost completely relegated to that required for entry of data. It goes without saying that although our time expenditure has been more than anticipated the quality of the statistics generated has unquestionably been improved.

Although it is not a reporting system per se, the approach used for generation of statistics in Maine is the most comprehensive method used in the United States and is the foundation on which both the systems of Connecticut and Rhode Island are based. It consists of port sampling for catch and effort information as well as biological and environmental data which the logbook systems are unable to obtain. Thus, it possesses a distinct advantage in this respect over any of the reporting systems generated from fishermen or dealers. Expansion of the sample data results in daily, monthly, and annual estimates of landings and the computation of a wide array of statistics. One major disadvantage of the system is that all men cannot be sampled, in particular, those who land at their own private dock.

However, this approach, combined perhaps with an annual landings report by all fishermen, may have the greatest potential for comprehensive generation of statistics from areas which have large numbers of politically active lobstermen who are firmly opposed to daily logbook reporting. The resultant statistics would satisfy requirements for fishery analysis

while the landing report would provide the most accurate catch summary for all fishermen.

Finally, I would like to discuss uses of the statistical reporting system. At various times, mention has been made of using logbook results as a foundation for any number of restrictive management measures such as quotas, vessel and fishermen allocations, stock certificate distribution schemes, and entry systems limited only to the "efficient" operators. Our system is probably operating about as accurately as possible with respect to submission of data. However, it still has serious disadvantages if one is contemplating some form of catch distribution scheme based on these reports. For example, some men fish as partners or as an employee of another during certain periods of the year and only report catch in one book. Under an allocation scheme, one of those men would gain some catch rights while the other man would lose some portion of his "rights." Also, as soon as any suggestion of one of these allocation schemes is made public, the past body of statistical data loses all meaning relative to that of the future because the rules under which the data have been solicited from the fishermen will have changed. It is my feeling that statistical reporting systems which are, in effect, voluntary should not be viewed as potential tools for use in restrictive management plans.

In summary, I think what the present systems need is standardization of data requirements and computational techniques. The method each state uses to achieve this objective should be at its discretion. One might suspect, however, that the differences in the present systems and also in departmental philosophies for achieving uniform goals may present the most formidable obstacles to future standardization of reporting objectives.

CANADIAN STATISTICAL REPORTING SYSTEM

by

M. C. Cormier

Program, Planning and Coordination Branch
Fisheries Management, Maritimes Region
P.O. Box 550
Halifax, Nova Scotia B3J 2S7

ABSTRACT

Cormier, M. C. 1980. Canadian statistical reporting system. Can. Tech. Rep. Fish. Aquat. Sci. 932.

The present fisheries statistical system in the Maritimes has evolved during the past 20 yr since it was introduced in its present form. It is intended to produce information on landings, effort, employment, and investment in the fisheries sector, and on output and export at the secondary level. The complexity and dispersion of the industry throughout the Maritimes present challenges to the measurement of these few parameters. Quality control is attempted through auditing the summary input, edit program, in computer processing and input/output comparisons. The system is reasonably accurate at the national or regional level.

INTRODUCTION

The following is a description of our current statistical system in the Maritimes. There are minor variations in reporting of statistics from British Columbia, the Western Region, Quebec, the Maritimes, and Newfoundland, but the data produced by the systems are reconcilable into a single set of national figures.

The present system was introduced in the early 1950's and could be generally characterized: (a) reflecting minimal government involvement in fisheries management with consequently limited needs for comprehensive information about the parameters of the fishery; (b) separation of commercial data from catch-effort data - the two were collected by separate agencies; and (c) designed to facilitate the provision of information on landings by obtaining it from fish buyers as a byproduct of their normal accounting.

Some of the more significant changes have been some integration of commercial and catch-effort data and the devising of a system to provide weekly information on captures of species, fishing methods, and areas of capture subject to quota. There have been some changes in the organization for the collection of this information.

Generally the system is intended to produce for publication:

- total quantity and value of each species, by type of gear used, by area of capture, landed in major areas during specified intervals of time;
- employment and investment in the primary fisheries;
- quantity and value of product by market form by province and by Atlantic on monthly and annual basis; and
- export - quantity and value of products by product form, by country.

INSTRUMENTS

The collection of information about the lobster fishery involves a number of instruments.

LANDINGS

Generally information on the catch and landings of lobster would be recorded on one of the following three instruments:

1. Purchase Slip - Whenever buyers use for their own purposes a purchase slip to record their purchase of lobster we obtain a copy of that document. We provide to them free of charge purchase-slip books or if they use their own, we pay one third of the cost of such purchase-slip books in order to obtain one copy of each slip that records purchases. These slips identify the buyer and seller, the date of the transaction, the place fish were bought, the gear used, the area of capture, the quantity and value of the species in question, as well as the unit price. If the vessel exceeds 25 gross tons (GT), that must also be identified.

Accompanying each group of purchase slips for a single buyer is a purchase slip guide completed by the field staff to explain unusual terms that may be used on the slip, to provide information that may not have been put on the individual slips and to correct any information that may have been improperly reported on the slips (place fish bought).

2. Supplementary Purchase Slip - Whenever buyers do not use a regular accounting system which provides individual purchase slips for each transaction information about the quantities of lobster they purchase is obtained by means of a supplementary purchase slip A. This identifies the buyer, the identity of the seller if a vessel over 25 GT is involved, the place the lobster is bought, the quantity and value of the lobster purchased, the gear used, and the period of time (usually 1 mo) covered. If the landings were made by a vessel over 25 GT, the area of capture would be provided.

3. Supplementary Purchase Slip B - To record landings of lobster that may not enter regular commercial channels another document called a supplementary purchase slip B is used. This covers such instances as the sales of lobster by fishermen to tourists and lobster consumed by fishermen and their families. In certain areas such consumption may be higher than would initially be suspected. These figures on sales or consumption are estimates provided by our field staff. The information provided involves quantity, unit price, and gear used.

To record catch effort data for vessels over 25 GT a log is used to record daily catch by area and number of traps used.

EMPLOYMENT

This information was previously obtained through an annual enumeration that would record all fisheries engaged in by individual fishermen as well as the duration of such employment. Now this same information is obtained as a byproduct of our licensing system which covers all fishermen.

Employment in processing is obtained annually through a special survey of processors which records maximum employment and average employment but only for the total establishment and not for the several processing activities of a single multi-product establishment. Thus, a cannery producing canned lobster, canned mackerel, and canned groundfish would report its total employment but not by activity.

No information is collected on employment in distribution of fish *per se*.

INVESTMENT

The licensing system referred to above provides information on the number and size of vessels used in fishing by port of landing and by home port of the owner. An estimate of value of each vessel is made annually.

No information is obtained on the number or value of lobster fishing gear either on inventory or in use.

No information is collected on investment in processing or in distribution.

PRODUCTS

Three separate forms are used to record the output of processed lobster.

Canned - Each cannery reports monthly on the quantity of lobster canned during the month and stocks held at month's end. This same form also covers shucked lobster meat that is not frozen.

Frozen - Each firm with freezing capacity reports monthly the amount of lobster in shell or shucked lobster meat frozen during the month and held in stock at the end of the month.

Live - Each firm reports the quantity of lobster in shell (not frozen) sold on an annual basis and such sales are separated as sales to market and sales to within the industry in other provinces; this is to produce provincial and non-duplicating national figures.

Each firm holding live lobster in lobster pounds also reports on a monthly basis on the quantity.

Value - On an annual basis selected firms provide average F.O.B. plant value of these individual products.

QUALITY AND MONITORING

The statistical system is intended to provide information about the overall industry on a timely basis and in a reasonably accurate manner but the degree to which it can meet its objectives is always constrained by budgets and manpower.

The system must accommodate itself to an industry comprising 18,000 fishermen located and operating from 1,000 communities in three provinces, landing about 50 species purchased by 500 buyers and 500,000 individual transactions. These landings are processed into several hundred different products.

Some of the characteristics that constitute weaknesses in the system are the total number of purchase slips involved, the distance and time in the physical transmission of the slips to a central headquarters, the chances for error in coding, the time interval between landing the fish and the establishment of a price (bonus), etc.

The mechanisms for monitoring for quality include: (a) review of printout by District by field personnel for gross errors; (b) edit systems built into computer programs - price, gear, area; and (c) comparisons between industry input and output through appropriate conversion factors and also value comparisons.

The degree of accuracy with which this reporting is done is believed to be reasonable for national statistics but deficiencies become more serious as the data are not aggregated, particularly for management purposes when either timeliness is very important for quota management or effort control or where accuracy of detail is needed.

ORGANIZATION AND OPERATIONS

The functional responsibility for the statistical system, for the establishment and operation of an efficient system, rests with a Statistical Coordinating Committee composed of a representative of each of four branches involved in the system. Line responsibility rests with each branch.

The collection of the information is with Field Services, monitoring for quality with Resource Branch, processing with Support Services and Program Planning. This division of responsibility is occasioned by reasons of economy mainly.

Some 100 field staff, representing from 40-50 man-years, are used in collecting and monitoring the information. These have other responsibilities connected with enforcement, inspection, and sampling.

Another 20 persons are engaged in editing, coding and computer processing of the information for publication. Publication is handled by Statistics Canada - Monthly Review of Canadian Fisheries Statistics[1] and Fisheries Statistics, New Brunswick and by Department of Fisheries and Oceans (1) Annual Statistical Review of Canadian Fisheries, (2) Monthly Canadian Fisheries - Products and Stocks, and (3) Monthly Canadian Fisheries - Primary Sector Activities.

---

[1]Publication ceased December 1978.

FISHERMAN'S SALES SLIP — BORDEREAU DE VENTE DU PÊCHEUR

NAME OF BUYER / NOM DE L'ACHETEUR

ADDRESS OF BUYER / ADRESSE DE L'ACHETEUR

NAME OF SELLER / NOM DU VENDEUR — DATE SAILED / BATEAU PARTIE

ADDRESS OF SELLER / ADRESSE DU VENDEUR — DATE LANDED / DÉBARQUÉ LE

PLACE FISH BOUGHT / POISSON ACHETÉ À — V.I.N. NO / N° D'IMMAT.

NAME OF BOAT / NOM DU BATEAU

GEAR USED / ENGINS DE PÊCHES UTILISÉS — LICENCE NO / LICENCE N°

QUANTITY / QUANTITÉ	SPECIES AND SIZES / ESPÈCES ET TAILLES	PRICE / PRIX	AMOUNT / TOTAL	

Environment Canada / Environnement Canada

Fisheries and Marine / Pêches et Mer

PURCHASE SLIP GUIDE (To be completed for each fish buyer)

GUIDE DE BORDEREAU D'ACHAT (À remplir pour chaque acheteur de poissons)

STATISTICAL DISTRICT OR SECTION (NFLD) NO. .....
DISTRICT STATISTIQUE OU RÉGION (T.-N.) N°

DATE ..... 19.....

1. NAME OF BUYER .....
NOM DE L'ACHETEUR

ADDRESS OF BUYER .....
ADRESSE DE L'ACHETEUR

Processor ..... *Fabriquant*
Commission Agent ..... *Commissionnaire en marchandises*
Peddler ..... *Colporteur*

Assembler ..... *Empaqueteur*
Other (specify) ..... *Autre (spécifier)*

PLACE FISH BOUGHT .....
Poisson acheté à (lieu)

2. FORM IN WHICH FISH OR SHELLFISH ARE SHOWN ON PURCHASE SLIPS (specify by species).
FORME SOUS LAQUELLE LES POISSONS OU MOLLUSQUES FIGURENT SUR LES BORDEREAUX D'ACHAT (spécifier par espèces)

Round .....
Poids brut

Gutted head off .....
Vidés, sans tête

Gutted head on .....
Vidés, avec tête

Split .....
Fendus

In shell .....
Dans l'écaille

Shucked .....
Écaillés

Other (specify) .....
Autre (spécifier)

3. WEIGHTS OF UNITS OF MEASURE (specify by species)
POIDS DES UNITES DE MESURES (spécifier par espèces)

How many pounds in a:
Nombre de livres dans

Tub .....
Une demi-tonne

Bucket .....
Un baquet

Barrel .....
Un baril

Gallon .....
Un gallon

Other (specify) .....
Autre (spécifier)

4. PRICE BY SPECIES (if not shown on purchase slips)
COUT PAR ESPÈCES (si non inscrit sur les bordereaux d'achat)

.....

5. GEAR USED
ENGINS DE PÊCHE UTILISÉS

.....

6. REMARKS
REMARQUES

.....

.....

Signature .....
Fisheries Officer / *Agent de pêche*

081-841 (08/75)

Environment Canada Environnement Canada
Fisheries and Marine Pêches et Mer

STATISTICAL DISTRICT OR SECTION (Nfld.) NO.
District statistique ou région (T. N.) n° .....

SUPPLEMENTARY PURCHASE SLIP – A
Monthly Report

BORDEREAU D'ACHAT COMPLÉMENTAIRE – A
Rapport mensuel

THIS REPORT COVERS THE PERIOD FROM ..... TO
Ce rapport porte sur la période allant du ..... Au ..... 19 .....

NOTE: To be used for recording purchases of fish from fishermen by processors, commission agents, assemblers and peddlers (door-to-door sellers) when regular purchase slips are not obtainable.

NOTA: Doit être utilisé pour inscrire les achats de poissons par les fabriquants, les commissionnaires en marchandises, les empaqueteurs, les colporteurs lorsque les bordereaux d'achat réglementaires ne sont pas disponibles.

NAME OF BUYER / Nom de l'acheteur

ADDRESS OF BUYER / Adresse de l'acheteur

PLACE WHERE FISH BOUGHT / Poisson acheté à (lieu)

NAME OF VESSEL / Nom du navire

QUANTITY (Net pounds) Quantité (poids net)	SPECIES AND MARKET FORM Espèce et forme commerciale	PRICE PER POUND Prix à la livre	AMOUNT Montant $	¢	GEAR USED Engins de pêche utilisés

REMARKS / Remarques

DATE

SIGNATURE

This report, when completed, is to be forwarded to the Regional office not later than the 5th of the month following.
Remplir le présent rapport et l'expédier au Bureau régional au plus tard le 5 du mois suivant.

081-842 (08/75)

Environment Canada Environnement Canada
Fisheries and Marine Pêches et sciences de la mer

SUPPLEMENTARY PURCHASE SLIP – B

This report covers the period from ..... to ..... 19 .....

Note: To be used for reporting all fish landings in a community during the month which were not recorded in fresh state on regular purchase slips.

Statistical District No. ..... Name of Community ..... County .....

1. FISH PROCESSED BY FISHERMEN – salted cod, pickled herring, etc.

Product Weight (lb.)	Species and Market Form	Fresh fish* Price per lb.	Gear used	For office use only

2. FRESH FISH SALES

Product Weight (lb.)		Fresh fish* Price per lb.	Gear used	For office use only

3. FRESH FISH USED AS BAIT BY FISHERMEN

Weight (lb.)	Species and Market Form	Fresh fish* Price per lb.	Gear used	For office use only

4. OTHER LANDINGS (Including fish consumed by fishermen and their families)

Product Weight (lb.)	Species and Market Form	Fresh fish* Price per lb.	Gear used	For office use only

*Price paid to fishermen for fresh fish in your district.

Date ..... Signature .....
Fisheries Officer

This report, when completed is to be forwarded to the Halifax office not later than the 5th of the month following.

F 6-6500 (Rev. 6/73) F-6803

19____ VESSEL _____ REGISTRATION NUMBER _____ CAPTAIN _____ TOTAL CREW _____

GEAR: SIZE _____ TYPE _____ NUMBER USED _____ BAIT _____

DAILY CATCH RECORD							LOBSTERS LANDED			REMARKS
TRIP No.	MONTH AND DATE	POSITION LAT. LONG. LORAN OR DECCA READING	DEPTH (FATH.)	NUMBER HRS. GEAR SET	NUMBER TRAPS HAULED	ESTIMATED CATCH LBS.	MONTH AND DATE LOBSTERS SOLD	BUYER	TOTAL LOBSTERS SOLD LBS.	GEAR LOSSES, TYPES AND NUMBER OF DISCARDS, WEATHER, MOVING GEAR, ETC.

CONFIDENTIAL

FISHERIES RESEARCH BOARD OF CANADA

Environment Canada Environnement Canada
Fisheries and Marines Pêches et services de la mer

QUEBEC BUREAU OF STATISTICS
BUREAU DE LA STATISTIQUE DU QUÉBEC

MONTHLY REPORT OF CANNED FISH, SHUCKED AND PEELED MEAT

RAPPORT MENSUEL SUR LE POISSON EN CONSERVE ET SUR LES PRODUITS ÉCAILLÉS

REPORT NO.
Rapport N° .....

MONTH
Mois de ..... 19 .....

NAME OF PLANT / Nom de l'établissement	LOCATION OF PLANT / Adresse de l'établissement		
Species and description of product *Espèces et description du produit*	Number and size of cans per case *Nombre et format des boîtes par caisse*	Total production this plant *Production totale de l'établissement*	Stocks held in this plant at end of month *Stocks dans l'établissement à la fin du mois*

....
Signature

....
Date

This report when completed is to be returned not later than the 5th of the month following to:

For Maritimes - Department of the Environment
Fisheries Operations
P.O. Box 550, Halifax, N.S.

For Newfoundland - Department of the Environment
Fisheries Operations
P.O. Box 5667, St. John's, Nfld.

For Quebec - Provincial Bureau of Statistics
Quebec, Que.

Le présent rapport dûment rempli doit être retourné au plus tard le 5 du mois suivant au:

Dans les Maritimes - Ministère de l'Environnement
Opérations des pêches
Case Postale 550, Halifax (N.-E.)

À Terre-Neuve - Ministère de l'Environnement
Opérations des pêches
Case Postale 5667, St. Jean, (T.-N.)

Au Québec - Bureau de la Statistique du Québec
Québec, Qué.

F-837 (Rev. 8/73)

Fisheries and Oceans Canada — Pêches et Océans Canada

MONTHLY REPORT OF FROZEN FISH FOR THE MONTH OF
RAPPORT MENSUEL SUR LE POISSON CONGELÉ POUR LE MOIS DE 19

Company / Compagnie

Address / Adresse

Net weight of fish in pounds / Poids net du poisson en livres

Products and species / Produits et espèces	Department's use only / À l'usage du ministère seulement	Freezings during month / Quantités congelées durant le mois	Stocks at End of month / Stocks à la fin du mois
FROZEN ROUND / CONGELÉS SOUS FORME ENTIÈRE		lb / lbs	lb / lbs
Cod / Morue	01200		
Haddock / Aiglefin	01250		
Species / Espèce	01357		
Hake / Merluche	01259		
Halibut / Flétan	01360		
Other - specify / Autre - spécifier	01001		
	01002		
FROZEN DRESSED / CONGELÉS SOUS FORME HABILLÉE			
Cod / Morue	02100		
Haddock / Aiglefin	02110		
Pollock / Goberge	02170		
Hake / Merluche	02171		
Cusk / Brosme	02173		
Redfish / Sébaste	02120		
Catfish / Poisson-chat	02174		
Halibut / Flétan	02130		
Turbot / Turbot	02144		
Flounders and Soles / Poissons plats et Soles	02149		
Herring / Hareng	02200		
Mackerel / Maquereau	02250		
Tuna / Thon	02258		
Swordfish / Espadon	02251		
Salmon / Saumon	02354		
Capelin / Capelan	02360		
Other - specify / Autre - spécifier	02001		
	02002		
FROZEN FILLETS / FILETS CONGELÉS			
Cod / Morue	03100		
Haddock / Aiglefin	03110		
Pollock / Goberge	03170		
Hake / Merluche	03171		
Cusk / Brosme	03173		
Catfish / Poisson-chat	03174		
Redfish / Sébaste	03120		
Halibut / Flétan	03130		
Turbot / Turbot	03144		
Flounders and Soles / Poissons plats et Soles	03149		
Herring / Hareng	03200		
Mackerel / Maquereau	03250		
Other - specify / Autre - spécifier	03001		
	03002		
FROZEN BLOCKS AND SLABS / BLOCS ET DALLES CONGELÉS			
Cod / Morue	04100		
Haddock / Aiglefin	04110		
Pollock / Goberge	04170		
Hake / Merluche	04171		
Cusk / Brosme	04173		
Catfish / Poisson-chat	04174		
Redfish / Sébaste	04120		
Halibut / Flétan	04130		
Turbot / Turbot	04144		
Flounders and Soles / Poissons plats et Soles	04149		
Other - specify / Autre - spécifier	04001		
	04002		

Products and species / Produits et espèces	Department's use only / À l'usage du ministère seulement	Freezings during month / Quantités congelées durant le mois	Stocks at End of month / Stocks à la fin du mois
FROZEN COMMINUTED FISH / POISSON HACHÉ FIN CONGELÉ		lb / lbs	lb / lbs
Blocks formed with only one species / Blocs formés d'une seule espèce			
Specify / Spécifier	05101		
	05102		
Blocks formed with more than one species / Blocs formés de plusieurs espèces	05103		
PORTIONS, STICKS, ETC. / PORTIONS, BAGUETTES, ETC.			
Fish sticks / Bâtonnets de poisson	06201		
Fish cakes / Croquettes de poisson	06202		
Portions			
(1) breaded / panés	06203		
(2) battered / enrobés	06204		
(3) non-breaded / non panés	06205		
Sticks / Baguettes			
(1) breaded / panées	06206		
(2) battered / enrobées	06207		
(3) non-breaded / non panées	06208		
Shrimp breaded / Crevettes panées	06357		
Scallops / Pétoncles	06356		
Other - specify / Autre - spécifier	06001		
	06002		
FROZEN SHELLFISH / MOLLUSQUES ET CRUSTACÉS CONGELÉS			
Oysters in shell / Huîtres en coquille	07705		
Oysters shucked / Huîtres sans coquille	07715		
Blue mussels in shell / Moules bleues en coquille	07708		
Blue mussels shucked / Moules bleues sans coquille	07718		
Lobsters in shell / Homards en coquille	07700		
Lobsters shucked / Homards sans coquille	07710		
Scallops unbreaded / Pétoncles non panés	07612		
Scallops breaded / Pétoncles panés	07622		
Shrimps in shell / Crevettes en coquille	07702		
Shrimps peeled / Crevettes sans coquille	07712		
Other - specify / Autre - spécifier	07001		
	07002		
FROZEN SMOKED FISH / POISSON FUMÉ CONGELÉ			
Cod / Morue	08100		
Haddock / Aiglefin	08110		
Haddock fillets / Aiglefin en filets	08111		
Pollock / Goberge	08170		
Hake / Merluche	08171		
Cusk / Brosme	08173		
Catfish / Poisson-chat	08174		
Redfish / Sébaste	08120		
Halibut / Flétan	08130		
Herring kippers / Hareng kippers	08200		
Mackerel / Maquereau	08250		
Other - specify / Autre - spécifier	08001		
	08002		

TOTAL / TOTAUX

Products and species / Produits et especes	Department's use only / À l'usage du ministère seulement	Freezings during month / Quantités congelés durant le mois	Stocks at End of month / Stocks à la fin du mois
FROZEN BAIT / BOETTE CONGELÉE		lb. / liv	lb. / liv
Herring / *Hareng*	09200		
Mackerel / *Maquereau*	09250		
Alewives / *Gaspereau*	09350		
Smelt / *Eperlan*	09613		
Capelin / *Capelan*	09360		
Other, specify / *Autre, spécifier*			
	09001		
	09002		

Products and species / Produits et especes	Department's use only / À l'usage du ministère seulement	Freezings during month / Quantités congelés durant le mois	Stocks at End of month / Stocks à la fin du mois
FROZEN ANIMAL FEED / ALIMENTS CONGELES POUR ANIMAUX		lb. / liv	lb. / liv
	10800		
OTHER FROZEN PRODUCTS / AUTRES PRODUITS CONGELÉS			
Tongues and cheeks / *Langues et joues*	11001		
Specify / *Spécifier*	11002		
	11003		

Signature

Date

NOTE

This is a pool survey of the Department of the Environment and of Statistics Canada, operating under the authority of section 48 of the Fisheries Act and section 11 of the Statistics Act.

The Fisheries and Marine Service would appreciate your comments and suggestions.

INSTRUCTIONS

Report only frozen fish, do not include fresh, cured or canned fish. Return your completed report each month even though your report may be Nil.

Freezing during month

Report in pounds the quantities of each product that were frozen in your plant during the month indicated above.

End of month's stocks

Report the quantities of each product on hand at the close of business on the last day of the month indicated above.

Fish processors, brokers, wholesalers, etc. are required to report all frozen fish or frozen shellfish (domestic and imported) held in their own establishments or in private rooms in other cold storage warehouses. Do not include fish held in public rooms in other warehouses as these will be reported by the warehouse.

Cold storage warehouses are required to report all frozen fish or frozen shellfish (domestic and imported) held for the account of their own firm, as well as frozen fish held in public rooms for the account of others. Do not include frozen fish held in private rooms for other firms as these will be reported by the owner of such fish.

This report when completed is to be returned not later than the 21st of the month following to:

1. For the Maritime provinces

   Department of the Environment
   Fisheries and Marine Service,
   P.O. Box 550,
   Halifax, N.S.

2. For Newfoundland

   Department of the Environment,
   Fisheries & Marine Service,
   P.O. Box 5667,
   St. John's, Newfoundland.

NOTA

Ce relevé est fait conjointement par les ministères de l'Environnement et Statistique Canada, sous l'autorité de la section 48 de la Loi sur les pêcheries et de la section 11 de la Loi sur la statistique.

Le Service des pêches et des sciences de la mer vous invite à lui communiquer vos commentaires et suggestions.

DIRECTIVES

Inscrire seulement le poisson congelé, non le poisson frais, salé ou en conserve. Prière de faire rapport chaque mois, même si vous n'avez rien à déclarer.

Quantités congelées durant le mois

Inscrire la quantité de chacun des produits que votre établissement a congelée durant le mois indiqué plus haut.

Stocks à la fin du mois

Inscrire la quantité de chacun des produits que vous avez en stock à la clôture des affaires, le dernier jour du mois indiqué ci-dessus.

Les producteurs, courtiers, grossistes, etc. sont priés de déclarer tous leurs stocks de poissons et de mollusques et de crustacés (domestiques et importés) congelés, soit dans leurs propres entrepôts, soit dans des locaux particuliers d'autres entrepôts frigorifiques. Ne pas déclarer le poisson stocké dans des locaux publics d'autres entrepôts, ainsi que ceux ci le feront.

Les entrepôts frigorifiques sont priés de déclarer tous les stocks de poissons et de mollusques et de crustacés (domestiques et importés) qu'ils détiennent pour leur propre compte, de même que le poisson congelé entreposé dans des locaux publics pour le compte d'autrui. Ne pas inscrire le poisson congelé stocké dans des locaux particuliers pour le compte d'autres établissements, ainsi que ceux ci le déclareront.

