SHARING THE WATERS: AN EVALUATION OF SITE FALLOWING, YEAR CLASS SEPARATION AND DISTANCES BETWEEN SITES FOR FISH HEALTH PURPOSES ON ATLANTIC SALMON FARMS

James E. Stewart

Science Branch
Maritimes Region
Department of Fisheries and Oceans
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia B2Y 4A2
Canada

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prepared for

The Department of Fisheries and Aquaculture New Brunswick
and
The Department of Fisheries and Oceans Canada

by

James E. Stewart

Science Branch
Maritimes Region
Department of Fisheries and Oceans
Bedford Institute of Oceanography
PO Box 1006
Dartmouth, Nova Scotia B2Y 4A2
Canada

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ABSTRACT

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This evaluation led to several clear conclusions. These were:

1) Fallowing and year class separation when coupled with Single Bay or Single Area Management are effective additions to fish health care and
2) the benefits from these three measures are fully realized only when they are joined to a basic set of sound farming practices and
3) none of the distances (mandatory or suggested) between sites in Norway, Scotland, Ireland, Chile and British Columbia are great enough to be barriers to the spread of infectious agents and the attendant diseases.

Fallowing has been shown to be effective in sea lice control by breaking the life cycle of the parasites and is believed also to reduce the problem of microbial diseases through removal of the host concentrations resulting in a decline in microbial pathogen numbers as well as benefits from flushing the area with clean water. Adding to the direct hazards of sea lice is the fact that they are apparent vectors for the spread of certain diseases. The fallowing periods recommended in the different countries range from 1 to 3 months; because of the cooler waters of the Bay of Fundy it is suggested that fallowing there would require at least two months to be effective against sea lice and that a three month period would be a safer provision.

A major problem with fallowing is that for it to work alternate sites are required, a production site and a fallowing site. In Norway each farm must have an alternate site; in Scotland farms routinely have 3-4 sites through which production can be rotated. Ireland is in the midst of resolving this problem.

Control of microbially caused diseases in Europe appears to have been achieved largely through ensuring that smolts, from strains selected for hardiness and rapid growth, are free of diseases and usually vaccinated before being transferred to seawater to avoid introducing pathogens in the first place and to offer protection against those which may already be present at the farm site. This plus good farm practice coupled with rapid confinement and eradication of developing disease situations have been the prime tools employed. Considerable effort has been focused on developing technology (nutritional and genetic) to accelerate growth thereby minimizing the period the fish have to be held at the farm site and as a consequence reducing exposure to disease and other hazards.

The data illustrate that specific distances should not be the prime measure for guarding against the spread of infectious diseases. The problems inherent in relying on distance for this purpose are summed up in the maxim "Share the water share the disease".

Limited mathematical modelling of the Passamaquoddy Bay region suggests that there may be several areas which are separated sufficiently to offer protection against the spread of infectious diseases. A final decision on this point should be based upon mathematical modelling of the area using a continuous insertion of suitable proxies for disease agents. Strategies involving full time or seasonal offshore/inshore rearing and fallowing rotations are discussed briefly. It is possible combinations of these strategies could be devised and applied with benefit to fish health in the Passamaquoddy Bay region of New Brunswick.

Résumé

L'évaluation a abouti aux conclusions suivantes :

1) La "mise en jachère" et la séparation des classes d'âge associées à la gestion par baie ou par zone contribuent efficacement à la santé du poisson.
2) Les avantages de ces trois mesures ne se matérialisent pleinement que lorsque ces dernières sont combinées avec de bonnes méthodes d'élevage.
3) Aucune des distances (obligatoires ou suggérées) entre les sites en Norvège, en Écosse, en Irlande, au Chili et en Colombie-Britannique n'est suffisante pour faire obstacle à la propagation des agents infectieux et des maladies concomitantes.

Parce qu'elle brise le cycle vital du parasite, la mise en jachère s'est avérée un bon moyen d'enrayer la propagation du pou du poisson; on croit aussi qu'elle permet une réduction des maladies microbiennes par le retrait des concentrations d'hôtes, entraînant une diminution du nombres de pathogènes microbiens et occasionnant un

curage bénéfique à l'eau propre. Outre les dangers qu'ils présentent directement, les poux du poisson sont des vecteurs apparents de la propagation de certaines maladies. Les périodes de jachère recommandées dans les divers pays varient de 1 à 3 mois; comme les eaux de la baie de Fundy sont plus froides, on pense qu'il faudrait au moins deux mois pour que la mise en jachère soit efficace dans la lutte contre le pou du poisson et qu'il serait plus sûr de l'étendre sur trois mois.