Ce rapport doit être rempli et retourné au plus tard le 21ème jour du mois suivant à:

1. Pour les provinces maritimes

   Ministère de l'Environnement
   Service des Pêches et de la Mer
   C.P. 550
   Halifax, N.E.

2. Pour Terre-Neuve

   Ministère de l'Environnement
   Service des Pêches et de la Mer
   C.P. 5667
   St. Jean, T.N.

Environment Canada Fisheries and Marine | Environnement Canada Pêches et Mer

QUEBEC BUREAU OF STATISTICS
BUREAU DE LA STATISTIQUE DU QUÉBEC

ANNUAL REPORT OF SALES OF SPECIFIED PRODUCTS
(Fish Processors, Packers and Handlers)

RAPPORT ANNUEL DES VENTES DE PRODUITS DÉSIGNÉS
(Conditionneurs, emballeurs et distributeurs)

19.....

Name of Firm
Nom de l'établissement .....

Address
Adresse .....

See back of form for definition of sales – *Voir définition des ventes au verso de la formule*

Product and species *Produit et espèce*	Total sales outside the fish processing and packing industry *Ventes totales en dehors de l'industrie du conditionnement et de l'emballage du poisson*	Sales to fish processors and packers in the other four Atlantic Provinces* *Ventes aux conditionneurs et emballeurs dans les quatre autres provinces de l'Atlantique**
FRESH FISH ROUND AND DRESSED – *POISSON FRAIS ENTIER ET HABILLÉ*	lb. – *liv.*	lb. – *liv.*
Cod – *Morue*		
Haddock – *Aiglefin*		
Pollock – *Goberge*		
Hake – *Merlu*		
Cusk – *Brosme*		
Redfish – *Sébaste*		
Catfish – *Poisson-chat*		
Other Groundfish – *Autres poissons de fond*		
Halibut – *Flétan*		
Flounders & Soles – *Poissons plats et soles*		
Skate – *Raie*		
Tomcod – *Poulamon*		
Eels – *Anguille*		
Herring – *Hareng*		
Mackerel – *Maquereau*		
Alewives – *Gaspareau*		
Tuna – *Thon*		
Swordfish – *Espadon*		
Salmon – *Saumon*		
Sturgeon – *Esturgeon*		
Shad – *Alose*		
Smelts – *Éperlan*		
Striped bass – *Bar d'Amérique*		
Herring Bait – *Hareng Appât*		
All Other – *Autres*		
FRESH FILLETS – *FILETS FRAIS*		
Cod – *Morue*		
Haddock – *Aiglefin*		
Pollock – *Goberge*		
Hake – *Merlu*		
Cusk – *Brosme*		
Redfish – *Sébaste*		
Catfish – *Poisson-chat*		
Other Groundfish – *Autres poissons de fond*		

Product and species *Produit et espèce*	Total sales outside the fish processing and packing industry *Ventes totales en dehors de l'industrie du conditionnement et de l'emballage du poisson*	Sales to fish processors and packers in the other four Atlantic Provinces* *Ventes aux conditionneurs et emballeurs dans les quatre autres provinces de l'Atlantique**
FRESH FILLETS (Cont'd) – *FILETS FRAIS (suite)*	lb. – *liv.*	lb. – *liv.*
Halibut – *Flétan*		
Flounders & Soles – *Poissons plats et soles*		
Skate – *Raie*		
Mackerel – *Maquereau*		
All Other – *Autres*		
SHELLFISH IN SHELL – *MOLLUSQUES ET CRUSTACÉS DANS LA COQUILLE*		
Lobsters – *Homards*		
Oysters – *Huîtres*		
Clams: Soft-shell – *Mye*		
Bar – *Mactre*		
Quahaugs		
All Other – *Autres*		
SHELLFISH MEAT (chilled) – *CHAIR DE MOLLUSQUES ET CRUSTACÉS (trigorifiée)*		
Oysters – *Huîtres*		
Scallops – *Pétoncles*		
Clams		
Quahaugs		
All Other (excluding lobster) – *Tous autres (sauf le homard)*		
SMOKED FISH – *POISSON FUMÉ*		
Cod Fillets – *Filets de morue*		
Haddock split – *Aiglefin tendu*		
Haddock Fillets – *Filets d'aiglefin*		
Other Groundfish Fillets – *Filets d'autres poissons de fond*		
Kippers – *Hareng doux*		
Salmon – *Saumon*		
All Other – *Autres*		
OTHER SALES† – *AUTRES VENTES†*	$	X X X X X X X

*The Atlantic Provinces include Nova Scotia, New Brunswick, Prince Edward Island, Quebec and Newfoundland.
**Les provinces de l'Atlantique comprennent la Nouvelle-Écosse, le Nouveau-Brunswick, L'Île-du-Prince-Édouard, le Québec et Terre-Neuve.*
†Other Sales: Give dollar value of – animal food, bones, fertilizer, glue, livers, roes, scales, seaweeds, fish skins, solubles, sounds, tongues, cheeks, blood worms.
†Autres ventes: indiquer la valeur en dollars des aliments pour animaux, os, engrais, colle, foie, oeufs, de poisson, écailles, algues, peaux de poisson, solubles, nerfs, langues, joues, sangsues.

This report is to be completed by February 1 and returned to:

Le présent rapport doit être rempli et retourné au plus tard le 1er février au:

FOR MARITIMES — Department of the Environment, Fisheries and Marine Service, P.O. Box 550, Halifax, N.S.

DANS LES MARITIMES — Ministère de l'Environnement, Service des Pêches et de la Mer, Case postale 550, Halifax, N.-É.

FOR QUEBEC — Quebec Bureau of Statistics, Quebec, Que.

DU QUÉBEC — Bureau de la Statistique du Québec, Québec, Que.

Signature

Date

081-844 (08/75)

INSTRUCTIONS

SALES OUTSIDE THE FISH PROCESSING AND PACKING INDUSTRY include sales direct on export or on your behalf to fish brokers, domestic wholesalers and retailers or sales directly to consumers. Do not include sales of fishery products to processors in the Atlantic Provinces. The Atlantic provinces include the following provinces: Nova Scotia, New Brunswick, Prince Edward Island, Newfoundland and Quebec.

We are attempting to eliminate the duplication resulting from many transactions within the fish processing industry in the Atlantic Area. For example, if firms A, B, C and D in one province produce wet salted cod and sell it all to firm X in the same province and firm X further processes it into boneless cod fillets, firms A, B, C and D will not report the sale of wet salted cod to X since X is the processor that sells the final product on export or for consumption in Canada.

Likewise, if firms A, B, C, D, E and F in one province produce bloaters and sell all of their production to firm X in the same province who in turn sells the product outside of the fish processing industry, the sales will all be reported by firm X.

We wish to obtain sales of fishery products outside of the confines of the fish processing and packing industry. Sales directly to Canadian wholesalers, retailers or directly to consumers should be included under this heading.

SALES TO FISH PROCESSORS AND PACKERS in the other four Atlantic Provinces. The Atlantic provinces include Nova Scotia, New Brunswick, Prince Edward Island, Newfoundland and Quebec. Do not report sales made to processing firms within the same province in which your fish plant is located. Fish plants located in Nova Scotia, for example, should report sales to fish processors in the remaining four provinces of New Brunswick, Prince Edward Island, Newfoundland and Quebec. It is not necessary to name the processor or the province to which the fish was shipped.

DIRECTIVES

LES VENTES EN DEHORS DE L'INDUSTRIE DU CONDITIONNEMENT ET DE L'EMBALLAGE DU POISSON comprennent les ventes directes à l'étranger ou les ventes faites pour votre propre compte aux courtiers, grossistes et détaillants du pays, ainsi que les ventes faites directement aux consommateurs. Ne pas inclure les ventes de produits de la pêche faites aux conditionneurs dans les provinces de l'Atlantique, qui comprennent la Nouvelle-Écosse, le Nouveau-Brunswick, l'Île-du-Prince-Édouard, Terre-Neuve et Québec.

Nous essayons d'éviter toute duplication pouvant résulter de bien des transactions qui s'effectuent au sein de l'industrie du conditionnement dans la région atlantique. Par exemple, si les établissements A, B, C et D d'une province donnée produisent de la morue salée en saumure et la vendent à l'établissement X de la même province et que ce dernier en fait des filets désossés, les établissements A, B, C et D ne doivent pas déclarer leurs ventes de morue salée en saumure consenties à X, vu que celui-ci est le conditionneur qui vend le produit fini sur les marchés étrangers ou aux consommateurs du Canada.

De même, si les établissements A, B, C, D, E et F d'une province donnée produisent du hareng bouffi pour le vendre entièrement à la X qui, à son tour, revend ce poisson en dehors de l'industrie du conditionnement, c'est à X de déclarer ses ventes.

Nous désirons obtenir les chiffres de vente des produits de la pêche en dehors des limites de l'industrie du conditionnement et de l'emballage du poisson. Par conséquent, vous devez indiquer sous la rubrique dont il s'agit ici les ventes faites directement aux grossistes et détaillants canadiens ou directement aux consommateurs.

VENTES AUX CONDITIONNEURS ET EMBALLEURS DE POISSON dans les quatre autres provinces de l'Atlantique. L'ensemble des provinces de l'Atlantique comprend la Nouvelle-Écosse, le Nouveau-Brunswick, l'Île-du-Prince-Édouard, Terre-Neuve et Québec. Ne déclarez pas les ventes faites aux entreprises de conditionnement établies dans la même province que votre propre entreprise Les établissements situés en Nouvelle-Écosse, par exemple, ne doivent signaler que les ventes faites aux conditionneurs de poisson établis dans l'une des quatre autres provinces, soit le Nouveau-Brunswick, l'Île-du-Prince-Édouard, Terre-Neuve et Québec. Il n'est pas nécessaire de désigner le conditionneur ni la province à laquelle le poisson a été expédié.

Environment Canada Environnement Canada
Fisheries and Marine Pêches et Mer

MONTHLY REPORT OF LOBSTER POUND FOR MONTH OF ..... 19 .....

OWNER ADDRESS

LOCATION LICENCE NO.

QUANTITY OF LOBSTERS IN POUND AT BEGINNING OF MONTH ..... LBS.

QUANTITY PUT IN DURING MONTH ..... LBS.

QUANTITY LIVE LOBSTERS TAKEN FROM POUND DURING MONTH ..... LBS.

QUANTITY DEAD LOBSTERS TAKEN FROM POUND DURING MONTH ..... LBS.

QUANTITY REMAINING IN POUND AT END OF MONTH ..... LBS.

REMARKS

DATE SIGNATURE OF OFFICER MAKING RETURN

081-6-5953 (02/76) F-6407

STATISTICAL REPORTING SYSTEMS (B. Halgren, rapporteur)

Caddy: What comparisons can we make between the two (U.S. and Canadian) systems and how does each system meet the needs of lobster management?

Smith: That depends on the management needs in each area. The daily logbook system has merit because it allows for the collection of catch and effort data by trip. These data are necessary for many management decisions.

Caddy: In Canada, the keeping of logbooks was on a voluntary basis up until a few years ago. It is now compulsory, but only for vessels over a certain size. This eliminates the requirement of keeping logbooks on many inshore boats, but the offshore vessels have them. When reporting is not voluntary, however, the question is often raised that deliberate misreporting may become commonplace.

Cormier: When a reporting system is on a voluntary basis, you have a chance to develop your own contacts and collect data in which you have a certain level of confidence. When you make a system mandatory, we have proof that in at least some circumstances you can obtain gross inaccuracies.

Bennett: In a voluntary system it seems that a bias might present itself insofar as the more efficient fishermen seem to be more cooperative and this leads to overestimates of catch per effort.

Smith: This is probably so, but the misrepresentation of data in a mandatory system does not necessarily occur in all cases. Connecticut conducted a 1-yr study in the field where we calculated values of catch-effort which are surprisingly close to those values from the monthly logbook summaries.

Caddy: Do you (in Connecticut) guarantee your fishermen that the data collected via logbooks will not be used for income tax purposes?

Smith: Yes.

Robinson: In a statistical sampling system, what size data base do we need for getting catch-effort type data from 13,000 fishermen spread out along many miles of shoreline? Do we need to sample 100% - I don't think so.

Thomas: In the paper Simpson put out I think that, out of 2,000 or so fishermen, he tried to sample 5%, whom he then paid to keep a log book.

Bennett: I am not sure but I believe that he tried to collect everything he could. We have tried to sample about 1 in 10 fishermen on a stratified basis, but that is only a guess as to a statistically valid sample size.

Caddy: We have conducted biological sampling on an intensive basis at two or three ports over fairly long time periods, but it is difficult to extrapolate these data to other nearby ports. It seems as though statistically valid methods of collecting statistics have not been given enough consideration.

Stasko: The agency that is collecting catch-effort data should not be the same agency that is policing any type of quota system.

Burns: NMFS is currently moving in the direction of compulsory logbook systems. They will be of a confidential nature and used primarily for evaluating stock status.

Smith: Reporting systems of a voluntary or compulsory nature primarily for the gathering of data that will be of biological aid in stock assessment work should not be used directly in policing a fishery - as in a quota system or for a policing situation. If you do use it also in this manner, you will bias your data as some fishermen may give false records to indicate whatever they think will help their cause.

Van Engel: The management agencies in Virginia have been looking at statistics gathering schemes for at least 30 yr. It has pretty much been agreed upon by the Virginia people that compulsory, 100% sampling schemes are doomed to failure. Some statistically valid sampling scheme on a random basis, such as that being recommended by FAO, seems much more responsible and would probably be much cheaper. What is needed is for someone to look into the design of a statistical sampling system.

Anthony: Jim Thomas is using a sampling method in Maine rather than a total interview or reporting method. He checks the dealers for landings and effort data. This is good for many parameters, but does not really get a handle on total catch and effort because of the numbers of lobsters that are sold directly to consumers from the fishermen. A system is necessary that allows for total catch and effort data to be collected.

Bennett: Sampling is very good, and when based on a good program, and the programs are there, the data are very reliable. This does not mean, however, that all the data are included. It would seem that a program that would allow for total catch statistics should be added to a good sampling program to fill all the needs of management.

Clark: There does not seem much doubt that better total catch data are needed. The offshore lobster statistics are a good example of that, because there is no way to get a handle on the amount of lobster that is currently being picked up as "shack" in the trawl fisheries and sold directly without being recorded. In addition to that, I think we need some controlled studies to check on the reliability of catch-effort information obtained from current statistics.

Briggs: The NMFS system of reporting by the work of port agents has certain problems. The individual collecting data has his own technique and frequently, when the port agents change, there will be a fairly major change in the reported catch of specific species when little or no change has really occurred.

Caddy: Does NMFS train the port agents in the preferred manner of collecting data?

Clark: Yes, with the aid of a very detailed manual itemizing procedures and requirements by area.

Morrissey: The regional councils are tending to prefer the idea of common logbooks for all species reporting - at least for those species under council management plans and for specific bycatch. The individual licensing agency (states) may have specific or additional requirements.

Anthony: We have recently held some public meetings in Maine on lobsters. During these meetings the lobstermen said they would definitely not keep logbooks, and if they were forced to, they would misrepresent their landings. They refused to provide any data at all.

Morrissey: The success of the logbook system may be misleading. The fishermen in that state (Connecticut) seem to go along with management recommendations more readily than fishermen in most areas.

Smith: I think the best approach may be a strong sampling program combined with an annual total catch reporting system.

Thomas: The fisherman feels that there are already too many forms to fill out. If we keep adding on more logbooks to fill out they are just going to rebel. We should pay for the maintenance of dealer and fisherman logs.

Bennett: The need for standardization of data collection systems was brought out much earlier. I don't feel that such a standardization can exist because of the great variety of people, techniques, numbers, etc. all along the U.S. and Canadian coast. The system must be flexible.

Robinson: I agree. Frequently we may need to add on systems to collect localized data needs.

Caddy: There seems basic agreement that a system is needed that will provide total catch data. Other analogous data, however, such as size frequencies, catch rates and the like only need to be statistically valid, and hence can be subsampled. The U.S. seems to have several systems for collecting effort data now, and possibly more on the way. In Canada we do not currently have good effort data - what can we do about it?

Jamieson: We are currently in the process of establishing a sales slip combined with a log form for introduction into the Maritime inshore scallop fishery. The sales slip portion has to be filled out anyway. The whole form is simple and only takes a minute or less to fill out. There are three copies on WCR paper where no carbon paper is necessary. The copy that goes to the buyer does not have any effort-location data and therefore would do an enforcement agency little good if they get it through court action. The second sheet goes to the statistics people and the fisherman keeps the third copy for his sales record to help him increase his success by looking back at past performance by area and time.

Stasko: The question of confidentiality has been raised several times and is still a very large question. Precedents go both ways. One request for some "confidential" data records was turned down, another upheld. Biologists would generally like to avoid the use of log records for prosecution, in order that we can protect this vital source of information from possible falsification.

APPLICATION OF U.S. BOTTOM TRAWL SURVEY AND COMMERCIAL DATA TO OFFSHORE LOBSTER ASSESSMENTS

by

T. Burns and S. H. Clark

Northeast Fisheries Center
Woods Hole Laboratory
Woods Hole, Massachusetts 02543

ABSTRACT

Burns, T., and S. H. Clark. 1980. Application of U.S. bottom trawl survey and commercial data to offshore lobster assessments. Can. Tech. Rep. Fish. Aquat. Sci. 932.

United States spring and autumn bottom trawl survey data for offshore lobsters from 1964-78 are presented and analyzed. For spring surveys, indices of relative abundance for the middle Atlantic and southern New England areas for 1968-78 declined 51-70% in weight (kg) and 17-56% in numbers per tow, respectively, but increased 32% in weight and 79% in numbers on Georges Bank. Corresponding values for autumn surveys for 1964-77 were 56-63% and 46-55% declines, respectively, for the middle Atlantic and southern New England areas; on Georges Bank weights declined 30%, but numbers increased 12%. Declines were most pronounced in the southern New England area. Commercial abundance indices for offshore lobster trap and trawl gear declined 88% and 23%, respectively. No trends are evident in mean carapace length measurements obtained during spring (1974-78) and autumn (1974-77) cruises; however, mean weights obtained from spring survey data for 1968-78 declined 26-42%, while mean weights obtained from autumn survey data for 1964-77 declined 17-37%. Spring survey data indicate high concentrations of lobsters in deeper water along the continental shelf edge and in the Gulf of Maine; autumn survey data indicate a more scattered distribution in deeper water and shoaler areas.

INTRODUCTION

The American lobster (*Homarus americanus*) occurs from North Carolina to Labrador and is most abundant from Nova Scotia to New York. Important commercial concentrations exist both in coastal waters and offshore along the outer continental shelf and upper slope areas from the eastern part of Georges Bank to Delaware Bay at depths of 110-457 m (Schroeder 1959). Lobsters in offshore areas are rather mobile, exhibiting lateral movement along the shelf edge as well as seasonal shoalward migrations in spring and summer with a return to deeper water in autumn and winter (Cooper and Uzmann 1971). Off southern New England, lobsters move from offshore canyon areas (Hudson, Block, Atlantic, Veatch) into inshore fishing grounds southwest of Cape Cod and are caught in coastal fisheries during spring and summer (Cooper and Uzmann 1971).

The offshore commercial fishery (i.e., that component of the U.S. fishery which is conducted over 19 km from shore in continental shelf and upper slope areas from Georges Bank to Virginia) was initiated in 1950 when 136 tons were landed. During the following decade reported landings increased gradually to 544 tons in 1960. In subsequent years, fishing pressure rapidly intensified and by 1969 reported annual landings had reached 3,138 tons. Reported landings peaked at 3,983 tons in 1972 and subsequently declined to 2,497 tons in 1977. Exact landings statistics are uncertain, however, as substantial quantities have been taken as "shack" (unreported landings) in otter trawl fisheries directed towards finfish species.

Rapid intensification of the lobster fishery and declining landings in recent years have stimulated considerable interest in the status of offshore lobster populations, and several studies have been completed relative to ecology, population density, migratory activity, growth, and maturation. Habitat availability and preference have been studied using submersible craft (Uzmann et al. 1977; Cooper, pers. comm. Nov. 15, 1978, Nat. Mar. Fish. Serv., Woods Hole, Mass.); results indicate minimal prime shelter exists in offshore areas. Warme et al. (1977) and Cooper (pers. comm. Nov. 15, 1978, Nat. Mar. Fish. Serv., Woods Hole, Mass.) provide population density estimates, and Cooper and Uzmann (1971) and Uzmann et al. (1977) have described migratory activity off New England based on 4 yr of tagging data. Observed distributions of tag recoveries indicate that a minimum of 20% of the offshore population (and probably 30-50%) migrates shoalward in spring and summer, returning to outer shelf and slope areas in autumn and winter; also, lateral movement has been documented between canyon areas. Further information on migratory behavior is provided by Saila and Flowers (1968), Lund et al. (MS 1971), and Stewart (1972). Data relative to growth and maturation are provided by Skud and Perkins (1969), Cooper and Uzmann (1971), and Uzmann et al. (1977).

Assessment information relative to the current status of offshore lobster populations is limited. Estimates of instantaneous fishing mortality (F) have been calculated for 1968-71 from tag return data, and preliminary yield-per-recruit calculations have also been completed (Lobster Scientific Committee MS 1976). Preliminary MSY estimates of 3,180 tons and 3,511 tons have been obtained from surplus-production modeling based on trap and otter trawl effort data, respectively. Based on trap effort data, results suggest that the 1977 effort level of 13.3 million trap haul set-over-days (THSOD) is substantially greater than the level corresponding to the long-term MSY of 4.3 million THSOD (Burns MS 1978).

An additional source of assessment information for offshore lobsters is provided by bottom trawl surveys. Since 1963, the Northeast Fisheries Center (NEFC) of the National Marine Fisheries Service (NMFS) has conducted bottom trawl surveys in continental shelf waters (<366 m) of the Northwest Atlantic. With the exception of lobster trap fields which cannot be sampled by the survey trawl, most of the area inhabited by offshore lobsters to a depth of 366 m is covered. Thus, bottom trawl survey data should be of value for assessment of offshore lobster populations.

The present paper presents information from U.S. bottom trawl surveys on trends in abundance and size composition of offshore lobster populations from Georges Bank to the middle Atlantic and an evaluation of these trends with respect to results obtained from analysis of commercial data.

THE SURVEY

Autumn bottom trawl survey data have been collected by the R/V's *ALBATROSS IV* and *DELAWARE II* in offshore areas (>27 m) since 1963; spring and summer surveys were added in 1968 and 1977, respectively. In the autumn of 1972 the survey was expanded to include inshore areas (<27 m) in the middle Atlantic area, and at present inshore areas from southern New England to Cape Fear are included. In all autumn and summer surveys, and in spring surveys from 1968-72, both vessels used a standard "36 Yankee" bottom trawl with a 1.25-cm stretched mesh codend liner. This trawl measures 24 m along the footrope, averages 3 m in height along the headrope, and is equipped with rollers to make it suitable for use on rough bottom. Since 1973 a modified high-opening "41 Yankee" trawl which measures 30 m along the footrope and averages 4-5 m in height along the headrope has been used during the spring surveys. These nets are obviously most effective for sampling finfish species, but invertebrates are also taken in quantity and there is evidence that trends in abundance and size composition observed in the survey data for invertebrate species (e.g., northern shrimp, *Pandalus borealis*; Northern Shrimp Scientific Committee MS 1978) are representative of the population as a whole.

The offshore area sampled extends from Nova Scotia to Cape Hatteras. A stratified random sampling design has been used in this survey (Cochran 1953); thus, the survey area has been stratified into geographical zones (Fig. 1) primarily on the basis of depth and latitude (Grosslein 1969). During 1963-66, only strata from Hudson Canyon and northward (1-42) were sampled; additional strata (61-76) were added in the autumn of 1967 to cover the middle Atlantic region. An additional section covering part of the Scotian Shelf was added in 1968 (Fig. 1).

During each survey, sampling stations are allocated to strata roughly in proportion to the area of each stratum and are assigned to specific locations within strata at random. A 30-min tow is taken at each station at a speed of 3.5 knots. After each tow, weight and numbers captured and

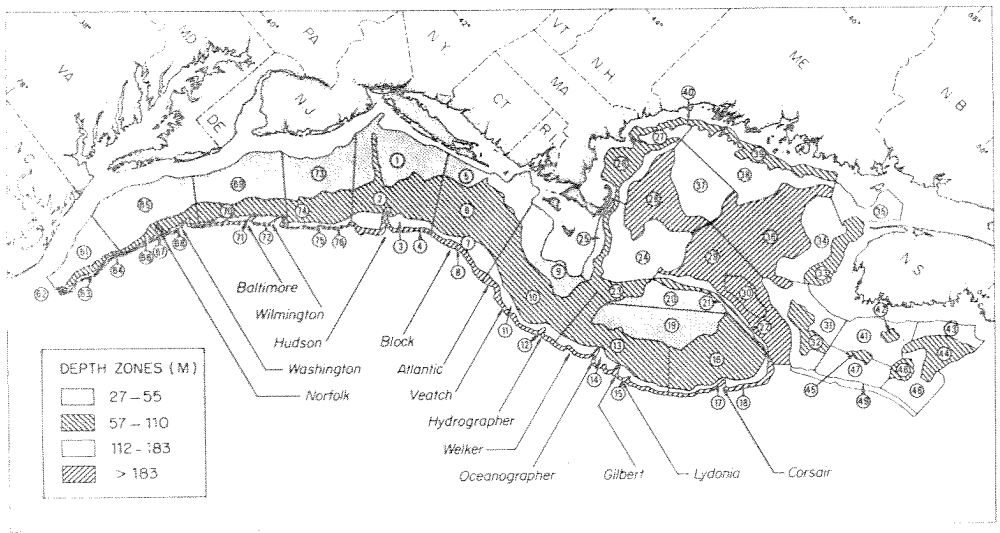


Fig. 1. U.S. groundfish survey offshore sampling strata.

other pertinent data are recorded for each species; for lobsters, individuals are sexed and carapace lengths measured (mm) from the eye-socket to the posterior mid-dorsal margin of the carapace. Prior to 1974, rostral lengths (i.e., from the tip of the rostrum to the posterior mid-dorsal margin of the carapace) were usually taken, but some carapace measurements were also included. Data are summarized, audited, and transferred to magnetic tape following the completion of each survey.

Stratified mean catch per tow in both weight and numbers has been calculated for all cruises following procedures given by Cochran (1953). Mean carapace lengths have been calculated for the strata sets by weighting individual length groups by stratified mean numbers caught per tow in that length group. Mean weights of lobsters were calculated by dividing the stratified mean weight (kg) per tow by the stratified mean number per tow for the time period indicated (Tables 1, 2).

RESULTS AND DISCUSSION

INDICES OF RELATIVE ABUNDANCE

Indices of relative abundance (stratified mean catch per tow in numbers and weight in kg) were calculated by season for three strata sets (middle Atlantic, strata 61-76; southern New England, strata 1-12 and 25; and Georges Bank, strata 13-23) (see Fig. 1). Indices obtained for spring and autumn surveys are given in Tables 1 and 2, respectively, and plotted in Fig. 2 and 3. Spring survey catch-per-tow data for 1973-78 were divided by correction factors of 2.66 (numbers) and 2.72 (weight) to adjust the fishing power of the "41 Yankee" trawl to that of the "36 Yankee" (Sissenwine and Bowman 1978).

The spring survey weight index for southern New England increased from 0.84 kg in 1968 to a peak of 1.25 kg in 1971 and subsequently declined to 0.14 kg in 1978. For the middle Atlantic area the index increased from 0.24 kg in 1968 to 0.80 kg in 1972, declined sharply to a mean of 0.12 kg for the 1973-77 period, and recovered slightly to 0.32 kg in 1978 (Table 1). Similar trends are apparent for autumn survey data; the southern New England index increased from 1.89 kg in 1964 to a peak of 2.58 kg in 1966 and then declined to 0.75 kg in 1977 (Table 2). The middle Atlantic index peaked at 0.97 kg in 1969, declined to 0.41 kg in 1975 and increased slightly to 0.58 kg in 1977 (Table 2). Trends in numbers agree closely with trends in weight (Fig. 2, 3). Thus, data for southern New England and middle Atlantic strata are consistent in indicating a general decline in abundance during the period covered by these surveys (Fig. 2, 3). Catches in both weight and number were usually higher in autumn (Tables 1 and 2), probably reflecting lower availability in spring when lobsters may concentrate in canyon areas and in deeper water (>366 m).

The spring survey weight index for Georges Bank increased to 0.54 kg in 1972 and then declined to 0.11 kg in 1975; it then increased to 0.44 kg in 1977 but declined to 0.12 kg in 1978 (Table 1). However, the autumn survey weight index generally declined from 3.48 kg in 1964 to 0.81 kg in 1975 and then increased to 3.55 kg in 1977 (Table 2). In 1977, a very large catch occurred in stratum 15 in which only one tow was taken. Again, catch rates were usually higher in autumn than in spring (Tables 1 and 2), and trends in numbers correspond closely with trends in weight (Fig. 2, 3).

Calculated averages for spring survey abundance indices for 1968-70 and 1976-78 declined by 51 and 70% in weight and by 17 and 56% in numbers for middle Atlantic and southern New England areas,

Table 1. Stratified mean catch per tow in weight (kg) and numbers of lobsters taken in U.S. spring bottom trawl surveys, Georges Bank to the middle Atlantic, 1968-78. Mean weight of lobsters and percent change are in parentheses.

Year	Southern New England Strata 1-12 + 25		Georges Bank Strata 13-23		Middle Atlantic Strata 61-76	
	wt	no.	wt	no.	wt	no.
1968	0.84	1.11	0.10	0.05	0.24	0.19
1969	1.05	1.42	0.27	0.17	0.29	0.29
1970	0.94	0.90	0.28	0.19	0.51	0.43
1971	1.25	1.67	0.33	0.22	0.35	0.20
1972	0.64	0.85	0.54	0.40	0.80	0.53
1973[a]	0.27	0.52	0.29	0.17	0.06	0.09
1974	0.39	1.00	0.11	0.09	0.11	0.13
1975	0.13	0.30	0.11	0.10	0.23	0.19
1976	0.42	0.76	0.30	0.29	0.09	0.19
1977	0.28	0.45	0.44	0.35	0.11	0.15
1978	0.14	0.30	0.12	0.10	0.32	0.41
Means						
1968-70	0.94	1.14(0.82)	0.22	0.14(1.57)	0.35	0.30(1.17)
1976-78	0.28	0.50(0.56)	0.29	0.25(1.16)	0.17	0.25(0.68)
% change	-70	-56(-32)	+32	+79(-26)	-51	-17(-42)

[a]Catch per tow data for 1973-78 were divided by correction factors of 2.66 (numbers) and 2.72 (weight) to adjust the fishing power of the #41 Yankee trawl to that of the #36 Yankee (Sissenwine and Bowman 1978).

Table 2. Stratified mean catch per tow in weight (kg) and numbers of lobsters taken in U.S. autumn bottom trawl surveys, Georges Bank to the middle Atlantic, 1964-77. Mean weight of lobsters and percent change are in parentheses.

Year	Southern New England Strata 1-12 + 25		Georges Bank Strata 13-23		Middle Atlantic Strata 61-76	
	wt	no.	wt	no.	wt	no.
1964	1.89	2.54	3.48	1.24		
1965	2.36	2.56	2.22	0.97		
1966	2.58	3.89	2.53	1.06		
1967	1.50	2.59	1.79	0.75	0.92	1.11
1968	1.70	2.00	1.56	0.90	0.82	0.79
1969	1.91	2.27	1.57	0.76	0.97	1.02
1970	0.93	1.40	1.27	0.96	0.32	0.44
1971	0.76	1.04	1.66	0.82	0.64	0.41
1972	1.64	3.70	1.07	0.53	0.19	0.26
1973	0.78	1.46	1.51	1.00	0.56	0.66
1974	0.87	0.80	1.27	0.81	0.12	0.13
1975	1.06	1.56	0.81	0.57	0.41	0.55
1976	0.72	1.42	1.38	1.02	0.20	0.28
1977	0.75	1.05	3.55	2.07	0.58	0.74
Means 1964-66					Means 1967-69	
	2.28	3.00(0.76)	2.74	1.09(2.51)	0.90	0.97(0.93)
1975-77					1975-77	
	0.84	1.34(0.63)	1.91	1.22(1.57)	0.40	0.52(0.77)
% change	-63	-55(-17)	-30	+12(-37)	-56	-46(-17)

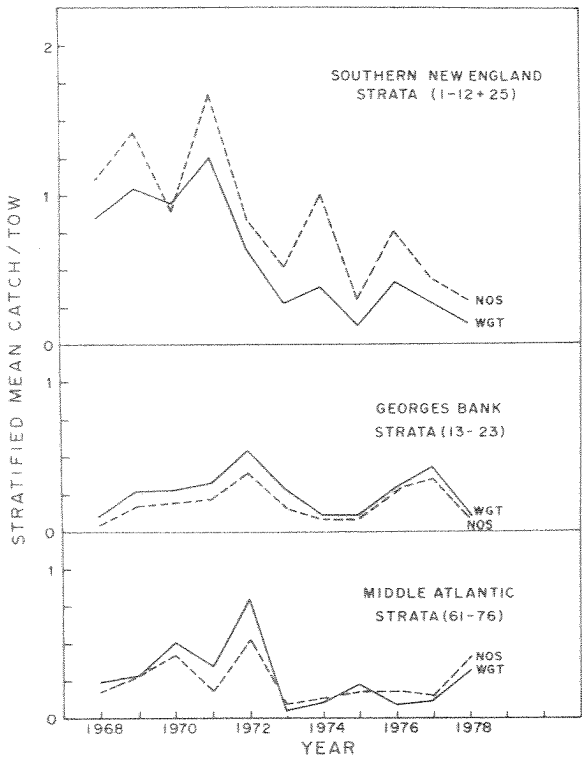


Fig. 2. Stratified mean catch per tow in weight (kg) and numbers for lobsters taken in U.S. spring bottom trawl surveys off southern New England, Georges Bank, and the middle Atlantic 1968-78.

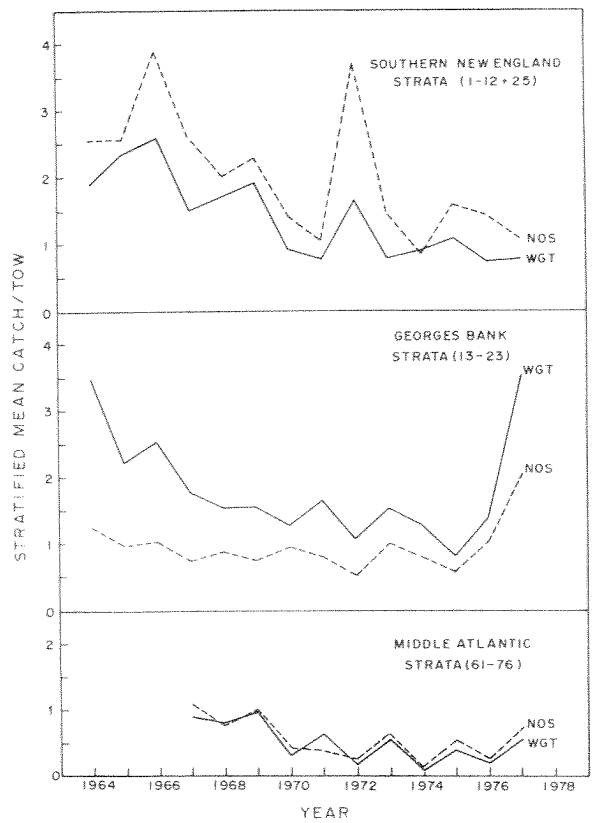


Fig. 3. Stratified mean catch per tow in weight (kg) and numbers for lobsters taken in U.S. autumn bottom trawl surveys off southern New England, Georges Bank, and the middle Atlantic, 1964-77.

respectively, but increased 32% in weight and 79% in numbers on Georges Bank (Table 1). Calculated averages for the autumn survey for 1964-66 and 1975-77 declined 30-63% in weight, and ranged from a 12% increase to a 55% decrease in numbers, depending upon the strata set considered (Table 2). In both surveys, declines were most pronounced for the southern New England and middle Atlantic areas. This appears to reflect the observed distribution of fishing effort in that the Georges Bank area appears to have received the lowest fishing pressure in recent years (Mayo and Schultz MS 1975).

Commercial abundance indices have been calculated for the offshore fishery from catch-effort data for lobster trap gear from 1969-77 as well as from catch-effort data for lobster trawl gear from 1964-77. The trap index (catch per THSOD) declined from 1.64 kg in 1969 to 0.19 kg in 1977, a decline of over 88%, while the trawl index (catch per day fished) declined from 680 kg in 1964 to 523 kg in 1977, a 23% decline. However, effort data have not been standardized by vessel and/or gear type in either case and thus the above trends may have been biased by shifts in effort. During the early 1970's the otter trawl fishery was largely replaced by a trap gear fishery. The survey indices suggest a rate of decline intermediate between the two commercial indices and would appear more representative in the present situation.

SIZE COMPOSITION

Mean carapace lengths (cm) for lobsters during spring (1974-78) and autumn (1974-77) bottom trawl surveys are given in Table 3. Earlier data have not been included due to inconsistencies in measurement which are unresolved at present. For the limited time period involved no trends are apparent.

Mean weights of lobsters for spring and autumn surveys are given in Tables 1 and 2. Calculated averages of spring surveys for 1968-70 and 1976-78 indicate declines in mean weight of 26-42%, depending on the area considered (Table 1). In autumn surveys mean weights declined 17-37% between 1964-66 and 1975-77 (Table 2). Calculated mean lengths (Table 3) and weights (Tables 1, 2) reflect observed effort patterns because in both surveys the smallest lobsters were usually taken off southern New England where the greatest fishing pressure has occurred, while the largest specimens usually were taken on Georges Bank, where the lowest fishing pressure has occurred (Table 3).

NOTES ON DISTRIBUTION

The *ALBATROSS IV* 1973-74 offshore surveys and the 1974 inshore survey data were combined to provide a composite plot of lobster distributions for the spring and autumn. Results are shown in

Table 3. Mean carapace lengths (cm) of lobsters taken in U.S. spring and autumn bottom trawl surveys (middle Atlantic to Georges Bank) 1974-78.

Year	Southern New England Strata 1-12 + 25	Georges Bank Strata 13-23	Middle Atlantic Strata 61-76
		Spring	
1974	7.9	10.9	9.6
1975	7.6	10.2	10.8
1976	8.0	9.8	8.0
1977	8.5	11.1	9.3
1978	7.8	10.8	9.8
		Autumn	
1974	9.4	12.3	10.0
1975	9.2	11.6	12.0
1976	7.9	11.1	9.0
1977	8.8	12.1	9.0

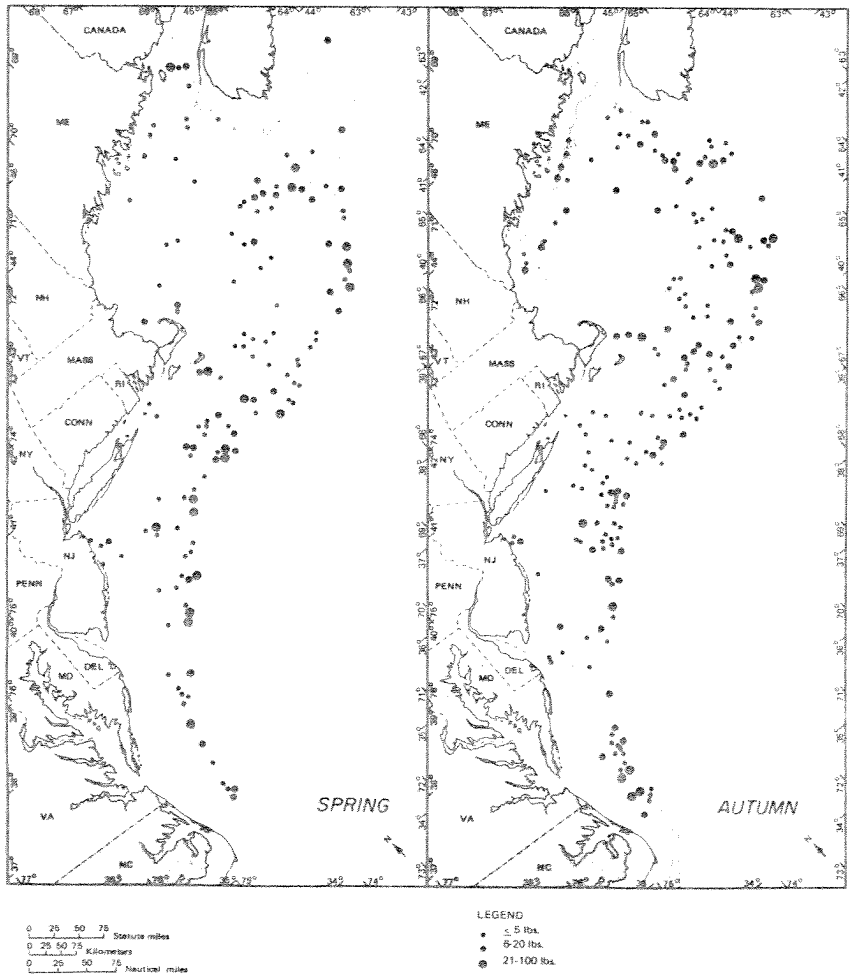


Fig. 4. Composite plots (cruises, offshore 1973-74, and inshore 1974) of lobster distributions (lb/tow) for spring and autumn U.S. bottom trawl surveys from Nova Scotia to Cape Hatteras, 1973-74 (from Grosslein and Azarovitz (in press)).

Fig. 4. Spring distributions indicate a higher concentration of lobsters in deeper water along the continental shelf edge and in the deeper water of the Gulf of Maine, whereas in the autumn lobsters tend to be scattered in the shoaler waters of southern New England, Georges Bank, and on the Scotian Shelf, with lesser concentrations along the shelf edge. These data appear to reflect migratory patterns documented in previous studies (Cooper and Uzmann 1971; Uzmann et al. 1977) as well as seasonal distribution of commercial effort (Mayo and Schultz MS 1975).

REFERENCES

Burns, T. S. MS 1978. Northern lobster. *In* Summary of Stock Assessments, p. 22-23. Nat. Mar. Fish. Serv., Woods Hole, Lab. Ref. Doc. No. 78-40, 26 p.

Cochran, W. G. 1953. Sampling Techniques. John Wiley and Sons, Inc., N.Y., 330 p.

Cooper, R. A., and J. R. Uzmann. 1971. Migrations and growth of deep sea lobsters, *Homarus americanus*. Science 171: 288-290.

Grosslein, M. D. 1969. Groundfish survey program of BCF Woods Hole. Comm. Fish. Rev. 31: 22-35.

Grosslein, M. D., and T. R. Azarovitz. Fish distributions, MESA New York Bight Atlas Monograph 15, Albany, NY: New York Sea Grant Institute, (in press).

Lobster Scientific Committee. MS 1976. Review of unpublished lobster growth and mortality data and preliminary assessment of lobster yield per recruit by the Lobster Scientific Committee (T. D. Morrissey, ed.). NMFS State-Federal Management Program, Gloucester, MA, 15 p.

Lund, W. A., L. L. Stewart, and H. M. Weiss. MS 1971. Investigation on the lobster *Homarus americanus*. Comm. Fish. Res. Dev. Act - Final Report, State of Connecticut, Proj. No. 3-44-R, 104 p.

Mayo, R. K., and R. L. Schultz. MS 1975. New England fisheries data summary for Georges Bank and southern New England fishing grounds (1965-1974). Nat. Mar. Fish. Serv., Stat. and Mkt. News Div. Northeast Region, Vol. 1, 182 p.

Northern Shrimp Scientific Committee. MS 1978. A current assessment of the Gulf of Maine northern shrimp resource. Nat. Mar. Fish. Serv., Northeast Region, Gloucester, MA, 24 p.

Saila, S. B., and J. M. Flowers. 1968. Movements and behavior of berried female lobsters displaced from offshore areas to Narragansett Bay, Rhode Island. J. Cons. Int. Explor. Mer 31: 341-351.

Schroeder, W. C. 1959. The lobster, *Homarus americanus*, and the red crab, *Geryon quinquedens*, in the offshore waters of the western North Atlantic. Deep-Sea Res. 5: 266-282.

Sissenwine, M. P., and E. W. Bowman. 1978. An analysis of some factors affecting the catchability of fish by bottom trawls. Int. Comm. Northw. Atl. Fish. Res. Bull. 13: 81-87.

Skud, B. E., and H. C. Perkins. 1969. Size composition, sex ratio and size at maturity of offshore northern lobsters. U.S. Fish. Wildl. Serv. Spec. Sci. Rep. Fish. No. 598, 10 p.

Stewart, L. L. 1972. The seasonal movements, population dynamics and ecology of the lobster, *Homarus americanus* (Milne-Edwards), off Ram Island, Conn. Ph.D. Thesis, Univ. Conn., Storrs, 152 p.

Uzmann, J. R., R. A. Cooper, and K. J. Pecci. 1977. Migration and dispersion of tagged American lobsters, *Homarus americanus*, on the southern New England continental shelf. NOAA Tech. Rep. NMFS SSRF-705, 92 p.

Warme, J., R. A. Cooper, and R. Slater. 1977. Effects of substrate type and other factors on the growth, survival, and cannibalism of juvenile *Homarus americanus* in mass rearing systems. Proc. Sixth Ann. Meet., World Mariculture Society, Seattle, Wash., Jan. 27-31, 1975, p. 261-274.

RESEARCH SURVEYS (A. Stasko, rapporteur)

Smith: How do you explain scarcity of lobsters in the central areas of the Gulf of Maine gyre prior to 1970?

Anthony: I think this indicates a shift in lobster distribution.

Morrissey: Is the distribution of lobsters in the central Gulf seasonal?

Clark: Neither the spring nor fall surveys yielded any quantities of lobsters there prior to 1970. Regarding the decline in abundance of offshore lobsters in the 1970's, the commercial pot index in southern New England area shows a greater catch-effort decline (88% reduction) than the commercial trawl index (23%). The amount of decline shown by the NMFS trawl survey falls between the two.

Thomas: Are the seasonal distributions shown by this survey compatible with the NMFS offshore tagging data?

Clark: Yes. Both indicate shoalward movement in spring and summer and the reverse in winter.

Anthony: U.S. offshore lobster fishermen follow lobsters shoreward in spring and out in the fall in most areas from North Carolina to Georges Bank.

Stasko: A similar but less pronounced movement of the Canadian offshore lobster boats occurs up and down the slope in the Browns Bank area and on N.E. Georges.

Anthony: The peak year in U.S. offshore lobster landings was 1972. There has been a marked decrease in offshore lobster abundance since then. If we assume a period of 6 yr from larva to legal size for New England lobsters, any resulting larval scarcity should begin to show in declining catches in New England waters beginning in about 1979.

Stasko: Canadian Fisheries Service bottom trawl surveys for fish on the Scotian Banks have kept records of lobster catches since about 1970. We are now trying to extract lobster data from these surveys.

SUMMARY OF LOBSTER, *Homarus americanus*, TAGGING STUDIES IN AMERICAN WATERS (1898-1978)

by

J. S. Krouse

Maine Department of Marine Resources
West Boothbay Harbor, Maine

ABSTRACT

Krouse, J. S. 1980. Summary of lobster, *Homarus americanus*, tagging studies in American waters (1898-1978). Can. Tech. Rep. Fish. Aquat. Sci. 932.

Tagging experiments conducted on the American lobster, *Homarus americanus*, in U.S. waters (Maine to North Carolina) from 1901 to 1978 have been summarized. Because growth and mortality have been treated separately in other sections of the lobster workshop, this paper deals only with those tagging results relative to lobster movement.

INTRODUCTION

Movements of the American lobster were first investigated in U.S. waters by Bumpus (1901) who, in the summer of 1898, tagged about 500 mature female lobsters near Woods Hole, Massachusetts, and by Mead and Williams (1903) who, during the summers of 1902 and 1903, tagged about 400 lobsters in Narragansett Bay near Wickford, Rhode Island. Even though these early attempts to define lobster movements were not conclusive, information obtained from a total of about 110 recaptures demonstrated to these early researchers that lobsters do, indeed, move considerable distances, as several recaptures had traveled 10-16 mi, and that lobsters may undertake directed movement as most recaptures, from both study areas, had followed a south to southwesterly course.

I believe it noteworthy that Bumpus (1901) reported, based on the high rate of tag recoveries from his study, that "the chances of continued life for a lobster that has reached a marketable size are extremely slight." He further stated that "it is therefore evident that, unless the supply of any one locality is replenished, either by immigration or by artificial propagation, the lobster will be exterminated; indeed elimination has actually occurred at certain localities, and there is every indication that before long an industry which has yielded many millions of dollars will have perished through the inexcusable abuses of our fishing privileges." Considering that these observations were rendered almost 80 yr ago and since that time the abuses of fishing privileges referred to by Bumpus have continued to remain for the most part unchecked, at least in the U.S. lobster fishery, it becomes quite apparent that lobster management has been a long time coming. Hopefully, this situation will be changed in the very near future.

U.S. LOBSTER TAGGING SINCE 1950

Surprisingly, after these initial tagging experiments during the early 1900's, nearly half a century elapsed before U.S. lobster tagging research resumed in the 1950's. Since that time up to the present several lobster tagging studies have been conducted along the eastern U.S. seaboard from Maine south to North Carolina (Fig. 1).

Beginning with the tagging work done off the Maine coast and then proceeding southerly, I have briefly summarized each of these studies. Although many of these studies have yielded valuable information on lobster growth and mortality, because these parameters have been discussed extensively in other papers of this workshop, I have limited my discussion of tagging results as they relate to lobster movement.

The first lobster tagging study along the Maine coast was conducted by Harriman (1952) from 1950 through 1951 in waters off Monhegan Island, which is about 10 mi from the mainland. Monhegan Island is the only area in Maine with a closed season (lobstering is permitted January through June). Of the 1,093 trap-caught lobsters (sizes were not indicated) tagged with a celluloid disc tag on the telson, 24% were returned over a 2-yr period. Recaptured lobsters showed minimal movement as only 10 returns traveled 2 or more miles, and what movement occurred appeared to be random.

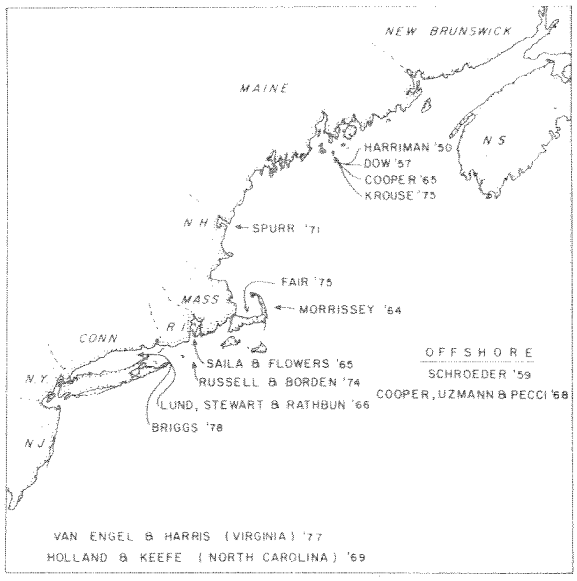


Fig. 1. Chart showing approximate locations of the American lobster tagging studies conducted in waters of the United States. Year following name(s) of investigator(s) refers to when the study was initiated.

In another tagging project at Monhegan Island from 1965 to 1966, Cooper (1970) marked 1,776 legal-sized lobsters (81-123 mm CL) with either a sphyrion tag inserted between the carapace and abdomen, a dart tag implanted in the elbow, or a brand made dorsally on the carapace. Based on laboratory as well as field experiments the sphyrion tag was selected as the most suitable mark because of its high retention through shedding and its negligible effect upon behavior. On the basis of these results as well as on work by Scarratt and Elson (1965), the sphyrion tag has become the most frequently used tag for marking the American lobster. In regards to movement, Cooper (1970) concluded as Harriman (1952) did, that the Monhegan lobsters were generally nonmigratory. Ninety-nine percent of the recaptured lobsters were caught within a 2-mi radius of Monhegan, while the remaining 20 lobsters had moved 4-21 mi NE to NW of the island before being caught.

In 1957 and 1958 Dow (1974) had several Maine commercial fishermen attach Petersen disc tags to the telsons of 162 illegal lobsters. Lobsters were classified as illegal if they were: 1) ovigerous; 2) smaller than the minimum legal size limit (81 mm CL); 3) larger than the maximum legal size limit (127 mm CL); or 4) marked with a V-shaped notch in the telson signifying a breeder (Me. law prohibits landing female lobsters with the so-called "V-notch"). Even though only 14% of the tagged lobsters were recovered, an interesting movement trend was revealed. Four oversize lobsters traveled 75-138 nautical miles (naut mi). One V-notched female (111 mm CL) moved 113 naut mi in 7 mo. All 5 of these major migrants followed a southwesterly course, resulting in four recoveries off the Massachusetts coast.