Un des grands problèmes de la mise en jachère réside dans le fait qu'elle nécessite un deuxième site, l'un devenant un site de production et l'autre le site en jachère. En Norvège, chaque exploitation doit disposer d'un deuxième site; en Écosse, les éleveurs disposent couramment de 3 à 4 sites, entre lesquels ils alternent la production. L'Irlande est en train de trouver des solutions à ce problème.

On semble avoir réussi à enrayer les maladies microbiennes en Europe essentiellement en s'assurant que les saumoneaux, provenant de souches choisies pour leur rusticité et leur croissance, sont exempts de maladies et en les vaccinant habituellement avant de les lâcher en eau de mer, ce qui permet d'abord d'éviter l'introduction de pathogènes dans le milieu et qui protège les poissons contre ceux pouvant déjà être présents dans l'exploitation. Cette façon de procéder, associée à de bonnes méthodes d'élevage, à un confinement rapide et à l'éradication des maladies naissantes ont été les principaux outils employés. Des efforts considérables ont été axés sur le développement d'une technologie (nutritionnelle et génétique) d'accélération de la croissance, qui permet de réduire la période de séjour du poisson dans l'exploitation et, partant, l'exposition de celui-ci aux maladies et aux autres dangers.

Les données illustrent le fait que des distances spécifiques ne devraient pas constituer l'élément premier de protection contre la propagation des maladies infectieuses. La maxime : "partage de l'eau, partage des maladies" résume bien le problème inhérent à cette façon de procéder.

Les modèles mathématiques limités dont on dispose sur la baie de Passamaquoddy indiquent que plusieurs zones sont suffisamment séparées pour offrir une protection contre la propagation des maladies infectieuses. Toute décision ultime à ce sujet devrait être fondée sur un modèle mathématique utilisant une insertion continuelle d'indicateurs adéquats pour les agents pathogènes. On discute ici brièvement de stratégies faisant appel à l'élevage continu ou saisonnier en eau côtière/eau de mer et aux rotations en jachère. Il est possible qu'on puisse combiner ces stratégies de manière profitable à la santé du poisson dans la baie de Passamaquoddy.

INTRODUCTION

This report was prepared in direct response to a request from the New Brunswick Department of Fisheries and Aquaculture and the Department of Fisheries and Oceans. Concern over the increasing incidence of fish health problems, in particular the disease designated Hemorrhagic Kidney Syndrome, led to the decision to conduct a study to determine the experience of other Atlantic salmon aquaculture producing countries in the use of site fallowing, single year class separation, site distances and related management practices. The conclusions reached at the 1997 meeting which led to the request are provided in the Background reproduced below followed by the Terms of Reference laid down to guide the study.

"Background:

The New Brunswick salmon aquaculture industry is concentrated in Charlotte County, with key growing areas in Lime Kiln Bay-Bliss Harbour-Back Bay, Passamaquoddy Bay and in the coastal areas of Deer, Campobello and Grand Manan Islands. At present, the eighty production sites produce about 16,000 mt of Atlantic salmon. The industry is therefore confined to a relatively small coastal region which has the essential environmental conditions required for salmon grow-out. Within this region, the area available to the industry must further take into account the requirements of other resource users such as the commercial fishery.

The separation distance between salmon culture sites is currently 324 metres. This was based on the scale of the industry a decade ago. There is concern that this distance is not adequate, given today's production levels and the increasing incidence of fish health problems (e.g. Hitra, sea lice and Hemorrhagic Kidney Syndrome[HKS]). Other salmon producing areas, particularly Norway, Scotland, Ireland and Chile, have demonstrated some success with the application of site management techniques that involve such measures as single age class separation and site rotation with fallowing.

There have been two main obstacles to the application of these site management principles in the Bay of Fundy: (1) the salmon growing area is relatively confined and the availability of new sites to accommodate such measures is limited; and (2) the extreme tides of the Bay of Fundy result in active water movement between all salmon producing areas, raising the question as to the merit of site isolation as a management objective under these environmental conditions.

At a New Brunswick Department of Fisheries and Aquaculture (NBDFA)/Department of Fisheries and Oceans (DFO) meeting following the August 14th (1997) meeting of the New Brunswick Minister's Special Advisory Committee for HKS, it was considered of importance to conduct a study to determine the experience of other Atlantic salmon aquaculture producing countries in the use of site fallowing, single year class separation, site distances and related management practices as a means of improving salmon health protection."

"Terms of Reference

This report would take the following into account:

1. The current status on the use of site fallowing, year class separation and distances between sites for salmon culture in Norway, Scotland, Ireland and Chile to address such questions as:

   a) is it mandatory for all operations to have a fallow site, year class separation and minimum distances?

   b) why are fallow sites, minimum distances and year class separation required (environmental quality, fish health, etc.)?

   c) has fallowing, year class separation and minimum distances been demonstrated to be of benefit for salmon health protection?

   d) are fallowing and year class separation a part of an annual site rotation process?

   e) are there any reports/information available that document the beneficial effects of fallowing, year class separation, and minimum distances between sites in terms of fish health?

   f) has the use of fallowing, year class separation and minimum distances between sites proven effective in controlling the incidence of bacterial or viral pathogens?