More recently, during the spring of 1975, Krouse (1977) tagged and released a total of 2,882 legal-sized lobsters (81-116 mm CL) near

Kennebunkport, Boothbay Harbor, and Jonesport, Maine. Tag returns ranged from 67-85% for each release area; 74-98% of the recaptures were caught within a 5-mi radius of the point of release and only 1% of the recaptures had moved more than 10 mi. The majority of lobsters traveled inshore or along the shore on a west to southwesterly course with minimal easterly movement. Similar to the southwesterly movement demonstrated by the migrants in Dow's (1974) study, the long-distance wanderers in this study, of which there were only 8 lobsters that moved more than 15 mi, all embarked on a southwesterly course. Thus, available data suggest that lobster migrants in nearshore Maine waters move in the direction of the counter-clockwise currents that prevail along the Maine coast. This apparent southwesterly pattern of lobster movement along the Maine coast is further supported by the return of several Canadian tagged lobsters from various locations in Maine during 1977-78 (James C. Thomas, pers. comm.). These particular lobsters were tagged and released off Grand Manan, N.B. (Groom 1978).

From 1971 through 1974 Spurr (1974) tagged and released 10,823 lobsters in the coastal waters of New Hampshire. Results of the study indicated that most lobsters were recaptured near the release site and that movement was random. Spurr noted that mature females appeared to move more than others.

Considering next the tagging done in Massachusetts, Morrissey (1971) has demonstrated substantial directional movement for berried female lobsters tagged in the summers of 1964 and 1965 near Nauset Light on the east side of Cape Cod. Of 350 ovigerous females tagged in 1964, all but 3 of 39 recaptures were caught to the north of the release area within 5 km of shore in Cape Cod Bay. These recaptures moved an average of 30.2 km. Results of the second summer's tagging in 1965 further substantiated this directed northerly movement. Unfortunately, because of the short-term tags used in this study it was not possible to determine whether or not the lobsters moved offshore in fall.

Ten years after Morrissey's tagging study, Fair (1977) in the late spring-early summer of 1975 and 1976 tagged and released a total of 2,000 legal-sized lobsters in the western inshore portion of Cape Cod Bay. About 70% of the tagged lobsters were returned for each year's releases. Emigration was extremely minimal since only 8 lobsters were recaptured outside the study area. A single female recovered on the east shore of Cape Cod might have entered the migration route described by Morrissey (1971).

Preliminary results of tagging work conducted by Russell (1975) in 1974 and 1975 off the Rhode Island coast in the vicinity of Cox Ledge, have suggested that tagged lobsters released in this area moved southerly toward the continental shelf in the winter and then returned to shoal water in the summer.

An interesting tagging experiment was initiated in the spring of 1965 by Saila and Flowers (1968) who tagged 1,258 berried female lobsters (102-159 mm CL) captured near Veatch Canyon and then released these same lobsters at various locations in Narragansett Bay (about 218 km from Veatch Canyon). Results showed that the relocated berried females did not move appreciably until their eggs were hatched, thus suggesting that movement might be related to the physiological condition of the lobster. After shedding their eggs, many of the females left Narragansett Bay and tended to travel toward the area of original capture. In fact, three tags were returned from lobsters recaught near the area of first capture. These lobsters were at liberty 264-361 d before they were recaught.

Shortly after the Saila and Flowers (1968) study, Uzmann et al. (1977) commenced a rather extensive offshore lobster tagging project. From 1968 through 1971, 7,326 lobsters were marked with sphyrion tags and liberated along the outer edge of the continental shelf from Corsair Canyon southwest to Baltimore Canyon. Information obtained from 945 recaptures (about 13% of the total) indicated that at least 20% of the offshore lobster population takes part in an inshore-offshore migration which appears to be related to temperature. Movement is directed shoalward in the spring toward the warmer nearshore waters and away from the shore toward deeper water in the fall as the coastal waters begin to cool. These seasonal migrations may be associated with an optimization of the temperature milieu for molting and reproduction. Tag recoveries also showed considerable lateral movement along the outer edge of the continental shelf, thus discrediting the notion of discrete canyon populations as was once advanced by some researchers. Although movement was not related to size, female lobsters were reported to undergo more extensive movements than males (Cooper and Uzmann 1971).

Returning once again to inshore tagging studies, Lund et al. (1973) have shown some interesting movement patterns of recaptured lobsters from a study in which about 4,000 animals were tagged and released at three locations in Long Island Sound from 1966 through 1972. Lobsters released in western Long Island Sound showed almost no movement. Philip T. Briggs (pers. comm.), who also tagged lobsters in western Long Island Sound during the spring and fall of 1978, has observed a similar lack of movement. In contrast, tagged lobsters liberated near Block Island and eastern Long Island Sound have demonstrated considerable movement. Some of the eastern Long Island Sound releases were recaptured off Block Island, Montauk Pt., and even as far as the edge of the continental shelf. This easterly offshore movement occurred primarily during the summer months; whether a return happens in the fall has yet to be determined. Block Island releases not only showed both inshore and offshore movement, but many recaptures stayed in the vicinity of the release site.

Lobster tagging studies conducted by Holland and Keefe (1977) in 1969 and by Van Engel and Harris (1978) in 1977 in the offshore waters of the mid-Atlantic coast have not revealed the extensive movements displayed by lobsters tagged in the offshore areas of New England (Uzmann et al. 1977). Holland and Keefe (1977) reported that about 40% of the recaptures traveled less than 5 naut mi, while 80% of the total moved less than 16 naut mi. Likewise, Van Engel and Harris (1978) noted that most lobsters were recaptured less than 10 mi from the release site and only 20% of the recaptures had moved more than 10 mi and most of this movement was toward shallower water.

SUMMARY

Considering the results of all the tagging studies conducted on the American lobster along the coasts of the lobster producing states, certain

patterns of movement become apparent (Fig. 2). The notable trends are: 1) south to southwesterly of predominantly large mature lobsters along the Maine coast (Dow 1974; Krouse 1977; Groom 1978); 2) directed movement of egg-bearing lobsters along the eastern shore of Cape Cod into Cape Cod Bay during the summer months (Morrissey 1971); 3) seasonal inshore-offshore migration of lobsters indigenous to the outer edge of the continental shelf from Corsair Canyon southwest to Baltimore Canyon (Cooper and Uzmann 1971; Uzmann et al. 1977); 4) lateral movement of offshore lobsters between canyon areas (Cooper and Uzmann 1971); and 5) apparent seasonal movement of some lobsters from eastern Long Island Sound and southern Rhode Island to the middle and outer margin of the continental shelf (Lund et al. 1973; Russell 1975; Saila and Flowers 1968).

In contrast to these studies which showed some rather extensive lobster movement, there have been several investigations where lobster movement was very minimal (Harriman 1952; Cooper 1970; Lund et al. 1973; Spurr 1974; Fair 1977; Holland and Keefe 1977; Krouse 1977). Even though many of these studies were in areas where high fishing intensities drastically reduced the time most tagged animals were at liberty, there is still sufficient evidence to indicate that certain size lobsters (primarily smaller, sexually immature) inhabiting certain areas are generally nonmigratory. This seemingly sedentary nature of the smaller lobsters is reasonable considering that the majority of lobsters showing migratory behavior have been the larger, sexually mature individuals.

REFERENCES

Bumpus, H. C. 1901. On the movement of certain lobsters liberated at Woods Hole during the summer of 1898. Bull. U.S. Fish. Comm. 19: 225-230.

Cooper, R. A. 1970. Retention of marks and their effects on growth, behavior, and migrations of the American lobster, *Homarus americanus*. Trans. Am. Fish. Soc. 99: 409-417.

Cooper, R. A., and J. R. Uzmann. 1971. Migrations and growth of deep-sea lobsters, *Homarus americanus*. Science (Wash., D.C.) 171: 288-290.

Dow, R. L. 1974. American lobsters tagged by Maine commercial fishermen, 1957-59. Fish. Bull. U.S. 72: 622-623.

Fair, J. J., Jr. 1977. Lobster investigations in management area 1: southern Gulf of Maine. NOAA, NMFS State-Federal Relationships Div., Mass. Lobster Rep. No. 8, Apr. 21, 1975-Apr. 20, 1977, 8 p., Appendix 5 p.

Groom, W. 1978. Interim investigation of lobster stock, size and migration system of lobster population in the Grand Manan region. N.B. Dept. Fish., Fredericton, 69 p.

Fig. 2. Movement patterns of American lobsters recovered from various tagging studies along the coast of northeastern United States.

Harriman, D. M. MS 1952. Progress report on Monhegan tagging - 1951-1952. Maine Dept. Sea Shore Fish., Augusta (unpubl. rep.).

Holland, B. F., and S. G. Keefe. 1977. A summary of American lobster (*Homarus americanus*) investigations offshore North Carolina and Virginia from 1968-1972. N.C. Dept. Nat. Econ. Res., Div. Mar. Fish., Mimeo. Rep., 45 p.

Krouse, J. S. 1977. Completion report, lobster tagging project #3-228-R, Oct. 1974 through Sept. 1977. NOAA, NMFS, Comm. Fish. Res. Dev. Act, 28 p., 8 tables, 22 fig., 3 Appendix tables.

Lund, W. A., L. L. Stewart, and C. J. Rathbun. 1973. Investigation on the lobster. July 15, 1970-June 30, 1973. NOAA, NMFS, Comm. Fish. Res. Dev. Act.

Mead, A. D., and L. W. Williams. 1903. Habits and growth of the lobster, and experiments in lobster culture. R.I. Comm. Inland Fish., 33rd Ann. Rep., p. 57-83.

Morrissey, T. D. 1971. Movements of tagged American lobsters, *Homarus americanus*, liberated off Cape Cod, Massachusetts. Trans. Am. Fish. Soc. 100: 117-120.

Russell, H. J., Jr. 1975. Management studies of inshore lobster resources. NOAA, NMFS, State-Federal Relationships Div., R.I. Lobster Rep. No. 5, June 24-June 30, 1975, 17 p., 7 tables, 17 fig.

Saila, S. B., and J. M. Flowers. 1968. Movements and behavior of berried female lobsters displaced from offshore areas to Narragansett Bay, Rhode Island. J. Cons. 31: 342-351.

Scarratt, D. J., and P. F. Elson. 1965. Preliminary trials of a tag for salmon and lobsters. J. Fish. Res. Board Can. 22: 421-423.

Spurr, E. W. 1974. Completion report, lobster research program. August 17, 1971-June 30, 1974. NOAA, NMFS, Comm. Fish. Res. Dev. Act, 34 p.

Uzmann, J. R., R. A. Cooper and K. J. Pecci. 1977. Migration and dispersion of tagged lobsters, *Homarus americanus*, on the southern New England continental shelf. U.S. Dept. Com., NOAA Tech. Rep. NMFS SSRF-705, 92 p.

Van Engel, W. A., and R. E. Harris, Jr. 1978. Biology and management of the American lobster. NOAA, NMFS State-Federal Relationships Div., Virginia Lobster Rep. No. 13, July 1, 1977-December 31, 1977, 19 p.

TAGGING AND LOBSTER MOVEMENTS IN CANADA

by

A. B. Stasko

Department of Fisheries and Oceans
Biological Station
St. Andrews, New Brunswick EOG 2XO

ABSTRACT

Stasko, A. B. 1980. Tagging and lobster movements in Canada. Can. Tech. Rep. Fish. Aquat. Sci. 932.

The use and advantages of various tag types are discussed. The movements of tagged lobsters are considered separately for three regions: Newfoundland, southern Gulf of St. Lawrence, and Bay of Fundy to Cabot Strait.

In Newfoundland lobsters are mostly restricted to shallow waters, mostly in the large bays, with no demonstrated migration from one large bay to the next. Short distance seasonal movements from depths less than 10 m in summer to over 15 m in winter have been noted in Bonavista Bay. In the southern Gulf of St. Lawrence average distances from tagging to recapture in various studies have been less than 15 km. In the Bay of Fundy and SW Nova Scotia some long distance movements have been noted.

A hypothesis is presented that lobsters in the Gulf of St. Lawrence and around Newfoundland do not undertake long distance movements since the deep water is cold both summer and winter, affording no temperature advantage to animals that might migrate to deep water in winter. By contrast, off SW Nova Scotia, lobsters moving to deep water in winter and to shallow water in summer are making use of warmer temperatures throughout the year.

INTRODUCTION

Lobsters are capable of moving considerable distances, in some cases more than 100 km over a period of months. The greatest distance reported is 426 km (230 naut mi) in 14 mo (Wilder 1974). Whether lobsters travel with any regularity at any particular geographic location has been argued by fishermen as well as biologists. Tagging and trapping studies, as well as sampling of the commercial fishery, provide relevant data. Such Canadian data are reviewed here separately for three regions: Newfoundland, southern Gulf of St. Lawrence, and Atlantic waters from Bay of Fundy to Cabot Strait (Fig. 1).

TAGGING METHODS

A variety of lobster marking and tagging methods has been used in Canada. The more common tags are shown in Fig. 2. The simplest is a rubber band forced over the claw and resting loosely over the narrower leg segments close to the body. Such colored, unmarked bands are occasionally used by fishermen for their own information, and by researchers as a second mark in double tagging (St. Andrews, unpubl. data).

An early lobster tag was the cattle ear tag, a 7 x 50-mm metal strip folded and clamped over the end of the tail fan (Templeman 1940). This tag was hard to spot and is lost when the animal molts.

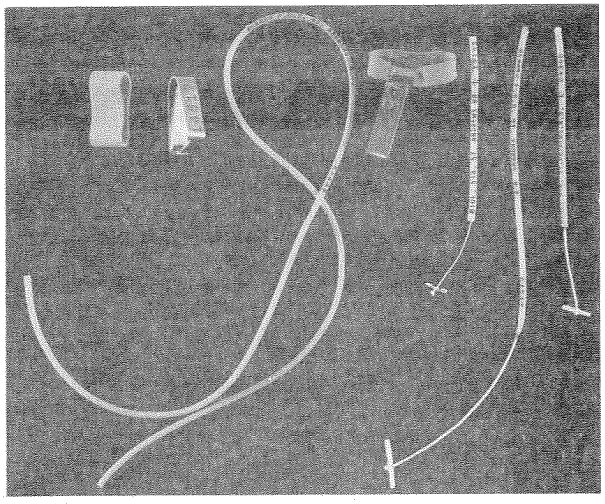


Fig. 2. Various lobster tags that have been used in Canada. From left to right they are: rubber band, cattle ear tag, vinyl tubing, carapace tag, sphyrion tag, toggle tag, anchor tag.

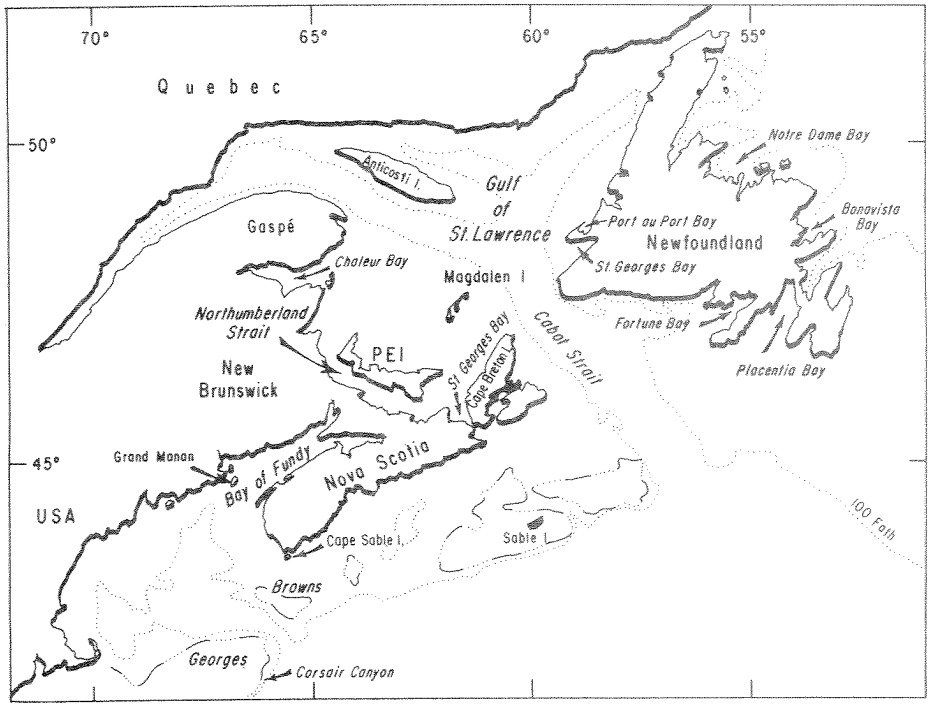


Fig. 1. Southeast coast of Canada, showing the general locations relevant to lobster tagging studies.

Marking, by drilling one or more 5-mm holes in different sections of the tail fan, allows identification of a number of groups of animals (e.g. ten groups of different sizes) for up to several molts (Wilder 1953). Such marking has been used extensively by Wilder (1953, 1963) in studies of growth, although in the 1970's (Ennis 1976) this method has been used only as a secondary mark to estimate tag losses. Disadvantages are the need to have informed people specifically looking for the marks.

A coded (ten codes) ferromagnetic wire tag, 2.4-3.0 mm long and inserted with a modified syringe into the base muscles of one of the second pleopods, was tested by Ennis in Newfoundland for growth studies. There was no difference in growth rate between lobsters tagged with the ferromagnetic tag vs. the subcarapace sphyrion tag (Ennis 1971, 1972). To find the tags, each animal has to be held close to an electronic detector. This makes the ferromagnetic tag impractical where the tagged lobsters are landed in many ports.

Printed and numbered vinyl tubing tied around the body has been used to tag some offshore lobsters in 1965-66 and in 1972 where there is a wide range of sizes, up to 15 kg (McKenzie 1966a, 1966b; St. Andrews, unpubl. data). Such a tag is, of course, lost when the animal molts.

The carapace or strap tag is a 32 x 6 mm numbered metal strip, bent around at one end to fit over the posterior margin of the carapace, with a rubber band from the other end passing around the rostrum to hold the tag in place. Over 200,000 such tags have been used from the mid-1940's to the present, mostly prior to opening of a fishing season, to estimate exploitation rates. Returns in excess of 90% have been obtained (e.g. St. Andrews' data from Miminegash 1962). Ennis (1976) estimated losses of this type of tag at 4% over a period of 6 mo (fall to April). A carapace dart tag (Gray 1965), consisting of a plastic disc attached with a barbed dart through the dorsal carapace, was field tested on 840 lobsters. Returns were up to 40% less than for the regular carapace tag (Ennis, pers. comm.). A tag attached to the carapace is lost when the animal molts.

A tag that would not be lost at molting - the subcarapace sphyrion tag - was developed in the mid-1960's (Scarratt and Elson 1965; Scarratt 1970). It has a wire anchor imbedded in the abdominal extensor muscle, a flexible monofilament neck passing through the membrane between abdomen and dorsal rear of carapace and a numbered vinyl sleeve showing externally. This has now become the preferred lobster tag in Canada. An alternative placement dorsally in the abdomen, with the anchor imbedded in the abdominal flexor muscle, gave lower returns in field trials (Scarratt 1970). The subcarapace sphyrion tag can be retained through a molt, and some tagged animals have been recovered 7 yr after release (Ennis, pers. comm.).

Similar to the sphyrion tag is the toggle tag, a modified Gundersen tag (Gundersen 1962) which has a small metal plate replacing the wire anchor of the sphyrion tag. It has been used on large offshore lobsters (Wilder and Graham 1973).

An anchor or t-bar tag (Floy model FD-67 or similar) has also been used on occasion in lieu of the sphyrion tag (St. Andrews, unpubl. data). It can be applied with a tagging gun.

A variety of other tags and marks on or under the carapace have been tried but have not been widely used.

Altogether some 250,000 tagged or marked lobsters have been released in Canadian waters. By far the greatest number of tags have been used to study exploitation rates in various lobster fisheries. Of the remainder, studies of lobster growth and movements have probably received equal emphasis. Up to the late 1960's growth studies were done almost exclusively by drilling holes in the tail fan. With the use of sphyrion tags, growth and movement can be studied simultaneously from the same tagging.

The effect of handling lobsters during tagging has not been adequately evaluated. In general, it seems advisable to tag an animal as soon as a trap is hauled and to release it within minutes at the capture location. Since the abdominal extensor muscle is a narrow one, some practice tagging is a prerequisite, with immediate dissections to verify position of the anchor.

Tag return rates up to 98% have been obtained with the sphyrion tag in the U.S. (Cooper 1970). Lack of interest, mistrust, etc., on the part of fishermen usually result in much lower return rates (Table 1), especially when trained research personnel are not continuously available in a port to actively enlist the cooperation of fishermen.

NEWFOUNDLAND

Templeman (1940) reports on lobster tagging on the west coast of Newfoundland, using the cattle tag on the telson. In St. Georges Bay (Fig. 1) 395 lobsters were tagged; 57.5% were recovered having moved an average distance of 3.7 km (2.0 naut mi), with a maximum of 25 km (13.5 naut mi). In Port au Port Bay 117 lobsters were tagged; 20.5% were recovered at an average distance of 9.4 km (5.1 naut mi), with a maximum of 28 km (15 naut mi). Tagging was done in July and August. Average time at large was over 9 mo. Squires (1970) reports on additional tagging in Port au Port Bay of 1,070 lobsters in 1961 with the carapace tag, and marking of 1,007 lobsters in 1962, presumably with holes drilled in the tail fan. Returns were 47%, but movements are not reported.

More recent tagging studies (Ennis 1972, 1974, 1976, 1978) deal with population estimates and growth. Reported recapture rates range from 21-82%. Since 1968, some 9,284 lobsters have been tagged with the carapace tag and another 3,977 with the sphyrion tag.

Preliminary analyses indicate no long-distance migrations of lobsters in Newfoundland. Lobsters appear to be restricted mostly to shallow waters (Squires and Ennis, 1968), mostly in the large bays. There are no reports of lobsters moving from one large bay to the next (e.g. St. Georges Bay and Port au Port Bay, Fortune Bay and Placentia Bay, Bonavista Bay and Notre Dame Bay). Short-distance seasonal movements from deeper waters in winter to shallower water in summer occur in at least one area. In Bonavista Bay, divers found lobsters concentrated at depths of 7-9 m in summer and 15-18 m in winter (Ennis, pers. comm.).

Table 1. Tagging studies with sphyrion tags.

Release location and date		No. tagged	Recap. No.	Recap. (%)
GULF OF ST. LAWRENCE				
Miminegash, PEI. 1966-67 (subcarap) (Scarratt 1970)		488	228	(46.7)
" " " " (abdomen) " "		448	139	(31.0)
Chaleur Bay, 1973-75 (Levesque-Charron, pers. comm.)		2,191	1,080	(49.3)
Northumberland Str., 1975 (Stasko 1976)		1,134	75	(6.6)
Magdalen I., 1978 (Montreuil, pers. comm.)	approx.	9,000	-	-
E. Northumberland Str., 1978 (Robinson, pers. comm.)		3,150	-	-
Sub-total, approx.		16,411		
NEWFOUNDLAND				
Newfoundland, 1968-78 (Ennis, pers. comm.)	approx.	3,922	-	-
Sub-total, approx.		3,922		
BAY OF FUNDY TO CABOT STRAIT				
Corsair Canyon to Sable I., 1972-73 (Stasko, unpubl.)		642	110	(17.1)
Browns Bank,1975 (Stasko and Graham 1976; plus unpubl.)		1,293	204	(15.8)
SWNS, Seal I. area, 1975 (" " " " ")		3,011	240	(8.0)
Shelburne, N. S., Displaced from Georges, 1976 (Stasko, unpubl.)		307	-	-
Cape Sable I. to Shelburne, N. S., 1978 (Stasko, unpubl.)		175	-	-
Grand Manan, 1977 (Groom, pers. comm.)		2,023	-	-
" " 1978 " " "		3,477	-	-
St. Mary's Bay, N. S., 1978 (Campbell, pers. comm.)		491	-	-
Chebogue estuary, SW Nova Scotia, 1978 (Stasko, unpubl.)		91	-	-
Eastern Nova Scotia, 1978 (Robinson, pers. comm.)		1,165	-	-
Sub-total		12,675		
Total, approx.		33,008		

GULF OF ST. LAWRENCE

The area considered here is the southern Gulf of St. Lawrence from Gaspé Peninsula and the Magdalen Islands, south to Northumberland Strait. In this area there has been extensive tagging of lobsters since the early 1930's (Templeman 1935; Wilder 1974). Much of this tagging has been done to determine growth of lobsters (Wilder 1953) and exploitation rates (Wilder 1947; Paloheimo 1963). Nevertheless, considerable data are available on movements as well.

The earliest tagging in the southern Gulf of St. Lawrence was in July-August 1931 at the Magdalen Islands, in Malpeque Bay and in western Northumberland Strait on the north shore of Prince Edward Island (Templeman 1935). In general, most of the recaptures from the 2,209 lobsters tagged with the cattle ear tag were near the release site. The 222 that had been at large for 8.5-12 mo moved an average of 8 km. Only 19 (8.6% of recaptures) were taken more than 16 km from the release site, the maximum distance being 43 km. There was no directional predominance, except that at Malpeque Bay and at the Magdalen Islands there was no fishery to catch lobsters that might have moved away from shore. At Malpeque Bay, males moved an average of 8 km, females 13.6 km.

Tagging to determine exploitation rates in the southern Gulf of St. Lawrence was started in 1939 (Smith 1939, 1940, 1941), but these data were not analyzed for movements.

At the Magdalen Islands, further tagging was done in the 1950's (Montreuil 1953, 1954; Bergeron 1967) using the carapace tag. From 1950 to 1957 they released a total of 12,231 tagged lobsters at 32 locations around the island. Return rates were the same for males and females, 34% for spring releases (before May 10) prior to the fishing season and 16% for fall releases (after July 10). Average distance moved was 4.2 km for the spring releases and 4.9 km for the fall releases. Maximum distance was 64 km. An analysis of movements along the long axis of the island (Axelsen and Dubé 1978) for the years 1951-53, using only those animals recaptured 3.7 km (2 naut mi) or more from the release site, shows that more animals moved north (71%) than south (29%). Perpendicular to the shore, movements appeared to be shoreward in the summer, though proper analyses taking into account relative fishing effort inshore and farther from shore were not done (Bergeron 1967).

In Chaleur Bay, there are two reports on tagging and movements of lobsters. Corrivault and Tremblay (1948) found very little movement at Grande-Rivière on SE Gaspé at the mouth of Chaleur

Bay in 1942-43. Maximum distance travelled in 9-22 mo at large was 11 km. However, based on trapping at various depths at Anticosti Island, the authors conclude that maximum lobster concentrations were at a depth of 4-7 m in July and at 18-33 m in October. Traps at 4, 7, and 11 m in October caught no lobsters. No experimental details or data are given, nor is there any discussion of the effect of temperature differences at these depths on catchability. Along the SE coast of Gaspé, Corrivault and Tremblay report similar movements inshore to shallower areas in summer and out to deeper water in winter, but the documentation is inadequate.

At the head of Chaleur Bay, Marcotte (1954) tagged 588 lobsters in September 1953, presumably with carapace tags. Based on 166 (28%) returns the subsequent spring (May-June), 154 (93%) had moved less than 12 km. Maximum distance travelled was about 68 km (Fig. 3).

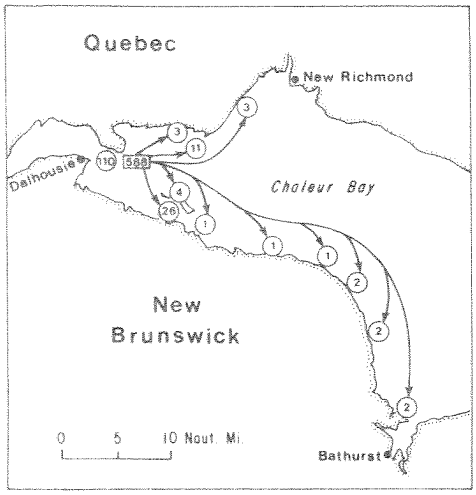


Fig. 3. Lobster tag recoveries in Chaleur Bay (after Marcotte 1954).

Farther south in the Gulf of St. Lawrence, much tagging has been done at Miminegash and Tignish on opposite sides of the NW tip of Prince Edward Island. Since the 1940's some 46,000 lobsters have been tagged with the carapace tag, and nearly 33,000 have been recovered. Since these studies were designed to determine exploitation rates, the lobsters were tagged just prior to the fishing season. As a result, most were recaptured within a few weeks of release and provide little information on movements. Nevertheless, some animals were at large overwinter before recapture. Such tag returns showed no movement between the two fishing grounds only 16 km apart (Wilder 1974). Similar lack of consistent migrations was observed in taggings at a number of other ports around the southern Gulf of St. Lawrence (Wilder, pers. comm.). A tag comparison study in the Miminegash area (Scarratt 1970) gave similar results with sphyrion tags. Average distance release to recapture was 2.9 km, with a maximum of 48 km.

More recent releases of lobsters tagged with sphyrion tags are summarized in Table 1. Most of these studies are still in progress or awaiting analysis of the data. However, up to now the results appear to be consistent with the earlier findings with carapace tags. Of considerable importance, from the point of view of lobster growth, is the study at Belledune on the south shore of Chaleur Bay (Centre de Recherche Noranda, Lévesque-Charron, pers. comm.). Here 400 recaptures were 2nd, 3rd and 4th recaptures of tagged animals captured and released again.

In one study in 1954 near the SW tip of Prince Edward Island a special effort was made to tag late in the season in October to maximize the time at large before start of the fishing season the following August. Only large lobsters over 76 mm CL (minimum legal size in this area is 63.5 mm CL) were used to minimize loss of the carapace tags during the summer molting period. Of the 1,996 lobsters tagged, 253 (13%) were recovered, 95% of them within 28 km (15 naut mi) of release. Average distance release to recapture was 13.5 km; maximum distance was 46 km (Wilder 1963).

In summary, lobsters in the southern Gulf of St. Lawrence appear to be restricted in their movements with average distance release to recapture being less than 15 km. Some seasonal short-distance movement to shallow water in summer and deep water in winter may occur but has not been adequately documented.

BAY OF FUNDY TO CABOT STRAIT

Early tagging data from this area since the 1940's show results similar to those in the Gulf of St. Lawrence and Newfoundland, i.e. no consistent long-distance migrations were noted. In the Fourchu-Gabarus and L'Archevêque areas on the SE coast of Cape Breton, some 27,500 tagged lobsters have been released and over 15,000 recovered. The average time release to recapture was 3.5 mo. Nearly 2,000 animals were at large for more than a year, yet few animals moved between the two fishing grounds only a few miles apart (Wilder 1974). Some 8,000 lobsters have been tagged off southern Grand Manan Island, N.B., at the mouth of the Bay of Fundy. Most were recaptured by local fishermen. None crossed the Bay of Fundy to Nova Scotia, a distance of 56 km (30 naut mi). Maximum distance release to recapture was 111 km (60 naut mi) southwest (Wilder 1974). Some 30,000 lobsters have been tagged at Port Maitland in SW Nova Scotia and about 12,600 recovered. Over 90% were recaptured by Port Maitland fishermen, and most of the others by fishermen from neighbouring ports. The average time release to recapture was 4 mo. Ten of the 12,600 recaptured lobsters were taken more than 74 km (40 naut mi) from the release site, one having apparently travelled a straight-line distance of 426 km (230 naut mi) (Wilder 1974).

The above tagging was done mainly to determine the effect of the fishery on the lobster stocks rather than to study movements, hence releases were scattered over the fishing grounds. In one special study off Port Maitland, N.S., lobsters were tagged and released on a transect perpendicular to shore at five stations 3.7 km (2 naut mi) apart. The data were analysed for movements. A total of 500 animals were tagged in early November 1956 prior to the start of the fishing season (Wilder and Murray 1958). In the first 3 mo (Dec.-Feb.) of the fishery, 107 were recaptured, with an additional 104 recaptured March-May. Of the 211 recaptures, most were taken within 2 km of release. Only 7 animals had moved more than 7 km.

Based on the above early tagging studies with the carapace tags, it appears that lobsters in this area might be generally nonmigratory, as in Newfoundland and Gulf of St. Lawrence. However, since most of the tagging was done to determine exploitation rates and growth, there are features in these early studies that discriminate against showing seasonal migrations, especially during the summer, June through October. First, the tagging was mostly done during the few weeks just prior to the fishing season and most of the lobsters were recaptured within a few weeks of release. Second, in this area (Bay of Fundy and SW Nova Scotia) the lobster season is open during the winter and early spring (mostly late Nov.-May). Thus, the results based on recaptures by commercial fishermen represent movements largely during the cold winter months when inshore water temperatures drop from around 10°C at the start of the fishing season to less than 4°C January through April (monthly temperature data from Yarmouth-Maine ferries). Most of the carapace tags used in these studies were lost during the summer molting period. Third, there was no fishery for lobsters distant from shore. Hence, long-distance migrations away from the coast could not have been detected.

Growth of the U.S. offshore lobster fishery in the 1960's, development of the Canadian offshore lobster fishery starting in 1971, and availability of the long-lasting sphyrion tags gave a new impetus to studies of lobster movements off SW Nova Scotia.

In 1965-66, from NE Georges Bank to Sable I., 204 offshore lobsters were tagged with printed vinyl tubing tied around the body (McKenzie 1966a, 1966b). In 1972-73, on NE Georges and SE Browns Banks, 642 lobsters were tagged mostly with the toggle tag but, some with vinyl tubing tied around the body. To date 110 tags have been recovered, all by offshore fishermen. One lobster had crossed from Browns Bank to Georges Bank. Seven had moved more than 50 km. None was recaptured by inshore fishermen (St. Andrews, unpubl. data).

In 1975, 4,304 lobsters were tagged off SW Nova Scotia with sphyrion tags, 3,011 in the vicinity of Seal Island some 30 km off the mainland, and 1,293 on Browns Bank some 100 km from the mainland (Stasko and Graham 1976). To date 444 tags have been recovered, 80% of them less than 37 km (20 naut mi) from the release site (Table 2). Fifty animals had moved more than 93 km (50 naut mi). In the SW Nova Scotia study area there is a trough of deep water between inshore lobster grounds and Browns Bank. In this trough there is no fishery for lobsters. Twenty-one of the recaptured animals had crossed this trough, 18 of them (13 females, 5 males) moving outward. The results are still preliminary, with only 10.3% of the tags returned to date. Relative fishing intensity in different areas must be considered in analysing the movements.

Tagging in the 1970's has added a new dimension to studies of lobster movements off SW Nova Scotia. There is now some evidence for movement of some lobsters between the Seal Island grounds off SW Nova Scotia and the Browns Bank area. However, since the tagging period was in July and August, the observed outward movements may be either an emigration of some of the inshore lobsters or part of seasonal movements to deeper water in winter, such as demonstrated by Uzmann et al. (1977). To detect any reverse movements, tagging must be done in deep water in early spring.

The study on Grand Manan indicates that there may be seasonal shoalward movement of large deep-water lobsters in this area (Groom, pers. comm.). A number of other tagging studies are still in progress (Table 1).

DISCUSSION

All the early tagging studies in the three geographical areas - Newfoundland, Gulf of St. Lawrence and Bay of Fundy to Cabot Strait - indicated that lobsters do not migrate long distances, although short-distance seasonal movements to shallower water in summer may occur. In SW Nova Scotia, where lobsters have been found in offshore areas up to 100 and more kilometers from shore, there is evidence that some lobsters do move considerable distances.

On the basis of environmental considerations in Newfoundland and the Gulf of St. Lawrence, long-distance migrations of lobsters seem unlikely. In Newfoundland the zone occupied by lobsters is a narrow band along the coast, wider in the large bays (Squires 1970); no deepwater lobster stocks have been found any distance from shore (Ennis, pers. comm.), though a few lobsters have been found down to 174 m mostly within a few kilometers of the SE coast (Squires and Ennis 1968). At this northern end of their range where the water is cold, averaging less than 0°C at all depths January through March at St. John's (Bailey 1961; Huyer and Verney 1975), and near 0°C down to 100 m in the Cabot Strait in February (El-Sabh 1977), there is probably little advantage for lobsters to travel long distances to deep water in winter. Similarly, in the southern Gulf of St. Lawrence water temperatures are below 0°C down to about 100 m depth, while at 50-200 m the temperature remains below 4°C all year round (Trites 1972). Thus, seasonal long-distance migration to deep water would not enhance growth in Newfoundland waters or the Gulf of St. Lawrence. By contrast, off SW Nova Scotia water temperatures at 200 m usually remain above 7°C all year round, enabling feeding and growth during winter when surface waters approach 0°C (NMFS monthly temperature data from Yarmouth-Maine ferries; Taylor 1961).

Off SW Nova Scotia circumstantial evidence other than tagging also points to some interchange between inshore and offshore lobsters in the Browns Bank area. It has long been recognized that berried lobsters here are scarce inshore, less than 1% of females (Stasko 1978). Egg production per unit area off Port Maitland has been estimated to be considerably less than that at Fourchu on SE Cape Breton and at Miminegash on the west end of Prince Edward Island (Wilder 1965). By contrast, berried females are abundant in offshore areas 80 km and more from shore. In a sample of 16,018 animals, 19% of females were berried (Stasko 1978). Conversely, sublegal lobsters less than 81-mm CL are abundant inshore (over 50% of catch), but almost totally absent offshore beyond the 50-mi limit. The modal size too is different, approximately 115 mm CL offshore vs. just above the 81-mm legal limit inshore. Thus, there appears to be a need for some external recruitment of larval or young animals to inshore areas where reproducing females are few, and of adult animals to offshore areas where small lobsters are not found.

Wilder, D. G., and D. E. Graham. 1973. Offshore lobster trap fishing July 10 to August 10, 1972. Fish. Res. Board Can. MS Rep. 1236, 24 p.

Wilder, D. G., and R. C. Murray. 1958. Do lobsters move offshore and onshore in the fall and spring? Fish. Res. Board Can. Prog. Rep. Atl. Sta. 69: 12-15.

TAGGING (S. Keefe and E. Smith, rapporteurs)

The discussion centered around the cautions that should be exercised when analyzing movements of American lobsters. These included:

1) The effects of size, sex and size at first maturity;
2) The effects of high exploitation rates;
3) The effects of highly seasonal fisheries;
4) The effects of handling lobsters during tagging experiments;
5) The effects on returns when personnel are at fishing ports.

Taggings studied in Grand Manan and Rhode Island have demonstrated some size-sex dependent movements. In Grand Manan, lobsters ranging from 2-18 lb, predominantly females, were tagged. Returns to date were described by Groom as follows: 10% local, 3% moved southwest along the Maine coast to Cape Cod, 3% moved north up into the Bay of Fundy. Thomas said the majority of returns from Maine were over 5 in. CL. The experiment has not yet been analyzed in relation to sex.

Anthony emphasized the importance of qualifying statements about populations which appear to be nonmigratory. In Long Island Sound, for example, tagged lobsters are small and exploitation rates are very high, therefore, movements may not be apparent due to the quick removal of tagged lobsters. In Canada, the fishing season in the Bay of Fundy and S.W. Nova Scotia is from November-June which may not be long enough to show lobster movements during other times of the year.

Handling lobsters may affect movements. Russell observed a 3-4 d refractory period after tagging with a sphyrion tag. Robinson also has observed this handling effect. However, there is little knowledge of lobster feeding behavior which may cause the same effects. Since the territorial aspects of lobster are little known, moving lobsters from the site of capture during tagging experiments may induce movement. It was suggested lobsters be returned to the site of capture as soon as possible after tagging. Stasko reported significantly higher tag returns in areas where he had personnel in fishing ports than in areas where no personnel were located.

A consensus about the inapplicability of the Faber method in growth analyses gave way to a general discussion on the merits of tagging versus modal analysis in estimating molt frequency and increment. Caddy suggested the possibility of polymodality of sizes within a "year-class" due to both variability in the frequency of molt during the 4-7+ pre-recruit years and the artificial modality created by the minimum legal size. Robinson suggested that modal analysis is impossible with an animal undergoing 16-18 growth increments before recruitment, each with its attendant variability. Caddy suggested that perhaps the problem would only arise with a seasonal rather than an annual fishery; however, phenomena such as the decline of molt frequency with onset of maturity should also be addressed.

Applicability of the von Bertalanffy growth equation was discussed with opinion generally divided. Consensus appeared to suggest it as an acceptable tool for analysis over a size range where frequency of molt is constant. Reliability of K and L_∞ was discussed with the observation expressed that an inaccurate K may yield an inappropriately low L_∞ and that, in many cases, L_∞ is too low simply because individuals larger than that size may routinely be observed in the commercial catch. Since the method is particularly sensitive to the set of data to which it is applied, it was felt that extreme caution should be used in the interpretation of results. Robinson pointed out that we may be measuring growth of the juvenile size group and extrapolating to the adult size group which is present in most fisheries in very small numbers.

The concern was expressed that, once the von Bertlanffy parameters are derived and application to yield equations is begun, the growth parameters tend to become "set in stone" and the imprecision or questionable assumptions on which they were derived tend to be forgotten. It was pointed out that the main value of the equation is that the resultant parameters facilitate use of the Beverton and Holt yield-per-recruit model.

Anthony suggested that the frequency of molt and incremental growth through the molt are some of the most important types of information that have been obtained to date. He also suggested that the von Bertalanffy equation may not be too useful in long-term studies and perhaps should be replaced by some other method such as a probability model using molt increment and frequency parameters.

Susan Waddy observed that egg-laying cycles may be different for different groups of females which may bias growth determinations. Robinson supported this observation by his tagging results; however Thomas expressed an opposite point of view in discussing the relative uniformity and dependability of seasonal egg-laying cycles along the Maine Coast. Ensuing discussion emphasized that different areas quite probably have largely dissimilar maturity, fecundity, and growth cycles which would tend to suggest separate studies for dissimilar areas. These phenomena were discussed relative to what might induce them i.e., either latitude or degree/days, or a combination of both.

U.S. SURVEYS OF LOBSTER LARVAE

by

J. J. Lair, Jr.

Massachusetts Division of Marine Fisheries
18 Heritage Professional Building
Route 6A, RFD 1
Sandwich, MA 02563

ABSTRACT

Stasko, A. B. 1980. Lobster larval surveys in Canada. Can. Tech. Rep. Fish. Aquat. Sci. 932.

Lobster larval surveys in Canada are reviewed starting with the early work of Templeman in the 1930's through to ongoing studies. In the Gulf of St. Lawrence, after early exploratory studies mostly in Northumberland Strait, a 16-yr series of samples was collected at the north end of Northumberland Strait. A 1-yr survey has just been completed at the Magdalen Islands. In Newfoundland the early studies were exploratory, while recent work is aimed at describing the microdistribution of larvae near the shore in relation to wind direction and force. In Atlantic waters from Georges Bank to Cabot Strait, after a few exploratory cruises in 1965-73, large-scale surveys were begun in 1976. Here results show an unexplained dearth of stage II and III larvae and a relative abundance of stage IV. In all areas lobster larvae are most abundant at the surface, decreasing rapidly within the first meter below the surface.

INTRODUCTION

In the 1970's, there have been several reviews of aspects of lobster larval studies. Aiken (1977) reviewed the growth of larval lobsters. Wells (1976) summarized studies on various aspects of lobster larvae, including development, culture, physiology, behavior and ecology. Caddy (1976) did a detailed examination of the effect of temperature on larval development and resulting survival in natural temperature regimes, with particular reference to the southern Gulf of St. Lawrence. Stasko (1977) summarized published information on larval distribution in Atlantic waters south of Newfoundland, including U.S. studies. The present paper is an overview of, hopefully, all lobster larval surveys in Canada.

For purposes of this paper the Canadian east coast waters (Fig. 1) are divided into three areas: southern Gulf of St. Lawrence (including Magdalen Islands), Newfoundland, and Atlantic waters from Bay of Fundy to Cabot Strait. To date, there are no reports of lobster larval surveys in the northern Gulf of St. Lawrence. Larval catches, from the various surveys discussed in this paper, are summarized in Table 1.

GULF OF ST. LAWRENCE

In the southern Gulf of St. Lawrence in 1936 and 1937, Templeman (1936b, 1937b) made the first exploratory tows for lobster larvae at the east end of Northumberland Strait, between Pictou, N.S., and Canso Strait. He caught mostly stage I larvae.

Exploratory tows in late July and August were continued the next 3 yr by Smith (Templeman 1937b; Smith 1937, 1938, 1939). Initial tows farther west in Northumberland Strait, between Point du Chêne, N.B., and Egmont Bay, P.E.I, yielded most larvae in Egmont Bay. Of the 37 larvae caught July 29-August 9, there was only one stage IV larva. In 1938 Smith (1938) found that, at the north end of Northumberland Strait, stage IV larvae were most concentrated near the New Brunswick shore, i.e. not at the same location as stage I larvae which presumably were more abundant on the P.E.I. side. In 1939, towing at 25 stations between the north shore of P.E.I. and the Magdalen Islands, Smith (1939) found that larvae were most abundant near both shores, but some were found in all waters in between.

The above exploratory work was supplemented by tows at several depths (Templeman 1936b, 1937a; Smith 1937); most larvae were caught at the surface. The data from Smith (1937) are summarized in Table 2, since the original is available only in an unpublished manuscript.

The exploratory work in the southern Gulf of St. Lawrence was followed by a systematic program of surface larval tows in northern Northumberland Strait for 16 yr, 1948-63 (Wilder 1953; Scarratt 1964, 1973), along with experimental tows at various depths below surface and at night (Scarratt 1973). A 3.7 x 0.9 m neuston net was used (Fig. 2). Scarratt (1968, 1969) also investigated the effect on larval distribution of bleached kraft mill effluent in the southern Northumberland Strait off Pictou, N.S. He found no measurable effect.

More recently Harding et al. (1979) did a preliminary analysis of 199 lobster larvae caught in

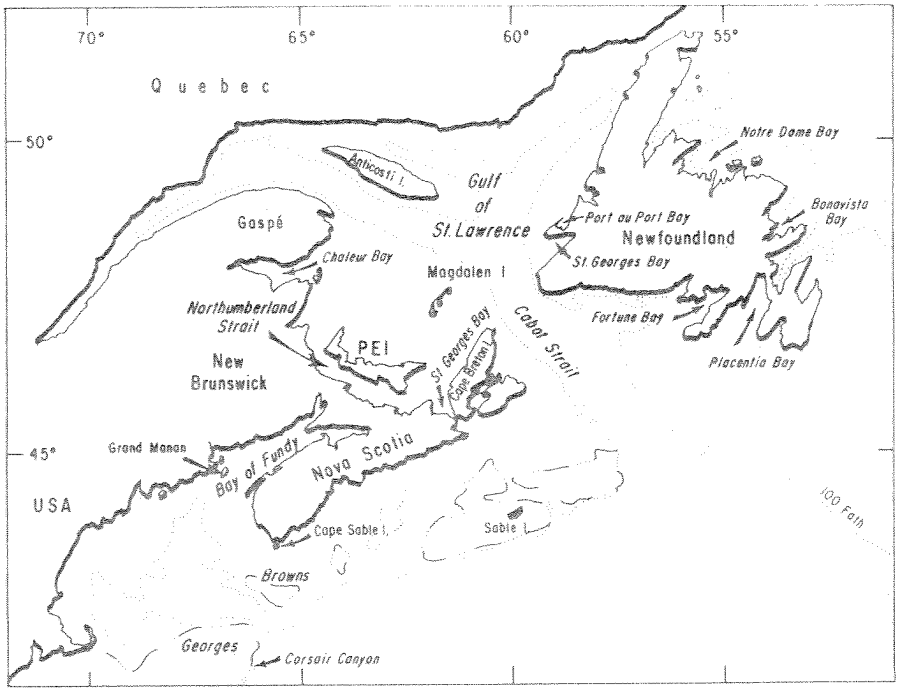


Fig. 1. Map of Canadian east coast showing the general locations relevant to lobster larval surveys.

Table 1. Breakdown of catches by project and larval stage. Catch data for the early exploratory studies may be incomplete.

Location and date		Type of tows	Reference	% larval stage I	II	III	IV	No. of larvae
SE Northumberland St.	1936	daylight, mostly surface	(Templeman 1937a)	95.8	3.0	0.6	0.6	333
N Northumberland St.	1937	mostly surface	(Templeman 1937b)	13.5	51.4	32.4	2.7	37
SE Northumberland St.	1937	mostly daylight, surface & deep	(Smith 1937)	97.5	1.4	0.6	0.6	355
SE Northumberland St.	1966	daylight, surface	(Scarratt 1968)	94.9	4.4	0.4	0.3	1984
SE Northumberland St.	1968	daylight, surface	(Scarratt 1969)	90.2	2.0	0.4	7.4	746
St. Georges Bay, N. S.	1975	daylight, surface	(Harding et al. 1979)	91.7	7.8	0.5	0	193
Magdalen I., Que.	1978	daylight, surface & subsurface	(M. Roy, pers. comm.)	79.9	12.3	4.2	3.6	4600
N Northumberland St.	1948	daylight, surface	(Scarratt 1964, 1973)	59.3	19.2	12.0	9.4	1570
" " "	1949	" "	" " "	85.2	10.0	3.9	0.9	8559
" " "	1950	" "	" " "	70.2	18.4	8.9	2.5	17142
" " "	1951	" "	" " "	78.3	12.7	5.5	3.5	12656
" " "	1952	" "	" " "	68.3	15.3	7.3	9.0	32870
" " "	1953	" "	" " "	84.7	10.3	2.7	2.3	31309
" " "	1954	" "	" " "	88.4	9.1	1.9	0.6	18028
" " "	1955	" "	" " "	82.7	11.7	3.5	2.1	30453
" " "	1956	" "	" " "	77.2	11.0	5.2	6.6	42578
" " "	1957	" "	" " "	73.8	16.6	5.6	4.0	38942
" " "	1958	" "	" " "	72.9	15.1	9.3	2.7	17935
" " "	1959	" "	" " "	83.2	12.6	2.6	1.5	9788
" " "	1960	" "	" " "	91.0	7.3	1.2	0.5	13502
" " "	1961	" "	" " "	74.2	24.2	1.2	0.4	23540
" " "	1962	" "(some night & subsurf.)	" " "	89.4	7.5	2.6	0.5	4579
" " "	1963	" "	" " "	88.4	9.2	1.8	0.6	7376
	1948-1963	combined		78.3	13.6	4.6	3.5	310,827
Newfoundland Bays	1938-40	daylight, surface	(Templeman & Tibbo 1945)	54	14	19	13	5037
Newfoundland Bays	1974-78	daylight, surface and deep	(Ennis, pers. comm.)		Mostly	stage	I	
NE Georges to Sable I., 1965-73, daylight, surface			(review by Stasko 1977)	0	16.7	66.7	16.7	12
Scotian Shelf, offshore, 1976, day & night, surface & deep			(Stasko 1977)	8.5	8.5	19.7	63.3	142
SW Nova Scotia. offshore, 1977, day & night, surface			(Stasko unpublished)	40.1	6.7	2.1	51.1	509
SW Nova Scotia, offshore, 1977, day & night, subsurface			(Stasko unpublished)	31.3	8.8	0	59.9	182
SW Nova Scotia, inshore, 1977, daylight, surface			(Stasko unpublished)	48.5	0	0.4	51.1	231
SW Nova Scotia, inshore, 1977, daylight, subsurface			(Stasko unpublished)	70.8	0	0	29.2	89
Georges Bank, 1977, daylight, surface			(Stasko unpublished)	16.8	16.8	55.0	11.5	191
Grand Manan I., inshore, 1977, daylight, surf. & subsurf.			(Groom 1978)	100.0	0	0	0	14

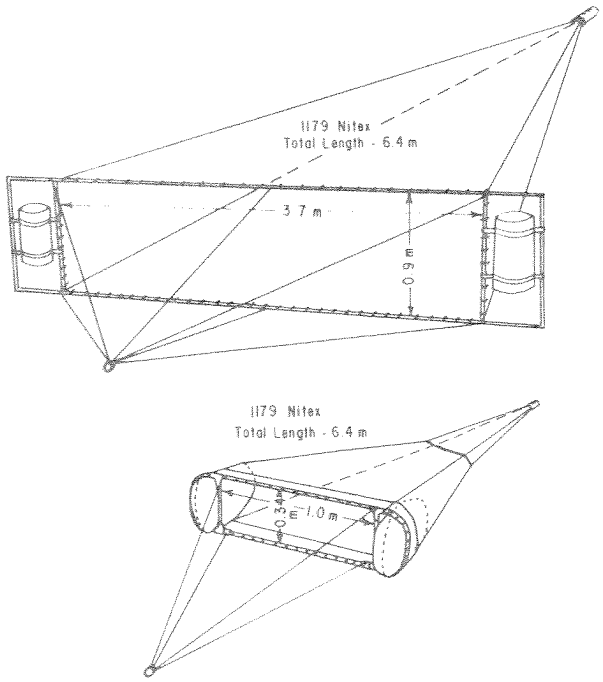


Fig. 2. Surface neuston nets used in major lobster larval surveys. Measurements of mouth opening are center to center of pipe frame.

1975 in surface tows in St. Georges Bay beyond the eastern end of Northumberland Strait. In the Magdalen Islands a major program of lobster larval sampling was begun in 1978 (M. Roy, pers. comm.). Over 4500 larvae were caught there June 20-Sept. 2.

NEWFOUNDLAND

In Newfoundland, lobster larval explorations were begun by Templeman in 1938 on the west coast (Templeman 1939; Templeman and Tibbo 1945) and continued on the southeast and east coasts in 1939 and 1940 (Templeman and Tibbo 1945). Over 5000 larvae were caught, mostly near shore and especially along shorelines facing the prevailing southwest summer winds. Larvae were more abundant off western Newfoundland than on the southeast and east coasts.