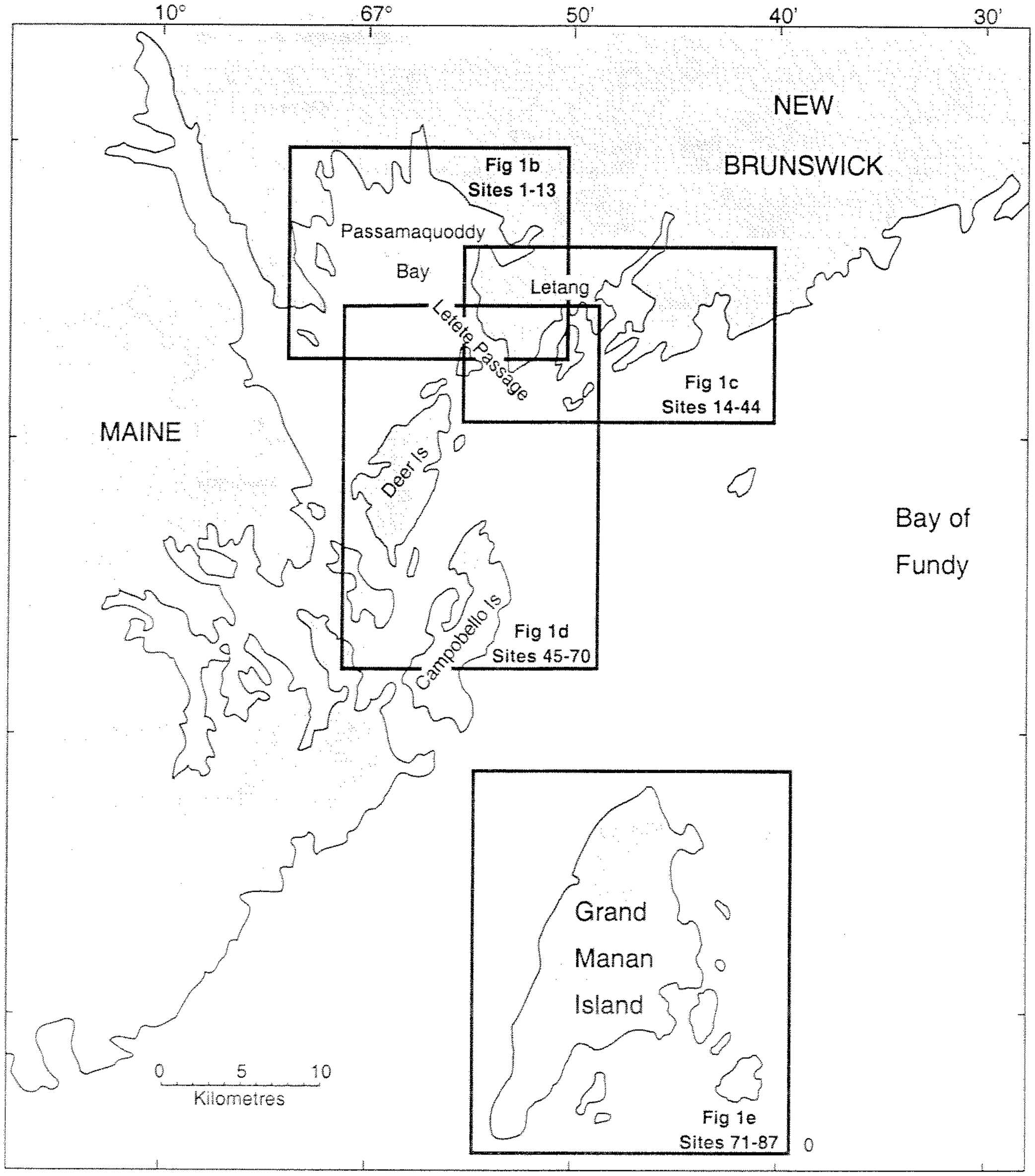
2. The report would be based on interviews with and documentation received from salmon aquaculture industry representatives and government officials responsible for fish health management and appropriate leasing authorities in those countries where fallowing, minimum distances and year class separation is a component of the site management regime. The objective of the inquiry is to determine the degree to which

fallowing, year class separation and distances between sites have been effective in the control of such pathogens as ISA, Hitra, sea lice, etc. and how this might have application to controlling HKS.