In 1962 Squires (1965, 1970) towed for zooplankton in Port-au-Port Bay on the west coast of Newfoundland and found lobster larvae mostly within 200 m of shore. In 1964 in the Bay of Islands just north of Port-au-Port Bay, Squires et al. (1971) collected 61 larvae in 49 tows with a 0.5-m net towed 15 min at or just below surface. Ennis (1975) observed the behavior of larval stages I to V released at sea both at surface and at depth. More recent work by Ennis (pers. comm.) is aimed at determining microdistribution of larvae near shore in relation to environmental factors, particularly wind.

BAY OF FUNDY TO CABOT STRAIT

In Atlantic waters, from the Bay of Fundy to Cabot Strait, there is little published on lobster larvae. Leim (1936) reports that, in the lower Bay of Fundy in 20 yr of general larval towing prior to 1937, only a single late-stage lobster larva was found. From 1937-59 no lobster larvae were found in monthly tows with a meter net 5- to 7-m deep and 18- to 23-m deep at one station in the St. Croix estuary and at one station between Campobello Island and the Wolves, off Passamaquoddy Bay (Legaré 1961; D.J. Faber, pers. comm.).

Along the Fundy and Atlantic shores of Nova Scotia there appear to be no records of any summer larval tows prior to 1976, while along the edge of the continental slope only 12 larvae were caught in 397 tows mostly with a 1-m wide neuston net towed at 2-4 knots (Graham and Wilder 1966; McKenzie 1966a, 1966b; Wilson and Wilder 1967; Wilder and Graham 1973; reviewed by Stasko 1977). In 1976 an annual summer fish larval survey was initiated by the Marine Fish Division, Department of Fisheries and Oceans covering the area from Georges Bank to Cabot Strait. The number of stations was increased from 72 in 1976 to 150 in 1977 and to about 230 in 1978. Stasko (1977) sorted the 1976 samples for lobster larvae and found 142 larvae almost exclusively in surface gear (1-m neuston net @ 5 knots, meter net @ 2.5 knots). Most were taken in the area from Browns Bank to LeHave Bank. There were no stations on Georges Bank in 1976. The 1977 and 1978 summer cruise samples are still being sorted at the writing of this paper.

In addition to the above synoptic surveys from Georges Bank to Cabot Strait, a time series of larval tows specifically for lobster larvae was carried out off southwest Nova Scotia in 1977 and 1978. Close to shore, mostly within 2 mi of shore, there were 33 stations; offshore, there were about 30 stations from Yarmouth-Shelburne to the Browns Bank area. In 1977 there were 6 inshore and 7 offshore cruises June 28 to September 18, plus some short tows taken during a scallop cruise on Georges Bank. Several gear combinations were used, but at all stations a 1.0 x 0.34 m neuston net (Fig. 2) was included, this being the most productive gear of those tested in this area. The catch was 322 lobster larvae inshore, 696 offshore, and 191 on Georges Bank. In 1978 there were 10 inshore cruises and 5 offshore cruises, plus 1 cruise on northeast Georges Bank. The samples are still being sorted. Preliminary analysis of the 1977 data (Stasko, unpublished) shows great variability in catches from station-to-station and concentration of larvae at the surface. Surface drifters were released during most of the offshore cruises to determine the direction and speed of summer surface currents. From the Browns Bank area surface water moves toward southwest Nova Scotia (Bumpus and Lauzier 1965; Trites, pers. comm.).

In Grand Manan, as part of a 2-yr investigation of lobsters in 1977-78, larval tows were made in inshore areas mid-July to early October. Only 14 larvae were caught in 1977 (Groom 1978).

SWIMMING DEPTH

Early trials with meter nets at different depths showed that lobster larvae are most abundant at the surface both in Northumberland Strait in the southern Gulf of St. Lawrence (Templeman 1936b, 1937a; Smith 1937) and off Newfoundland (Templeman 1939, Templeman and Tibbo 1945). At the east end of Northumberland Strait, Templeman (1936b) caught 7.8 larvae per hour at the surface, 1.1/hr at 0.2-4 m,

Table 2. Lobster larvae caught July 22-Aug. 5, 1937 in Northumberland Strait near Pictou, N. S., using 1-m nets with 0.75 mm mesh towed simultaneously or sequentially at surface and at 3.7-7.3 m depth (from Smith 1937). Total catch surface and deep tows was 341 and 14 larvae in 34 and 15 tows for an average catch of 10.03 and 0.93 larvae per tow (from Smith 1937).

Date	Tow	Place	Time	Tide	Wind	% cloud	No. of nets	Depth (fath)	Larval stage I	II	III	IV
July 22	1	Pictou Hbr.	15:25	Fl	E	0	1	0	-	-	-	-
" "	2	off " "	16:25	"	"	"	1	0	8	1	-	-
" "	3	" " "	16:25	"	"	"	1	2	-	-	-	-
" "	4	" " "	18:15	"	"	"	1	0	11	-	-	-
" "	5	" " "	18:15	"	"	"	1	4	-	-	-	-
" "	6	" " "	19:45	"	"	"	1	0	6	-	-	0
" "	7	" " "	19:45	"	"	"	1	2	-	-	-	-
" "	8	Chance Hbr.	21:35	E	SW	"	1	0	-	-	-	1
" "	9	" "	21:35	"	"	"	1	2	-	-	-	-
July 24	10	Pictou Hbr.	0:35	"	"	"	1	0	-	-	-	1
" "	11	" "	0:35	"	"	"	1	2	-	-	-	-
" "	12	" "	2:10	"	"	"	1	0	-	-	-	-
" "	13	" "	2:10	"	"	"	1	2	-	-	-	-
" "	14	" "	5:00	Fl	"	60	1	0	1	-	-	-
" "	15	" "	5:00	"	"	"	1	2	2	-	-	-
" "	16	" "	6:35	"	"	"	1	0	11	-	-	-
" "	17	" "	6.35	"	"	"	1	2	-	-	-	-
July 26	18	Little Hbr.	15:15	E	"	"	1	0	4	1	-	-
" "	19	" "	15:15	"	"	"	1	4	-	-	-	-
" "	20	" "	16:30	"	"	"	1	0	7	1	-	-
" "	21	" "	21:00	Fl	"	Moon	1	0	6	-	-	-
" "	22	" "	21:00	"	"	"	1	3	9	-	-	-
July 27	23	Pictou Hbr.						B	-	-	-	-
July 28	24	" "	3:20	E	WSW	-	1	0	2	-	-	-
" "	25	" "	3:20	"	"	-	1	2	-	-	-	-
" "	26	" "	6:00	"	"	100	1	0	9	-	-	-
" "	27	" "	6:00	"	"	"	1	2	1	-	-	-
July 29	28	" "	10:50	Fl	NE	10	2	0	6	-	-	-
" "	29	Little Hbr.	13:55	E	"	2	2	0	2	1	-	-
" "	30	" "	16:00	"	"	"	2	0	91	-	-	-
" "	31	Chance Hbr.	17:35	"	"	5	2	0	44	-	-	-
July 30	32	" "	12:20	Fl	SE	10	2	0	-	-	-	-
" "	33	Pictou Is.	15:15	"	"	30	2	0	1	-	-	-
" "	34	32 - 33	17:50	E	"	100	1	0	1	-	1	-
" "	35	" "	17:50	"	"	"	1	2	-	-	-	-
Aug. 2	36	Pictou Hbr.	17:05	Fl	W	50	1	0	1	-	-	-
" "	37	" "	17:05	"	"	"	1	3	-	-	-	-
" "	38	" "	15:25	"	SW	80	1	0	1	-	-	-
" "	39	Pictou Is.	17:20	"	"	10	1	0	68	1	-	-
" "	40	" "	19:25		"	100	1	0	5	-	-	-
" "	41	" "	20:50	E	"	"	1	0	2	-	-	-
Aug. 4	strong easterly gale											
Aug. 5	42	Pictou Is.	15:45	Fl	W	90	1	0	2	-	-	-
" "	43	" "	17:35	"	"	50	1	0	38	-	-	-
" "	44	" "	21:00	"	"	40	1	0	6	-	-	-
" "	45	" "	22:00	"	"		1	2	2	-	-	-
									347	5	1	2

Table 3. Ratio of catch rates deep net vs. surface net from all Canadian matched sets of surface and deep samples taken simultaneously or in close succession. Where different type of gear is used for surface vs. deep tows, the catches are prorated for equal volume of water strained, e.g. M. Roy and A. Stasko data. When there is a difference in number of tows or towing time at surface vs. deep (e.g. Templeman 1936b, 1939; Templeman and Tibbo 1945), the catch is prorated for equal number of tows of equal towing duration. The southwest Nova Scotia to Browns Bank 1977 figures exclude paired tows with no larva in both gears; the others include all tows.

Location	Reference	No. of gear tows	Catch ratio deep/surface	Depth of deep net (m)
Northumberland Strait, E.	(Templeman 1936b)	(28 h)	0.14 0	0.2-4.0 5.5-11
Northumberland Strait, E.	(Smith 1937)	50	0.10	3.7-7.3
Northumberland Strait, N.	(Scarratt 1973)	21 x 2 13 x 2 13 17	0.02 0.19 low 0	0.6-1.2 0.6-1.2 4-18, midwater 5-13, near bottom
Magdalen Islands	(M. Roy, pers. comm.)	161 x 2	0.21	1-2
Nfld. W.	(Templeman 1939)	13	0.02	0.6-3.4
Nfld., Placentia Bay	(Templeman and Tibbo 1945)	5 x 2	0.75	3.8-4.3
Nfld., Notre Dame Bay	(Templeman and Tibbo 1945)	8	0.20	0.4-3.7
Nfld., Placentia Bay	(Templeman and Tibbo 1945))	7 x 2	0.04	2.9-3.7
Nfld., Placentia Bay	(Templeman and Tibbo 1945)	12	0.14	1.2-3.7
Georges Bank to Cabot Strait 1976 (Stasko 1977)				
1-m neuston net @ 5 knots vs. meter net @ 2.5 knots		76 x 2	0.11	0-1
1-m neuston net @ 5 knots vs. Isaacs-kidd net @ 5 knots		76 x 2	0.01	bottom to 2 m
SW Nova Scotia to Browns Bank 1977 (Stasko, unpubl.)		88 x 2	0.09	1-2

and no larvae at 5.5-11 m in 15, 8 and 5 h of towing; the deep/surface catch ratios were 0.14 and 0 respectively (Table 3). Smith (1937) caught 341 larvae in 34 tows at the surface and 14 larvae in 15 tows at 3.7-7.3 m for a deep/surface catch ratio of 0.09. At the northwest end of Northumberland Strait, Scarratt (1973) in paired round-the-clock tows obtained a subsurface (0.6-1.2 m) to surface (0-0.6 m) catch ratio of 0.02 in July and 0.19 in August; larvae were scarce in midwater at 4-18 m and absent near bottom at 5-13 m. At the Magdalen Islands in 1978 (M. Roy, pers. comm.) up to Sept. 2 the ratio of larval catches at the surface vs. 1-2 m below was variable, although overall results when reduced to a common volume strained gave a meter/neuston catch ratio of 0.21. The ratios of catch rates in deep vs. surface nets for the various Canadian studies are summarized in Table 3.

In Newfoundland, using some sequential 1/2-h tows with a 1-m net at different depths and some simultaneous tows with two nets, Templeman (1939) and Templeman and Tibbo (1945) found that the larvae were mostly concentrated at the surface (Table 1). Overall, the matched tows at different depths averaged 13.0 larvae/tow at surface vs. 0.8 larvae/tow at depths of 0.6-4.3 m.

Off southwest Nova Scotia in August 1976, lobster larvae of all stages were most abundant at the surface. The neuston net caught 110 larvae vs. 29 in the meter net towed with the top of the rim just above the surface; volume swept by the meter net at 2.5 knots was about 2.5 times that swept by the neuston net at 5 knots. Only 3 larvae were caught in the Isaacs-Kidd and bongo nets towed stepwise oblique from bottom to 2 m below surface (Stasko 1977). In the series of 13 cruises off southwest Nova Scotia in 1977, using only results from paired neuston and 1-2 m depth meter net tows, the meter/neuston catch ratio per equal volume strained was 0.09 (Stasko, unpubl.).

Tabulation of the ratios of larval catch rates in deep vs. surface tows (Table 3) illustrates the general rapid decrease in abundance of lobster larvae below the surface even at a depth of less than a meter.

DISCUSSION

Considerable work has been done on lobster larvae in the Gulf of St. Lawrence and in Newfoundland waters. In the Bay of Fundy and Atlantic waters off Nova Scotia successful larval surveys were begun in 1976. The larvae are concentrated in surface waters, abundance declining rapidly even at less than a meter depth. Early-stage larvae constitute the majority of larvae caught in the Gulf of St. Lawrence and in Newfoundland while off SW Nova Scotia and on Georges Bank the majority were late-stage larvae.

Estimates and comparison of abundance and survival of larvae at different locations are as yet in the early stages of development. Among the more significant difficulties to resolve are comparability of sampling gear and towing speeds; lack of knowledge about what percentage of larvae in the total water column is being sampled; lack of knowledge about settling time in terms of days into stage IV at changing temperatures, and about temperature history of stage IV larvae being sampled (Templeman 1936a); patchy geographical distribution of larvae offshore, and changing microdistribution of larvae inshore in response to changing environmental conditions (availability to sampling); and long-distance transport of larvae in surface currents.

ACKNOWLEDGMENTS

The manuscript was reviewed by D. J. Scarratt, G. P. Ennis, and D. E. Graham. Figures were prepared by P. W. G. McMullon.

REFERENCES

Aiken, D. E. 1977. Molting and growth in decapod crustaceans with particular reference to the lobster *Homarus americanus*. Pages 41-73 *In* B. F. Phillips and J. S. Cobb (eds.), Workshop on Lobster and Rock Lobster Ecology and Physiology. CSIRO (Australia), Div. Fish. Oceanogr. Circ. 7, 300 p.

Bumpus, D. F., and L. M. Lauzier. 1965. Surface circulation on the continental shelf off eastern North America between Newfoundland and Florida. Serial Atlas of the Marine Environment, Folio 7. Am. Geogr. Soc., N.Y.

Caddy, J. F. 1976. The influence of variations in the seasonal temperature regime on survival of larval stages of the American lobster (*Homarus americanus*) in the southern Gulf of St. Lawrence. ICES Special Meeting on Population Assessments of Shellfish Stocks, Paper 10, 40 p.

Ennis, G. P. 1975. Behavioral responses to changes in hydrostatic pressure and light during larval development of the lobster *Homarus americanus*. J. Fish. Res. Board Can. 32: 271-281.

Graham, D. E., and D. G. Wilder. 1966. Offshore lobster trap fishing, July 13 to August 19, 1966. Fish. Res. Board Can. MS Rep. (Biol.) 896, 16 p.

Groom, W. 1978. Interim investigation of lobster stock, size and migration system of lobster population in the Grand Manan Region. N.B. Dept. Fish. Rep., 69 p.

Harding, G., P. G. Wells, and K. Drinkwater. 1979. The distribution and abundance of lobster larvae in St. Georges Bay, Nova Scotia, in 1975 and 1976 and the possible effect that the Canso Causeway has had on Chedabucto Bay lobster fishery. *In* Fish. Mar. Serv. Tech. Rep. 834, Part 3.

Legaré, J. E. H. 1961. The zooplankton of the Passamaquoddy region. Fish. Res. Board Can. MS Rep. (Biol.) 707, 37 p.

Leim, A. H. 1936. Herring gulls and lobster larvae. Atl. Biol. Sta. Ann. Rep. 1936, App. 44, 1 p.

McKenzie, R. A. 1966a. Offshore lobster investigations, 1965. Can. Fish. Rep. 6: 4-32.

1966b. Canadian Atlantic offshore lobster and red crab investigations, 1966. Fish. Res. Board MS Rep. (Biol.) 895, 35 p.

Scarratt, D. J. 1964. Abundance and distribution of lobster larvae (*Homarus americanus*) in Northumberland Strait. J. Fish. Res. Board Can. 21: 661-680.

1968. Distribution of lobster larvae (*Homarus americanus*) off Pictou, Nova Scotia. J. Fish. Res. Board Can. 25: 427-430.

1969. Lobster larvae off Pictou, Nova Scotia, not affected by bleached kraft mill effluent. J. Fish. Res. Board Can. 26: 1931-1934.

1973. Abundance, survival and vertical and diurnal distribution of lobster larvae in Northumberland Strait, 1962-63, and their relationships with commercial stocks. J. Fish. Res. Board Can. 30: 1819-1824.

Smith, G. F. M. 1937. Plankton tows for lobster larvae 1937. Biol. Board Can. MS Rep. 193B, 4 p.

1938. The distribution of lobster larvae. Atl. Biol. Sta. Ann. Rep. 1938, App. 43, 1 p.

1939. The distribution of lobster larvae. Atl. Biol. Sta. Ann. Rep. 1939, App. 46, 1 p.

Squires, H. J. 1965. Decapod crustaceans of Newfoundland, Labrador and the Canadian eastern Arctic. Fish. Res. Board Can. MS Rep. 810, 201 p.

1970. Lobster (*Homarus americanus*) fishery and ecology in Port au Port Bay, Newfoundland 1960-65. Proc. Nat. Shellfish. Assoc. 60: 22-39.

Squires, H. J., G. E. Tucker, and G. P. Ennis. 1971. Lobster (*Homarus americanus*) in Bay of Islands, Newfoundland, 1963-65. Fish. Res. Board Can. MS Rep. 1151, 58 p.

Stasko, A. B. MS 1977. Lobster larvae on Scotian Shelf. CAFSAC Res. Doc. 77/31, 10 p.

Templeman, W. 1936a. The influence of temperature, salinity, light and food conditions on the survival and growth of the larvae of the lobster (*Homarus americanus*). J. Biol. Board Can. 2: 485-497.

1936b. Habits of larval lobsters in nature. Atl. Biol. Sta. Ann. Rep. 1936, App. 43, 1 p.

1937a. Habits and distribution of larval lobsters (*Homarus americanus*). J. Biol. Board Can. 3: 343-347.

1937b. Capture of lobster larvae. Atl. Biol. Sta. Ann. Rep. 1937, App. 45, 1 p.

1939. Investigations into the life history of the lobster (*Homarus americanus*) on the west coast of Newfoundland, 1938. Nfld. Dept. Nat. Resources, Res. Bull. (Fish.) 7, 52 p.

Templeman, W., and S. N. Tibbo. 1945. Lobster investigations in Newfoundland 1938-1941. Nfld. Dept. Nat. Resources, Res. Bull. (Fish.) 16, 98 p.

Wells, P. G. 1976. Effects of Venezuelan crude oil on young stages of the American lobster, *Homarus americanus*. Univ. of Guelph, Canada. Ph.D. Thesis, 241 p.

Wilder, D. G. 1953. The growth rate of the American lobster (*Homarus americanus*). J. Fish. Res. Board Can. 10: 371-412.

1972. Cultivation possibilities for lobster conservation and management. Oceanol. Int. 72: 87-90.

Wilder, D. G., and D. E. Graham. 1973. Offshore lobster trap fishing July 10 to August 10, 1972. Fish. Res. Board Can. MS Rep. 1236, 24 p.

Wilson, A. J., and D. G. Wilder. 1967. Lobster trap fishing on Georges Bank and Seal Island grounds August 14 to September 20, 1967. Fish. Res. Board Can. MS Rep. 948, 15 p.

LARVAL STUDIES AND RECRUITMENT INDICES
(D. G. Robinson, rapporteur)

Anthony: Is there one season of the year when you catch more larvae than others?

Stasko: In southwestern Nova Scotia and offshore areas, we sampled from late June to mid-September. At the beginning and at the end we caught practically nothing. The larvae were most abundant from the latter part of July through August. In the Northumberland Strait area larvae were present for a longer period.

Scarratt: Larvae occur from mid June-late September in Northumberland Strait.

Clark: I think this distribution of stage I through IV larvae is very peculiar. How long does it take a lobster larvae to go from stage I to stage IV?

Stasko: Depending on the temperature, as little as 20 d to as much as 3 mo (rapporteur's note: at about 20 and 10°C, respectively (Templeman 1936)).

Scarratt: You're certainly getting behavioral changes as the lobster matures. You could quite easily get lobsters that originate more or less at random over large areas and have piled up in windrows or in localized gyres. They are longer in stage IV and are available to the net for a longer period, so that you get an inflated value of their abundance then. If the larva is going to be there twice as long you have got twice as many chances of catching it - hence, your values are doubled. Now we have to modify that slightly because fourth stage larvae are not in the surface waters for the full time "in stage." I think they go down about half the way through or two-thirds of the way through.

Clark: Jim, what size area are we talking about in your larval sampling? Where were you sampling?

Fair: The upper part of Buzzard's Bay, a fairly restricted area, subject to almost constant and strong SW wind driving the larvae up against the eastern shore. That is where we got the big catches. Sampling was conducted over the entire period the larvae are up.

Caddy: I think you had the same experience in Newfoundland, Gerry (Ennis) - piling up of larvae against the shore?

Ennis: Yes. Have you any ideas on what happens to the larvae after they disappear when the wind changes?

Fair: We never caught any appreciable numbers of larvae when the wind was offshore. If the wind switched for a couple of days and blew onshore, we would start picking up larvae. We were sampling the entire water column and got very small numbers in the subsurface layers.

Ennis: Our experience has been that with onshore winds we get many larvae in the nearshore area and very few beyond a quarter of a mile from shore. As soon as the wind turns offshore they virtually disappear, and the sorts of numbers downwind suggest it is not downwind dispersal that accounts for the disappearance near the shore. We have not been able to find them below the surface either, in the nearshore area. We cannot figure out what happens to them.

Caddy: If you had 10 larvae dispersed under each square meter in a 50-fath column, what is the probability of hitting a larva anywhere in the water column? It is almost an impossible sampling problem.

Anthony: It sounds very logical that when the wind blows the wrong way they drop in the water column somewhere. When the wind blows in the right direction they come up to the surface again.

Caddy: The problem gets a little more difficult when you move offshore and then your question is how do they know that they are getting off station if they do not have a bottom reference point.

Anthony: I think the whole thing is if they are doing it, why are they doing it? - they are obviously doing it to take the wind to the shore - they are drifting shoreward.

Robinson: There was a study reported at ICES this year on crab larval distributions with time on the east coast of England. There was an apparent lack of obvious trend in movement from stage to stage with time. This tends to reflect the data Aivars (Stasko) showed us for lobster larvae, in that we are finding stage IV over an area where brood stock is caught and not in areas where brood stock does not exist - which suggests maintenance of position. In the English study, sequential sampling of stage I to V+ megalopa indicated there were no apparent large-scale movements of the concentrations of larvae even though there are surface and residual currents.

Scarratt: I think that could be a little misleading because our experience in Northumberland Strait has shown that the very area where we did get concentrations of stage IV larvae was over the one part of the area which was recognized as the spot to go to find small lobsters and there were never any large lobsters seen there - certainly no brood stock. I do not think you can draw a generalization from those comments.

Robinson: There are two points with respect to your comment: 1) our analyses of relative fecundity for the Northumberland Strait population and inshore Maritimes populations, in general, consistently indicate that the majority of eggs are produced by the smaller, but much more numerous, lobsters. The large lobsters are more important as individuals but, because of their rarity, account for a relatively small percentage of total egg production. Thus the "brood stock" is dominated by relatively small lobsters in the early stages of maturity, which reflects the ubiquitous high fishing mortality rates; 2) Northumberland Strait, in relation to the areas represented by the two studies I referred to, is a smaller, semi-enclosed, shallow area which overall is a good juvenile nursery. The generalization which may be emerging is that larvae may have some ability to keep from being swept offshore in an open-coast area, or "off-location" in an outer-bank area. The question is still whether these data represent a real phenomenon or an artifact of the statistics of sampling referred to earlier by Caddy.

Van Engel: There was a comment earlier that you do not get lobster larvae in a strong offshore wind. If they are surface organisms, they may be washed out - may be passively helpless drifters away from where they have been produced to areas where they may be lost completely unless they have an onshore wind.

Anthony: I cannot believe that they are passive in the water column, that they just drift where the current says they have to go. It is obvious in some of the studies here that when the wind blows in the wrong direction they move down the water column. As far as I can make out herring larvae do the same thing and we now know that they select currents in the water

column to move on. If lobster larvae have this ability they must have this ability for some reason and perhaps they do it to select the water column, the drift that they want to move on, to move in a certain direction. Normally they do not have to go down to deeper water. They want to ride the surface if the wind is shoreward. When there are times that you cannot find them, it may be because the current is going in the opposite direction to shoreward. They are moving up and down and selecting the transport that they want.

Caddy: Oceanographic observations offshore suggest that wind-driven currents fall off rapidly below a certain rather limited depth. In other words, if a larva "wants" to stay in one place in a wind-driven current system, it does not have to go down too far to remain relatively stationary unless there is a residual current.

Thomas: That would imply that short-term phenomena are more important than long-term ones.

Fair: I have to repeat that we sampled intensively subsurface, making use of the same net opened and closed by messengers so we sampled a discrete level. The larvae are not there. When they are not at the surface they are not subsurface either. Instead of a migration downward in the water column, I firmly believe they are being transported offshore. It is very clear in a closed bay where all the larvae are concentrated on one side where the prevailing wind blows and they are not on the other side.

Scarratt: Has anyone else tried to look at specific places in the mid-water column? Work in the lab showed that when lobsters did drop down in the water toward the end of the stage they would tend not to go through a very sharp thermocline. I tried to fish on the thermocline and we came up with nothing. Has anyone else tried this? This is one place where you might look.

Fair: We sampled the entire water column from bottom to top at 5-ft intervals and did not find any.

Caddy: Can Vaughn summarize where we are so far?

Anthony: We'll try a couple of things and see if we can get over this. We can perhaps conclude two things: 1) that berried females are known to make directed migrations in order to hatch their eggs in an environment that seems to improve the survival of the larvae; and 2) can we assume that lobster larvae drift in a "directed manner" to also increase their probability of survival and to get them into shallow water?

Fair: Vaughn, I could not agree that the females make a directed movement that puts them in a position to release the larvae favourable to larval drift towards shore, and I would not agree with the latter part of it. These females are apparently making some type of - you could stretch it to say reproductive migration, but it is either something to do with the release of the larvae or with the coming molt of the female. We are not saying that would put them in a position to allow the release of the larvae for drift towards shore. I do not think that is an essential element. (General sounds of agreement)

Anthony: I will go along with that then. The migrations that you see seem to be inshore into shallow areas; the berried females move up into Georges Bank in the summertime. In Grand Manan in the summertime, they move into shallow water; over and over you hear about the berried females moving shoreward in the summertime prior to hatching out their eggs. They seem to move into shallower water, onto shoals, or shoreward, probably for warmer water or for some reason having to do with the release of the larvae or where the larvae are going to grow or survive better.

Anthony: I think there may be a third conclusion we can talk about, the conclusion that in a system like the Gulf of Maine, the inshore ground can be a nursery ground for juvenile lobsters and that, when lobsters become mature, they tend to move to offshore areas where they remain as adults and produce larvae and the larvae are carried shoreward to produce a cycle.

Caddy: To my knowledge attempts to discriminate sub-stocks of lobsters around the Atlantic coast have not been successful in picking up separate genetic units. Does anybody know of any evidence that there is genetic isolation from studies such as biological tags? Is there any evidence that we have discrete populations which do not mix with each other?

Stasko: Saila did a comparison from different areas based on morphometric characteristics, something like 16 measurements on each animal and concluded that there is more difference along the coast between areas than there is between inshore and offshore.

Caddy: Any other comments on this aspect? I think it is very important that we try to pin this one down because on the one hand we have an idea that suggests there are distinct population subunits but the studies I have seen on trying to identify amino-acid groupings seem to show that there are not discrete offshore and inshore stocks.

Anthony: I do not think we have any evidence to indicate there is any difference between the inshore and offshore stock. As a matter of fact, it is the other way around. What evidence we have got indicates that they are one and the same. I think we have tagging evidence that is overwhelmingly in support of this.

Caddy: In relation to Mike Dadswell's hypothesis, that a series of discrete sub-stocks or "cells" exist along the Atlantic coast, I think that Mike will have to admit that his hypothesis, in particular, the concept that drift through the Canso Causeway was responsible for all southeastern Nova Scotia recruitment, is not unanimously agreed to by Canadian scientists. It is pretty hard to prove something that happened 25 yr ago. There was an exhaustive series of meetings on this and Mike's point of view was one point of view and to be fair, it did not gain widespread acceptance. The cell concept may well have some advantages in defining management units but, in the case of the east coast of Nova Scotia and the collapse of the fishery there, there are other factors to consider.

Stasko: The decline of larvae, overfishing, and kelp beds all came at the same time.

Roach: From work I have done in the area, I found that along with the initial decline there was a change in the effort of the fishermen. They started using large-ring traps. This might border on the refugia we have been talking about. But from the late 1950's through the 1960's the percentage of gear went from about 5-50% into large-ring traps, and there were tremendous numbers of jumbo lobsters from 5-15 lb landed in the 1960's both in Richmond and Guysborough Counties. So the fishery has cycled in its history. But this is one change

in the effort pattern that might eliminate any possible rebound. The landings in the 1970's of these jumbo lobsters are down considerably, suggesting that the brood stock of large lobsters is severely depleted.

Caddy: There is one other point: based on the rate of drift of current from the Canso Causeway, if we follow Mike's postulate, the larvae could certainly have arrived in southwest Nova Scotia in one generation. There would not have been any reason to postulate several generations.

Morrissey: Also the failure is going from Richmond Co. in the west to the east around Cape Breton Co., so the current does not really explain that. It seems to me that when you get down to examining a situation like this you try to assign a cause of the collapse to a particular event when, in fact, it is probably a combination of events so that all of these things probably apply. From my point of view, it seems to me that we are talking about fishing mortality rate being very high. The effect of high fishing mortality rate is to set the stage - it is a basic factor - it reduces the resource to a point where, by itself or when in combination with other factors, you will get a resource collapse. These are the sorts of things we have to keep in mind in these theories.

Robinson: That is it exactly.

Anthony: Can we conclude anything about tagging, migrations, and movements?

Voice: I think we can conclude that along the western Gulf of Maine there is a general southwesterly movement. I also think the tendency is for lobsters to move offshore to deeper areas.

Anthony: Let me try this. The Canadians have indicated that there is a movement of larvae at least from Browns Bank shoreward. Is that correct?

Stasko: We are indicating that larvae exist throughout that area and that there are surface currents moving northward. We are postulating, on the assumption that there is passive drifting, that the larvae from Browns and perhaps Georges move towards the Nova Scotia coast.

Scarratt: I postulated that Kouchibouguac Bay (western Northumberland Strait) is basically fed by larvae coming down from the mouth of the Miramichi. I think Paul Montreuil is suggesting that the larvae around the Magdalen Islands are hatched on the one side and tend to be deposited on the other. I think there are a number of statements that suggest we recognize that larvae are being moved.

Robinson: I am postulating that central Northumberland Strait may be supplied by larvae that hatched in the western part of the Strait (Lobster District #8).

Anthony: We know from tagging experiments that large lobsters migrate in a particular direction. Can we then postulate that there is a counter-clockwise circulation in this area (Gulf of Maine) of large lobsters moving to the offshore areas and larvae moving back to the shore in some way? We all know that there is a seasonal movement, but there is also a directed movement associated with berried females as well.

Scarratt: I would prefer to talk about the type of wording where Vaughn was at the beginning when he was leaving offshore out of it and talking about directed movements in one way or another without specifying offshore and onshore and the fact that the larvae seem to be transported.

Caddy: It is gratuitous to say that the movement is counter-clockwise at this point. Some Grand Manan tags have also been found further up the Bay of Fundy, and also in southwest Nova Scotia.

Anthony: Okay. He (Scarratt) has a point there, because you know they are definitely along the shore. What we see along the shore tends to be counter-clockwise but it could be going offshore in the long run - very true. Can we make this statement? Can we agree that larvae seem to drift in a directed fashion?

Robinson: We have no data that suggest they drift in a directed fashion.

Anthony: I think we do.

Caddy: I think we can make a hypothesis that they do - let us not nail all of these thoughts down on the basis of what little data we have.

Robinson: Okay. We need more data.

Morrissey: I would like to see some specifics in there somehow - mention of larval drift and some general statement on the movement, the counter-clockwise movement, along the the Maine coast. I think there is something very significant here - this link to the offshore stocks and the whole problem of overexploitation. We have a two-edged sword. On the one hand we are worried by exploitation in offshore areas and yet we are increasing effort in inshore areas very significantly in the past few years and mortality has gone up very significantly. It looks as if we are levelling a two-edged sword at lobster stocks in the way of recruitment to the offshore area as well as exploiting offshore areas and affecting recruitment to the inshore. This is a significant idea.

Robinson: The Gulf of Maine is a system. I suspect that basically we are looking at the Gulf of St. Lawrence system, especially the southern Gulf, and we are also looking at the Gulf of Maine system. Somewhere along the outer coast of Nova Scotia there is perhaps an interaction or perhaps it is a third system. Perhaps Newfoundland is isolated and perhaps it is not. I think the systems are much bigger than we have tended to think.

Caddy: Just on that point - Paul (Montreuil) mentioned yesterday that Anticosti Island has a significant population of lobsters. Now where are the larvae from there going? We could be talking about a large system.

Montreuil: They must contribute something to the system. The Gulf is a system - a complex one.

Caddy: I personally cannot see us talking about population "cells" much smaller than that.

Robinson: This is the point. The north Atlantic could be hypothesized as a cell but that is obviously ludicrous. We do have these two rather large lobster production areas that seem to show some very, very strong internal relationships in events that have occurred: the Gulf of Maine events, the Gulf of St. Lawrence events.

Anthony: Can we conclude that as lobsters get larger they tend to move to deeper water? (long pause)

Voices: Would not like to be committed on this point.

Robinson: Can we say that generally there is evidence, anecdotal or otherwise, that suggests that there is a tendency to be in shallow water as small sizes and in deeper water as larger

sizes? Our fisheries reflect the recruit sizes which are juvenile lobsters.

Caddy: Yes.

Montreuil: The Magdalen Islands is a case that would support this. The observation has been made that the smaller lobsters are in the southern area and larger ones on the northern bank. At the very beginning of the lobster fishery there in the late 1800's, the same thing prevailed. It was predicted as a result that the canneries could not operate on the north side of the island, and this is also true today. The canneries were on the south side and they still are.

Robinson: We have to remember that there is a tendency for the more productive areas to be inshore, and thus have more juveniles and more fishing pressure. That does not mean that big ones will not stay inshore when it optimizes say, hatching time of eggs.

Halgren: I will go along with that - that the females have a tendency to move in some direction when it is going to help the regeneration of the stock.

Stasko: I think we should not talk about 100% of any component of the population migrating. There is some movement towards deeper water with age but, in addition to that there must be a residual stock of large lobsters remaining in shallow water. Before 1900, the average size of inshore lobsters was of the order of 3 lb.

Caddy: We will have to be very careful because there are several things that have come up over the last few days that are confounding - like, for example, the fact that lobsters may be smaller inshore maybe because the fishery pressure is higher inshore than offshore. Can we really say that does not have some influence? I think we ought to use a little statistical common sense when we look at some of these things.

Anthony: Does anyone know of any offshore deepwater populations of small lobsters? - juvenile lobsters - less than 3 3/16 in.?

Many voices: Yes, yes!

Morrissey: Would it not be more accurate to say the evidence is that as adult lobsters become larger and as they approach maturity there is a tendency for them to become migratory, and this migratory behavior appears to have something to do with the reproductive mechanism of these populations? It seems to me that is all the evidence we have.

Caddy: I think we ought to break now. I realize we could talk at much greater length on this subject, but we are all deriving our own conclusions, and I am not sure that the data are good enough to support any one hypothesis at this stage.

CURRENT STATUS OF EUROPEAN LOBSTER MANAGEMENT

by

D. B. Bennett

Ministry of Agriculture, Fisheries and Food
Fisheries Laboratory
Remembrance Avenue
Burnham-on-Crouch, Essex CMO 8HA, England

ABSTRACT

Bennett, D. B. 1980. Current status of European lobster management. Can. Tech. Rep. Fish. Aquat. Sci. 932.

In many traditional inshore European lobster fisheries catches and catch rates have fallen. Present-day regulations are few in number, based mainly on the use of the minimum landing size (74-83 mm carapace length). Other regulations in some countries include protection of ovigerous females, closed seasons, a ban on diving, lath spacing, trap limits, unlimited entry licensing and sanctuaries.

Many of these regulations have no clear conservation or management rationale. Recent stock assessments conclude that the size of first capture should be increased above the size at first maturity and fishing mortality should be reduced by limited entry licensing, together with pot limits.

INTRODUCTION

Fisheries for the European lobster, *Homarus gammarus* (L.), have existed for several hundred years. In the early years stock abundance was high and exploitation rates were low, but eventually the need for management regulations was recognized and some of the existing regulations have their origins in the nineteenth century. Despite this long historical experience, the present-day regulations are few in number and fairly simple in their application. In this paper it is intended to summarize the state of the stocks, the existing regulations, and their rationale (if any and if known), and to look at possible future management strategy.

STATE OF THE EUROPEAN LOBSTER STOCKS

The total recorded catch of the European lobster is around 1,800 tons, about 6% of the catch of the American lobster. In Europe the catches from the well-established fisheries in Norway, Sweden, and Denmark have fallen alarmingly from a combined annual average in 1950-59 of 1,059 tons to 183 tons for 1970-77 (Table 1). The catches from the east coasts of Scotland and England, Orkney and Shetland (Scotland) have also decreased substantially. However, the overall landings in some countries have been maintained or increased by the discovery of previously unexploited stocks (e.g. English Channel, west coast of Scotland) or by an increase in fishing effort (e.g. Ireland).

The overall catch is being maintained in some countries by the development of so-called "offshore fisheries," fishing previously unexploited stocks. However, these stocks, which when first fished give a high catch-per-unit-effort and initially support a high fishing intensity, are quite quickly fished down to a catch rate which is uneconomic for the larger boats. Thus, fishing effort on the offshore English Channel grounds is already, within 4-5 yr of their discovery, being switched to the west coast of Scotland.

The state of the stocks in Europe seems to be somewhat similar to those in North America. In the traditional inshore fisheries many of the stocks are declining, and catches and catch rates are falling.

REGULATIONS

MINIMUM SIZE

The main lobster regulation used in Europe is the minimum landing size. This is set at between 74-83 mm carapace length (CL), although in some countries total length (TL) is used as the method of measurement (Table 2). None of the size limits have been chosen following a yield assessment. Some are believed to have been chosen in relation to size at maturity. Size at first maturity is about 80 mm CL for many European stocks! It is quite clear that the management of the majority of the stocks depends upon a minimum size which has little relevance to protection of the breeding stock and has not been (knowingly) set to optimize yield per recruit.

PROTECTION OF OVIGEROUS FEMALES

The landing of ovigerous (berried) females is banned only in Spain and in one area of Denmark (Limfjord) and in Portugal for a short period (Table 2). A ban on the landing of berried lobsters did exist in the United Kingdom from 1953 to 1966; there were two main reasons for removing it: (a) it was difficult to enforce due to removal of the eggs by scrubbing; (b) it could not be justified as being of benefit to recruitment as nothing was known about the stock-recruitment relationship.

CLOSED SEASONS

Closed seasons exist in Portugal, Spain, Germany, Norway, and Sweden (Table 2). Those in Portugal and Spain are during the winter period when fishing activity would be low anyway. The closed season in Norway is aimed at the protection of the breeding stock and the recently molted lobsters. In Sweden the closed season during the summer reduces fishing, particularly by hobby fishermen. A natural closed season in the winter exists in all areas due to bad weather and reduced catchability.

Table 1. European lobster landings (tons); source: Bulletin Statistique, ICES.

	Denmark	England and Wales	France	Ireland	Norway	Scotland	Spain	Sweden	All European countries
1970	22	491	324	277	202	602	47	71	2,108
1971	15	451	310	285	133	678	20	50	1,952
1972	16	429	373	221	161	585	16	43	1,893
1973	13	457	420	258	150	545	13	42	1,898
1974	11	377	336	253	140	600	12	38	1,825
1975	14	382	385	330	127	503	14	36	1,826
1976	12	348	328	370	116	531	29	33	1,852
1977	14	444	353	339	99	541		33	1,841
Averages 1950-59	126	439	573	234	743	690	40	190	3,078
1960-69	49	442	414	233	420	736	43	99	2,536
1970-77	15	422	354	292	125	573	22	43	1,899

Table 2. European lobster regulations.

Country	Minimum size (mm) CL	TL	Berried protected?	Closed season?	Other regulations?
England and Wales	80		No	No	None
Scotland	80		No	No	None
Northern Ireland	80		No	No	None
Ireland	83		No	No	Diving banned
France	(~80)	230	No	No	15 sanctuaries. Hatchery-reared juveniles released. Boats licensed. Lath spacing
Portugal	(~80)	200[a]	1 Jan.-1 Mar.	1 Oct.-1 Jan.	None
Spain	(~80)	200[a]	Yes	1 Sept.-31 May	None
Denmark	(~74)	210	In one area only	No	None
Germany	(~84)	240	No	15 July-1 Sept.	None?
Norway	(~77)	220	No	1 June-1 Oct.	None
Sweden	(~77)	220	No	15 June-20 Sept.(N) 15 July-15 Sept.(S)	Diving banned. Trap limitations. Lath spacing

[a]Eye socket to telson.

OTHER REGULATIONS

Diving as a method of capture is banned in Ireland and Sweden, mainly to prevent hobby fishing and to placate full-time trap fishermen.

Specially designed escape gaps are not in use in Europe, although France and Sweden do have lath spacing regulations.

The only attempt to limit fishing effort, other than by closed seasons, is in northern Sweden where trap limits of 40/1 fisherman, 75/2 fishermen, and 35/fishermen for more than 3 men/boat have been set.

Only in France is there a licensing scheme administered by the "Comité Interprofessionnel des Crustacés." This covers all full-time fishermen, but the number of licenses is unlimited. The main purpose of the license is the use of its suspension or withdrawal as a determinant in the enforcement of minimum size and closed area regulations.

France has pioneered the establishment of 15 sanctuaries on the Atlantic and Channel coasts. The purpose of these is the establishment of reservoir breeding stocks, berried lobsters having been purchased and released into the sanctuaries. In addition, hatchery-reared post-larvae and 1-yr-old juveniles have been released in certain areas. In 1977 approximately 172,000 post-larvae were released into three sanctuaries, and a similar number was released in 1978.

FUTURE STRATEGY

The present-day lobster regulations in Europe have evolved slowly without, in many cases, a clear conservation or management rationale. Recent increases in the level of fishing effort and efficiency have outstripped the usefulness of regulations brought into operation many years ago.

Crustacean biologists have faced particular difficulties in attempting yield assessments. However, in recent years more data have become available and they are beginning to carry out stock assessments which enable them to offer advice on the management of lobster stocks. Within certain constraints regarding the probable range of some parameter inputs to yield-per-recruit models, it is possible to conclude that for the majority of European lobster stocks the size at first capture is too low and the fishing mortality too high. Although the stock-recruitment relationship is not known, common sense suggests that in highly exploited fisheries the minimum size should be set above the size at maturity.

Future management strategy in Europe can be expected to include a general increase in size at first capture, the introduction of escape gaps, and the establishment of effort control by limited entry licensing, together with pot limits.

CHANGE IN MINIMUM SIZE LIMITS, GEAR REGULATIONS AND THE BERRIED LOBSTER LAWS IN THE U.S.

by

T. Morrissey

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Fisheries Management Operations Branch
State Fish Pier
Gloucester, MA 01930

ABSTRACT

Morrissey, T. 1980. Change in minimum size limits, gear regulations and the berried lobster laws in the U.S. Can. Tech. Rep. Fish. Aquat. Sci. 932.

The protection of berried female lobsters is traditional in the U.S. fishery, dating back to about 1878. At present, the taking of berried lobsters is prohibited by all the lobster producing states of Maine through North Carolina.

Although several states limit the number of traps which may be fished by non-commercial fishermen, trap limits have not been widely employed in the U.S. to regulate lobster fishing effort. Laws requiring the incorporation of escapement openings or vents in the construction of lobster traps are relatively recent in the U.S.; however, five states at present have venting laws and all the lobster producing states are committed to enactment of venting requirements by 1981.

To the present, minimum size limits in the U.S. have been enacted by the individual coastal states. Although there usually has been wide variation among the states in the size limits in effect at any time, social and economic factors have exerted considerable pressure for uniformity in the size limits among the leading producer states, in particular. At present, only three states have size limits smaller than the 3 3/16-in. CL limit in effect in the other lobster producing states. Under a plan adopted recently by the Northeast Marine Fisheries Board of the State-Federal Management Program, all the states are committed to be at 3 3/16 in. by 1981 and to thereafter consider annually whether to increase the size limits uniformly by 1/16 in. toward an optimum uniform size limit of 3 1/2 in. carapace length.

Restrictions on the taking of berried lobsters are among the first laws enacted to regulate lobster fishing in the U.S. Berried lobster laws traditionally have been favored by the U.S. fishermen above all other forms of regulation, and remain popular to the present. Beginning about 1878, when Connecticut enacted a closed season on egg-bearing female lobsters followed quickly by other New England states, berried lobster laws have spread among the various coastal states roughly in time with the geographic expansion of the lobster fishery. At present, the taking of berried lobsters is prohibited by all the lobster producing states of Maine through North Carolina, with the more southern states enacting such laws in the mid-1970's following the recent southward expansion of the fishery along the continental margin.

Until recently, gear regulations in the U.S. consisted mainly of prohibitions on the use of the otter trawl as a catching device for lobster or requirements that only pots or traps could be used. In some states, the use of strings or trawls of traps is prohibited or limited, usually on a small area (community) basis. Such regulations generally have been enacted only in the more northern, traditional lobster producing states. Although groups of lobstermen commonly have agreed informally to limit the number of traps they fish in an area, formal trap limits have not been enacted generally in the U.S. At present, three states limit the number of traps that may be fished by each non-commercial fisherman; only one state (Delaware) has imposed a limit on the number of traps that may be fished by each commercial fisherman. As the U.S. experience has been that trap limits have not been an effective means of limiting the non-commercial fishery, some states currently are giving serious consideration to establishing daily possession limits for recreational fishermen as an adjunct to the trap limits.

Regulations to provide for escapement of sub-legal lobsters from traps or pots apparently are relatively recent in the U.S. Connecticut and New York, acting jointly, implemented in the 1950's regulations requiring the incorporation of escapement openings in the construction of lobster trap gear. Within a few years, the requirement was dropped in New York at the behest of local fishermen who claimed it resulted in substantial loss of sea bass which provide an important bycatch for the lobstermen in that area, and the agreement between the two states was dissolved. In 1974, the Lobster Scientific Committee of the State-Federal program reviewed available information on trap-related lobster mortality, injury, and escapement and recommended enactment of regulations requiring venting of all pots and traps used in the lobster fishery. Subsequent to the recommendations of the Committee, regulations requiring the incorporation of escapement openings in the construction of lobster traps were implemented in Maine, Massachusetts, New Hampshire, Maryland, and North Carolina. Under a management plan adopted by the Northeast Marine Fisheries Board of the State-Federal Program in October 1978, all the lobster producing states are committed to enactment of escape vent requirements by 1981.

A variety of minimum size limits has been imposed on the U.S. fishery over the years. This is illustrated by the following table of size limits that have been in effect in Maine since 1874 when the first size limit was imposed in that state.

Minimum size limits in Maine

Year enacted	Size in inches	Comments
1874	10 1/2 TL	Total length. Measured from tips of rostrum or "beak" to tip of tail.
1883	9 TL	
1885	10 1/2 TL and 9 TL	Nine-inch minimum allowed only during special "canner season".
1895	10 1/2 TL	Seasonal 9-in. minimum repealed.
1907	4 3/4 CL	Carapace length. Measured from tip of rostrum to rear of body shell.
1919	3 1/2 CL	Method of measuring changed. New length measured from rear of eye socket to rear of body shell.
1933	3 1/16 CL	
1942	3 1/8 CL	
1958	3 3/16 CL	

Size limits in the U.S. have been enacted by the individual coastal states, and there usually has been wide variation among the states in the size limits in effect at any one time. Social and economic factors have exerted considerable pressure for uniformity and in the size limits among the leading producer states, in particular. During the 1950's, efforts were made to increase the size limits uniformly from 3 1/16 to 3 3/16 in. carapace length. These efforts met with limited success, and only four of the seven or eight states involved complied.

At the start of the State-Federal Program in 1972, two of the lobster producing states had no size limit, four were at 3 3/16 in., four at 3 1/8 in., and one state was at 3 1/16 in. At present, only three states have size limits less than 3 3/16 in. and one of these (Rhode Island) has implemented a program of size increases that will result in a 3 3/16-in. limit by 1981. Under the plan adopted by the Northeast Marine Fisheries Board, all the states are committed to be at 3 3/16 in. by 1981 and to thereafter consider annually whether to increase the size limits uniformly in 1/16-in. increments toward 3 1/2 in.

Currently, the New England Regional Management Council, established under the Fishery Conservation and Management Act of 1976, is developing a plan for management of the offshore fishery (i.e. the fishery beyond the territorial sea). It is anticipated the Council plan will contain minimum size limit recommendations compatible with those incorporated in the State-Federal plan.

GENERAL DISCUSSION ON EUROPEAN LOBSTER FISHERIES SIZE LIMITS, GEAR REGULATIONS, AND THE BERRIED LOBSTER LAW (S. Clark, rapporteur)

Thomas: How many European biologists are actively engaged in lobster research in Europe?

Bennett: Perhaps the equivalent of 10 full-time researchers or so - this is really a minor fishery and many that do work on lobsters have other commitments as well.

Anthony: How are lobsters caught in Norway - tangle nets?

Bennett: In Norway, lobsters are caught in pots. Tangle nets are used in Swedish and British fisheries but in Britain most tangle net effort is directed towards *Panulirus*.

Anthony: Lost gillnets appear to be very effective in catching lobsters.

Smolowitz: What is the basis for establishment of sanctuaries by France? Does this policy relate to the spawning cycle?

Bennett: My information on French policy is limited.

Clark: What is the current status of minimum size laws in Rhode Island?

Fogarty: Current feeling in the Rhode Island legislature is that a more conservative increment is needed than the 1/16-in. increment being used in other states. Rhode Island now has a 3 3/32-in. legal size; this will be increased to 3 1/8 in. on January 1. We will be using 1/32-in. increments.

Bennett: Do you have any enforcement problems?

Fogarty: We do, but a lot is left to the discretion of the conservation officer involved. By 1981 we hope to be in good shape here.

Morrissey: There has been talk of socio-economic studies relative to minimum size increases. We do not have a completed study on the impact of an increase to 3 1/2-in. minimum carapace length but a discussion paper has been prepared based on input from a variety of industry sources and other data. It concludes that a 3 1/2-in. minimum would not have a serious socio-economic impact but, to the contrary, substantial economic benefits could accrue to both the industry and the consumer from improved yield and improvement of the product.

Van Engel: It would appear that a stimulus is needed in some areas; speaking for Virginia, we have a favorable atmosphere for raising minimum size and would do so if other states took the initiative.

Robinson: Of course, you do not have the negative pressure that other states, e.g., Maine, might have.

Anthony: This is a good point. If some states were to unilaterally raise minimum size it would make it easier for Maine.

Morrissey: The problem here is that we would be asking certain groups of fishermen to throw back lobsters that others in neighboring areas could catch.

Anthony: Agreed. There are many problems here.

Bailey: Are your proposals for minimum size dependent upon biological or political considerations?

Anthony: Biological, of course. And, in fact, we are not even recommending a biological optimum; rather we are attempting to improve the situation by moving in the right direction. In any situation recommendations will depend on the management objectives that are being addressed and a wide range of factors have to be considered other than biological.

Montreuil: We had a rather interesting situation in the Magdalen Islands some time ago in which we proposed a substantial increase in minimum size. We marshalled support for this, pointing out potential short-term impacts and long-term gains, and the change was duly made. Fortunately we started the program at a favorable time, and there was no noticeable initial loss and in subsequent years there was a noticeable rise in yield. The fishermen felt that this change, in effect, saved their fishery. A report is provided in the 1954 Annual Report of the Quebec Department of Fisheries.

Roach: This information will be very valuable to biologists defending proposals for similar increases in other areas.

Montreuil: This only works when you are dealing with a self-sustaining population.

Morrissey: In response to a motion for a unilateral size increase to 3 1/2 in. for Massachusetts which was made at a Massachusetts Lobsterman's Association meeting some time ago, I recommended that Massachusetts should not act unilaterally. It was my concern that effects from other areas could result in failure of the measure.

Fair: The Massachusetts Legislature recently adopted a resolve to the effect that all states should increase minimum size limits simultaneously and we are working with other states to effect this.

Anthony: Actually, even if a few states do move ahead unilaterally, in the long run everyone will benefit.

Robinson: We must make two aspects perfectly clear. In the first place, we are certain that yield per recruit will increase and total yield from the resource will be improved. The other area involves the more complex question of stock-recruitment relationships; we can say that we are reasonably sure that we will be moving closer to age at maturity thereby improving recruitment prospects. We should point out, however, that mortality should not be allowed to increase at the same time as resulting gains from minimum size increases could be wiped out.

Caddy: I believe that some reference to maximum size is also needed. Perhaps it should be stressed that mortality on spawning stocks should not be allowed to increase. It would be very unwise to take off any existing maximum size limit until the minimum size limit is moved up to a safe level.

Anthony: We need to maintain present age composition of the spawning population - there should not be a push to increase minimum size and to do away with larger animals at the same time. In effect, we have no protection for large lobsters except along the Maine coast where the 5-in. maximum carapace length exists for territorial waters. This probably has little impact. Should we consider more effective regulations?

Stasko: For the Nova Scotia-Bay of Fundy area, we have just recommended that there should not be a seasonal change and that minimum size should be increased or, failing this, we should perhaps have a maximum legal size.

Fair: The danger here is that maximum size limits are politically acceptable and could be used by managers as a substitute for raising the gauge.

Anthony: We should remember that large lobsters in offshore areas which were formerly lightly exploited, are now exploited very intensively;

thus, we are depleting the spawning stock and in my opinion we are treading on very dangerous ground. In my judgment we need to provide better protection to our spawning population to provide a hedge against recruitment failure.

Briggs: There is some evidence for economic constraints on landing of larger lobsters in New York; the price drops (about 50¢/lb) above 3 lb.

Anthony: Of course, raising the minimum size to 3 1/2 in. gets us into the most highly priced "select" range, so we are upgrading the situation economically.

SCIENTIFIC RECOMMENDATIONS FOR MANAGEMENT

A. REVIEW OF POPULATION PARAMETERS

Unanimous agreement was reached that the following recommendation receive the highest priority for implementation:

1) Size limits. A significant increase in size limits is needed in all areas, both to increase the yield per recruit from the population (maximum yield/recruit is calculated to occur at 4-5 in. carapace length), and also to increase the size at first capture in heavily exploited fisheries to a point above the size at first female maturity. A number of biological criteria for judging the appropriate size limit were discussed, including: 1) size at first female maturity, and 2) the size limit (with current exploitation rate) that ensures that 50% recruited females can reproduce at least once before capture.

Increasing minimum size limits was regarded as the first priority, and the most successful long-term strategy for maintaining historical levels of recruitment and minimizing the real dangers of stock collapse with the current fishing regimes in some areas. However, it is recognized that in some of the most productive areas, the fishery has been almost exclusively on immature animals, and has probably relied on recruitment from areas outside the most heavily fished grounds. These unfished or lightly fished grounds ("refugia") which have not been heavily fished in the past (and often in somewhat deeper water than the juvenile fisheries) are in many cases now being exploited by larger traps with greater ring diameter of opening.

2) If it is planned to maintain these fisheries on the same basis as formerly, then (pending increase in minimum size limit to the point of partial maturity) some measures may be necessary to protect these former refugia from exploitation of the brood stock. Such measures may include an upper size limit, gear regulations limiting size at entry to the trap, seasons or closed areas when and where mature stock components are most vulnerable to exploitation.

3) Fishing effort levels. Recognizing that effort levels are well above the level giving a maximum sustained yield for most fisheries, and have been, and are continuing to rise, due to a combination of increasing number of fishing units (boats, gear), and technological improvements in gear and vessels, serious efforts should be made to reduce fishing mortality rates wherever possible.

B. EFFORT MEASURES, SURVEYS, AND STATISTICAL REPORTING

1) Escape vents. Escape vents should be incorporated into the trap design whenever possible in order to reduce injury and mortality to pre-recruit lobsters. The size of vent obviously depends on the minimum size limit, and the timing of introduction should be related to imminent size limit changes.

2) Ghost fishing. All traps should include, whenever possible, a biodegradable section or biodegradable links to prevent ghost fishing. (This problem is believed to be most serious in deep water.)

3) New regulations. Funds should be specifically allocated to carry out a cost-benefit analysis of new regulations introduced in the lobster fisheries, together with the impact of different levels of enforcement of new and existing regulations.

4) Compensation. The role of direct and indirect compensation payments (e.g. trap replacement schemes) in the lobster fishery and their impact on current attempts to reduce fishing effort in most fisheries should be a subject of bioeconomic study.

5) Research surveys. The role of research surveys as an independent tool for assessment of lobster populations has been greatly neglected in the past, while their value in the few cases where they have been introduced (e.g. ALBATROSS surveys) has been apparent. The value of research surveys is even more apparent for lobsters than for other species groups, since commercial catch statistics often exhibit an unacceptable margin of error, and are often incomplete. In Canada, surveys are essential to establish abundance indices in what are essentially very restricted fishing seasons.

6) Statistical reporting systems. Current statistical reporting systems, particularly in Canada, have not been designed for scientific management needs. No effort data are collected, and catch statistics have a significant amount of error. Changes to the reporting system are urgently required in some areas to ensure timely and accurate reporting. Effort data should be collected!

C. DEFINITION OF MANAGEMENT UNITS AND RECRUITMENT MECHANISMS

1) Tagging. In order to increase tag returns, a regular review of the size of reward is in order (currently $1.00 in Canada). U.S. and Canadian agencies carrying out new tagging experiments (state, federal, and provincial governments) should inform each other via a mailing list; and [through NAFO (formerly ICNAF)], inform foreign fishing fleets. The tag should bear a clear mailing address. Arrangements for reciprocal payments of rewards should be considered.

2) Management areas. Although our knowledge of stock interrelationships and boundaries is still in a rudimentary state, we now recognize that the geographical limits of many current management areas may not necessarily coincide with the true boundaries of the stock. A number of interrelationships are now being postulated (either by larval drift or adult migrations/dispersal), between a number of management areas. These interrelationships should clearly be taken into account in arriving at management measures within individual areas.

RESEARCH NEEDS

	Priority (H = high, L = low)
A. Population Parameters	
Growth:	
1. Further emphasis in growth studies should be focused on estimating and utilizing molt increment and molt frequency data. A comparison between molt rates and estimates based on tagging experiments is needed.	H
2. Multiple capture and release experiments along the lines of those of Gundersen should be encouraged.	H
3. Von Bertalanffy growth curves have advantages when calculating long-term gains but drawbacks when applied to seasonal fisheries. Nevertheless, estimates of von Bertalanffy parameters are missing for populations at several points in the geographical range of *H. americanus*, namely, the Maritimes and Quebec.	L
4. The effects of tagging and handling on molt increment and frequency should be further defined.	L
Mortality Rates:	
1. Evaluation of estimates of Z and F from tag data. These estimates may differ from those obtained from size frequency distribution analysis. These discrepancies should be resolved.	H
2. Evaluation of migration as a factor in apparent mortality.	H
3. Obtain or update estimates of mortality for offshore areas.	H
4. Evaluate magnitude of M for larvae and juveniles.	H
5. Evaluation of tag-induced mortality using double tagging/marking experiments and the development of analytical techniques for performing this evaluation.	L
6. Evaluation of differential mortality among males and females.	L
Yield Per Recruit:	
1. The effects of different growth models on the predictions of yield-per-recruit analyses would be desirable.	L
Maturity and Fecundity:	
1. A better understanding of the cycle of ovarian development and its relationship to the molt cycle is essential.	H
2. More accurate estimates of fecundity are needed for inshore lobster stocks around the Maritimes.	H
3. The frequency of occurrence of multiple broods from a single insemination should be explored in the field.	H
4. The AW/CL ratio should be detailed for all areas and its relationship to the 50% maturity size explored.	L
5. Estimates are needed of egg loss between extrusion and hatching.	L
6. The "cement gland" staging technique for predicting size at maturity should be developed as a field technique.	L
B. Effort Measures, Surveys and Statistical Reporting	
Gear Selectivity:	
1. Determine the area of attraction of a trap: are there synergistic effects in gear?	H
2. Determine the overall selection curves for types of lobster traps in current use.	L
3. What is the most effective escape panel for different types of traps, especially wire traps, in each specific fishery, to allow escapement after a few months if the trap becomes a ghost trap?	L

	Priority H = high L = low
Measures of Effort:	
1. Determine the best measure of effort for each area and each fishery.	H
2. Develop a standardized research trap for use in comparisons to other gear modifications.	H
3. It is recommended that Canada take steps to obtain complete data on fishing effort.	H
4. What are the effects of temperature on catchability?	L
5. Fishing power studies are needed to determine the relationship betwëen units of effort now in use and fishing mortality.	L
6. How have standard units of effort changed in effectiveness with time? There is a need to re-examine historical data.	L
Catch-effort Trends and Estimates of MSY - none identified.	
Research Surveys:	
1. Lobster bycatch data from Canadian groundfish surveys should be made available for comparison with U.S. groundfish surveys.	H
2. Monitor numbers of prerecruits, so the data can be used in studies of relationship with subsequent catch.	H
3. Intensify offshore surveys for lobsters, with new gear (traps) and changing seasonality if necessary, to the degree necessary to estimate abundance and mortality rate so that we can more accurately evaluate the effects of the offshore fishery.	H
4. Re-evaluate Canadian historical data on the relationship between prerecruits and subsequent catch.	L
Statistical Reporting Systems:	
1. We urgently need studies to evaluate the accuracy of the statistics we are getting.	H
2. Studies are needed to evaluate sampling designs and intensity to achieve various levels of precision.	H
3. We need better catch statistics in the offshore lobster fisheries in the U.S., and on the bycatch from other fisheries in the U.S. and Canada.	H
C. Definition of Management Units and Recruitment Mechanisms	
1. There is an urgent requirement for more detailed knowledge of surface currents (distribution, direction, speeds, temporal variations, etc.) in terms of effects they are likely to have in the distribution of pelagic larvae. The level of information should be sufficiently fine to achieve understanding of the mechanisms which control recruitment within stock units, and within larger "systems" like the Gulf of St. Lawrence and Gulf of Maine.	H
2. There is a need for behavioural work on lobsters: what factors underlie migration or dispersal of juvenile or adult lobsters?	H
3. We should try to get a clearer understanding of what environmental characteristics are sought by lobster at various stages of its life history.	H
4. We need more data on relative mortality with different types of tags (e.g. plastic vs. metal sphyrion), and on handling-related mortality, and on the behavioral effects of tagging and release.	L

SUMMARY

I. GROWTH AND MORTALITY

Estimates of von Bertalanffy growth equations, made from probability analyses of length modes and from tagging data, were compared from Virginia and the offshore waters of southern New England to Newfoundland. Problems of estimating growth from these two methods were discussed. The von Bertalanffy growth equation is not particularly suitable for describing lobster growth over its entire size range but it is acceptable and valid for preliminary studies of yield per recruit. However, most of the information available on growth is for immature lobsters and the change in growth rate upon reaching maturity is not well defined. Fishing mortality rates from Virginia to Newfoundland are extremely high for almost all lobster fisheries. Seldom were instantaneous rates of fishing found to be less than 0.5 and, generally, they were greater than 2.0. Natural mortality rates for lobsters, on the other hand, are considered to be very low, especially after recruitment. Mortality estimates have been obtained from tagging data and declines in catch per effort from molt group to molt group. The latter procedure depends heavily on an estimate of frequency of molting which varies greatly from fishery to fishery. Lobster migrations affect estimates of fishing mortality, and it is now recognized that they are very extensive in certain areas at certain times of the year.

II. YIELD PER RECRUIT

Yield-per-recruit assessments have recently been completed for lobster fisheries throughout the U.S., in Europe, and in several areas in Canada. The standard Beverton and Holt procedure with a von Bertalanffy growth equation as input has been adopted in most cases, but a model with a more biologically realistic growth curve derived from estimates of molt increments and molt frequencies has also been proposed. Both techniques show that yield per recruit would be greatly increased by large reductions in fishing effort and, in most fisheries, by increases in minimum size at first capture.

III. SIZE AT MATURITY

The size at maturity of lobsters varies regionally and appears to be associated with water temperature. The criteria for determining maturity are varied and a maturity index has not been standardized. In most of the U.S. and Canadian fisheries, the bulk of the lobsters caught are immature. In areas of warm water, such as in western Long Island Sound or the southern Gulf of St. Lawrence, some lobsters do mature and even carry eggs at a size less than the current minimum size allowed in the fishery. Although mating has been reported as much as several months after the female has molted, it almost always occurs within 24 h of the molt if a male of relatively similar size to the female is available. Males can mate with more than one female within a few hours, and most successfully when the male is slightly larger than the female. The laying of eggs may follow mating by as little as 1 mo or by more than a year, and may even occur if the female did not mate after the last molt. The 2-yr ovarian cycle appears to exist in lobsters even after lobster growth slows down, because recent evidence shows that two batches or broods of eggs can be fertilized from one mating. Fecundity increases logarithmically with size. Estimates of eggs per female range from as low as 150 eggs per female (reported for Long Island Sound) to over 100,000 at 200 cm carapace length. Approximately one-third of the eggs extruded die before they have an opportunity to hatch. The review of population parameters revealed that a considerable increase in knowledge has been gained since the last U.S.-Canadian workshop.

IV. GEAR DESIGN AND SIZE LIMITS

Because of the high levels of fishing mortality in nearly all fisheries, the subjects of measuring fishing effort, recording of catches, and the problems of gear selectivity were considered to be very important and comprised the second section of the workshop. Although Newfoundland has had required vent spacing in its traps since 1937, many of the states and other Canadian provinces have been reluctant to impose regulations allowing escapement of pre-recruit lobsters by use of a lath spacing. Recent studies in many states have shown that the use of proper size lath spacing will decrease handling damage to prerecruits and increase the catch per effort of legal lobsters. The U.S. State-Federal Lobster Scientific Committee recently recommended the use of such vent spacing in all traps. Restrictions on the maximum size of the entrance hoops in Canadian traps have been investigated recently in an attempt to prevent exploitation of large lobsters that may be providing significant progeny to an area. The problem of ghost traps has become important in recent years due to the significant increase in number of traps fished throughout both Canada and the U.S. With the wooden trap and vent spacing, ghost fishing might not be a great problem in the inshore areas. In offshore areas, however, where storms do not destroy lost traps and because of the steel and plastic traps used in these fisheries, the problems of ghost fishing and subsequent mortalities are considered to be significant. Biodegradable panels should be used in all traps to alleviate the ghost fishing problem.

V. LANDING AND EFFORT MEASURES

Many effort measures are currently being used by Canadian and U.S. scientists and this problem needs to be investigated further. Information on number of set-over-days, seasonal changes in catchability, and gear saturation was lacking in most areas. It was generally agreed that catch-per-trap-haul-set-over-days adjusted for seasonal changes in catchability was the best measure of abundance, using effort, but it was difficult to determine how much better this estimate was than other estimates now used elsewhere. The increasing number of traps fished in recent years may have significantly reduced their individual catchability due to area saturation. The size of trap and material of construction have also changed, and hoop size and lath spacing have been altered in many areas. In examining catch-effort trends over time and area, additional problems were voiced concerning the adequacy of the catch data themselves. In recent years in the United States, a greater percentage of the catch is going directly from the fisherman to the consumer, bypassing the dockside dealer. Landing statistics in most cases come from tabulation of dealer records; therefore, the landings in recent years have more and more underestimated the actual catch. Because of the problems in estimating catch and obtaining adequate measures of fishing effort, catch-effort trends over long periods of time are difficult to evaluate, but

estimates of maximum sustainable yield for the U.S. fishery were estimated at about 36 million lb. No comparative estimates are available for the overall Canadian fishery, but from information on historical catches in the late 19th century, sustainable yields of the order of 50 million lb seem possible, with size limits closer to optimum than at present. These levels are influenced by temperature trends and could only be achieved at a long-term level of fishing effort much less than current levels. Small increases in the allowable minimum size of lobsters landed would increase the yields considerably in both countries. Catch statistics in Canada and the U.S. are collected by a variety of methods. In Canada, log books are used to record catch and effort data for vessels in excess of 25 gross tons (GT). Purchase slips record catches at the buyer stations, and supplemental purchase slips are used to record sales made other than through dealers for vessels under 25 GT. Sales made directly from the fishermen to tourists are estimated. In the U.S. there are generally three reporting systems: through dealers, by annual submissions, and from trip reports by fishermen. Due to the high unit value, lobster landings data are among the least reliable in the United States. Fishermen, in the offshore fishery in particular, land at many small ports which are not covered by the U.S. reporting system. Many sales from the fishermen direct to the consumer go unreported. New Hampshire, Massachusetts, and New York use the annual reporting system as the major means of determining lobster catch statistics. Connecticut and, just recently, Rhode Island have adopted a detailed log book reporting system. New Jersey, Delaware, Maryland, Virginia, and North Carolina depend on the National Marine Fisheries Service trip reports at dealer locations for their catch statistics. Maine uses this procedure also, but has a three-man sampling crew that interviews fishermen at many dealer locations throughout the state. Detailed information from these interviews are then expanded to provide various catch and effort statistics. It was agreed that statistically valid methods of collecting statistics have not been given sufficient consideration by the states and federal governments. Large quantities of lobsters are caught routinely and retained in trawl fisheries, which generally go unreported because taking of lobsters by otter trawl is prohibited in nearly all areas except for offshore fishing. There was basic agreement that some system should be designed to provide total catch statistics in addition to other systems which could subsample and obtain special statistics such as rates of fishing, size frequencies, etc. The question of confidentiality and use of log book records for enforcement remains an unsolved problem.

VI. OFFSHORE FISHERY AND TRAWL SURVEYS

The offshore lobster fisheries have become more important in recent years as the effort has increased in these areas, and the U.S. has been conducting spring and fall bottom trawl surveys since 1963. From 1968-78 the relative abundance of lobsters in the mid-Atlantic declined by 17% and 46% in numbers per tow for spring and autumn surveys respectively, the southern New England states declined by 56% and 55% respectively, and Georges Bank increased by 79% and 12% respectively, depending on the survey used. The average weight of individual lobsters declined over the period 1968-78 by 17-42% depending on the survey and area involved, reflecting progressively higher rates of exploitation of the population. This offshore fishery is relatively new; the offshore trap fishery began in 1969 and overall catches peaked in 1971 at a level twice that sustained during the mid-1960's from the otter trawl fishery alone. These surveys indicated a shoreward movement in the spring of the year, with lobsters remaining in shallow waters until late in the fall when they move back to the deep canyon areas along the Continental Shelf. Canadian bottom trawl surveys exist only since 1970 for the Scotian Shelf and data are currently being extracted from these surveys.

VII. TAGGING AND MIGRATION

The tagging of lobsters was reviewed in an attempt to define movements and relationships between inshore and offshore lobsters. Extensive tagging studies have been conducted on lobsters since the turn of the century in both Canada and the U.S. These studies indicate that migrations of lobsters can be very extensive and directional, generally commencing with the onset of maturity. Immature lobsters do not appear to migrate extensively, although tagging studies on these lobsters have been in areas of high fishing exploitation so that the majority of tagged lobsters have been caught before they have had much opportunity to move. Early tagging experiments were conducted when fishing effort was very low in offshore areas so that all recoveries must have come from local inshore areas. Lobsters have migrated as far as 230 nautical miles in 14 mo, and in the Gulf of Maine the movement appears to be in a southwesterly direction from Grand Manan to Maine and from Maine to Massachusetts. This movement is very pronounced with very little coastal movement in the other direction. Well defined directional movements by egg bearing lobsters have been noted along Cape Cod. In Newfoundland, lobsters appear to be restricted to shallow waters with little migration from one area to the next. Migration appears to be restricted in the Gulf of St. Lawrence as well, apparently because only the shallow waters are warm enough to support lobster populations, thus affording no temperature advantage to migration. On Browns and Georges Banks and in the canyons to the south, however, a significant proportion of lobsters move to shallower water in spring and summer, returning to deep water in the winter.

VIII. LARVAL STUDIES

Lobster larval studies were reviewed by the lobster workshop in an attempt to understand movement of larvae in the surface water layers and perhaps define a source of recruitment to the inshore lobster populations. Lobster larval surveys have been carried out intermittently in Canada since the 1930's. Larval surveys in the U.S. are relatively recent and have become extensive in the mid-1970's in the Cape Cod Bay and Massachusetts Bay area. In all areas, lobster larvae were most abundant in the surface layers with the abundance declining rapidly even at less than a meter depth. Lobster larvae have been found consistently in the Gulf of St. Lawrence and Newfoundland areas for a great many years. There is little information on lobster larvae, however, in the U.S. north of Cape Cod, in the Bay of Fundy, and Nova Scotia to Cabot Strait, although surveys have been extensive in some areas. In those areas where lobster larvae have been discovered, the patchy distribution and general lack of knowledge about the biology of lobster larvae and its association with the environment have made it extremely difficult to reach conclusions on movements and recruitment.

IX. COMPARATIVE FISHERIES STUDIES

A general session of the workshop allowed comparative discussion on the lobster fisheries in Europe and the recent development of a State-Federal lobster management plan in the U.S. In 1975, ICES set up an *Homarus* working group which provided a vehicle for scientists in Europe as well as in the U.S. and Canada to meet and assess the status of their lobster stocks. The U.S. State-Federal Scientific Committee performed a similar function for scientists in the U.S. Mr. Bennett, the Secretary of the ICES Lobster Working Group, discussed the current status of European lobster management. Lobster stocks (*Homarus gammarus*) in Europe are much smaller than in North America, and the total recorded catch of European lobsters is only about 6% of the catch of the American lobster. Most stocks are overfished and harvested at an immature size, although in general, rates of fishing are much lower, and size limits are higher (in comparison to maximum size attainable), than in the northern Atlantic for *H. americanus*. Yield-per-recruit relationships with mortality and minimum size at harvest are very similar to those found in the U.S. and Canada. Regulations vary widely between countries, but show similar features to the U.S. and Canada, with minimum sizes for lobsters, and in some cases bans on Scuba diving, and regulations on gear design. One big difference in France is the use of sanctuaries as a means of maintaining a source of recruitment, and the fact that berried lobsters can be legally taken in some countries. Recent European stock assessment experts conclude, as in the U.S. and Canada, that the size at first harvest should be increased above the size at first maturity and fishing mortality should be reduced substantially.

Scientists from eleven U.S. states and the Federal government have been meeting over a period of years to prepare an overall management plan for the U.S. A draft of this plan has been prepared recommending several management measures. The traditional practice of protecting berried females was recommended to be continued. The plan prohibits the landing of lobster parts and meat and recommends vent spacing in all traps to allow the escapement of pre-recruit lobsters. Five states now have venting laws. All lobster producing states are committed to the enactment of venting requirements by 1981. Three states have size limits less than the 3 3/16-in. carapace limit in effect in the other producing states. The lobster plan[1] recommends an increase in the minimum size to 3 3/16 in. by these three states, and then an increase in minimum size towards the 3 1/2-in. minimum if socially and economically feasible in each state. This will increase the yield per recruit and allow an increase in the numbers of lobsters reaching maturity. Fishing effort is excessive in all fisheries and the Federal lobster plan recommends some means of reduction in the fishing effort. The State of Maine is the only state with a maximum size law of 5 in. carapace length and the only state that allows notching of females as a protection measure. The State-Federal management plan recommends that these two regulations be removed. General discussion on the 5-in. maximum law indicated that there are small areas in Canada where such a law would be advantageous due to concentrations of large females which are now being heavily fished, although the group strongly advised against the introduction of notching and return of large lobsters. The U.S. State-Federal lobster plan was unable to consider socio-economic analyses relevant to management suggestions as very few states have sociologists and economists available to work on this problem, although the need for these studies is quite apparent.

Considerable discussion on future research needs (Section C) and scientific recommendations for management (Section D) produced unusual agreement among the scientists who are working on a variety of lobster fisheries. The present levels of over-exploitation in the inshore lobster fisheries throughout Canada and the U.S. and the expanding offshore fishery in the U.S. raise serious questions as to the future viability of lobster stocks without appropriate and immediate changes in fishery regulations. Most important, size limits must be raised above size at first maturity in all areas, and effort levels for all fisheries brought more into line with those levels providing the maximum yield. The many difficulties faced by resource managers in accomplishing these two objectives were clearly recognized. However, there is a need for prompt and coordinated action between all parties concerned.

ACKNOWLEDGMENTS

The authors would like to express their thanks to Ruth Garnett for editing advice, to the St. Andrews Word Processing Unit and to Anne Williamson for compilation assistance, to P.W.G. McMullon and F.B. Cunningham for preparing a number of the illustrations, and to Therese Parker for the French translation of the abstract.

---

[1]Morrissey, T. D. (editor). 1978. American lobster fishery management plan. Prepared by the Lobster Sub-board of the Northeast Marine Fisheries Board. File MS. NMFS State-Federal Management Program, Gloucester, Mass.

APPENDIX

The Lobster REFUGIUM - A Definition

During the Canada-U.S. Workshop, frequent allusion was made to a rather helpful concept, but one which is not formally defined in the literature or in Webster's Shorter Oxford dictionaries. It seems appropriate to mark such a gathering of eminent lobster biologists as occurred in St. Andrews by allowing them to indulge themselves and invent at least one new word to be introduced into both the American and English languages (or at the very least, provide a new lease on life to an existing, but somewhat obscure and under-utilized word by some creative etymology!).

The word in question: A refugium - origin, Latin refugere to escape.

First, perhaps, a definition of what it is not, namely, a refuge. Most relevant definition in the Webster's New Collegiate Dictionary:

refuge: "A shelter or protection from danger or distress."

This is not fully satisfactory, in that it does not address the point that a refugium is:

a) a source of new recruits to the rest of the species range;
b) may be other than a spatial concept;
c) it also ignores the present use of the word refuge in marine ecology as either an underwater park, or an area (consisting of old automobile tires, and other relics of the machine age) used to induce fish, lobsters, etc. to congregate in an otherwise unsuitable terrain.

Refugium as a word already exists:

Present definition from Webster's Dictionary:

"An area of relatively unaltered climate that is inhabited by plants and animals during a period of continental climatic change (as a glaciation) and remains as a center of relic forms from which a new dispersion and speciation may take place after climatic readjustment".

Although the time span is obviously longer, and the ecological hazard more specific than in the proposed new usage of the word, the general meaning of a protected pool of genetic material is quite clear. An alternative, less specialized definition might be as follows:

Refugium: "A spatial or temporal enclave within the normal range of distribution of a species (elsewhere subject to catastrophic mortality prior to maturity), or a characteristic of the scheduling of harvesting mortality, which allows a proportion of the stock to survive to maturity and reproduce the population as a whole".

An example:

A refugium may have several components:

1) The distribution of fishing effort in the Bay of Fundy prior to the 1970's did not extend much below 15 fath. The offshore areas which are now found to contain significant numbers of mature lobsters may constitute a refugium, if larvae produced by this component contribute to recruitment in the inshore fishery.

2) We now believe that this offshore mature stock component moves onto the inshore grounds in the summer months and into deeper water in the winter months; thus, the summer closed season constitutes another part of the refugium as long as fishing in winter is on the inshore grounds.

3) The former use of traps with a 5-in. maximum entrance diameter did not allow entry of large lobsters to the gear; thus, was yet another component of the refugium.

In other words, the refugium not only consisted of the formerly unfished deepwater areas offshore from the main fishery for juveniles, but the seasonal closure of the inshore fishery between June and November, and the gear type used, were also essential factors contributing to the refugium.