3. The report should provide an assessment on the potential benefits of applying the practice of fallowing, year class separation and distances between sites to salmon farms in the Bay of Fundy for fish health purposes, taking into account space availability for salmon aquaculture and the unique environmental characteristics of the area."

The geographical area of concern is the Passamaquoddy Bay and approaches illustrated in Fig. 1a-e in which the 1997 locations of the aquaculture farms are displayed. Accordingly a report fulfilling these Terms of Reference (TOR) was prepared and submitted in mid-November, 1997 to the New Brunswick Department of Fisheries and Aquaculture and the Canada Department of Fisheries and Oceans. The questions asked in TOR #1 were dealt with briefly in Section I followed by a more detailed commentary on specific points and additional considerations in the subsequent sections of the report.

As the material in the original report was considered to be of general use and applicability it was decided later to issue it, for wider distribution, in the form of this Canadian Technical Report of Fisheries and Aquatic Sciences. The original report was amended where necessary to conform to the Technical Report style and revised to clarify some points and, in several instances, to supplement the information.



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14	MF0333	32	MF0017	50	MF0320	68	MF0055	*86*	***MS0970***
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17	MF0276	35	MF0023	53	MF0057	71	MF0213		
18	MF0036	36	MF0025	54	MF0051	72	MF0368		

Fig 1a Overview of Passamaquoddy Bay and approaches, Charlotte County. New Brunswick. The area is subdivided in the following (Fig 1b to 1e) to show the location of the aquaculture farms (coded numerically in the box above). Source: New Brunswick Department of Fisheries and Aquaculture, Marine Aquaculture Sites, Bay of Fundy Map FAL19Au7 (19 August 1997).

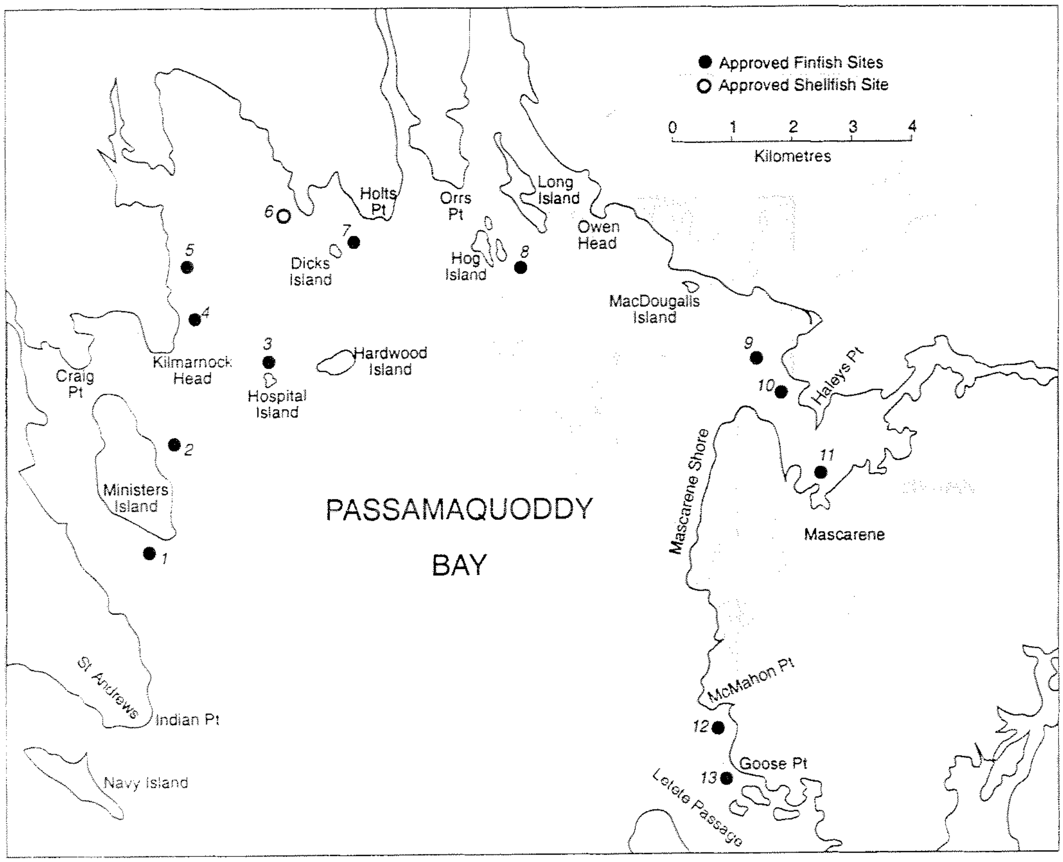

Fig 1b Passamaquoddy Bay area of Fig 1a

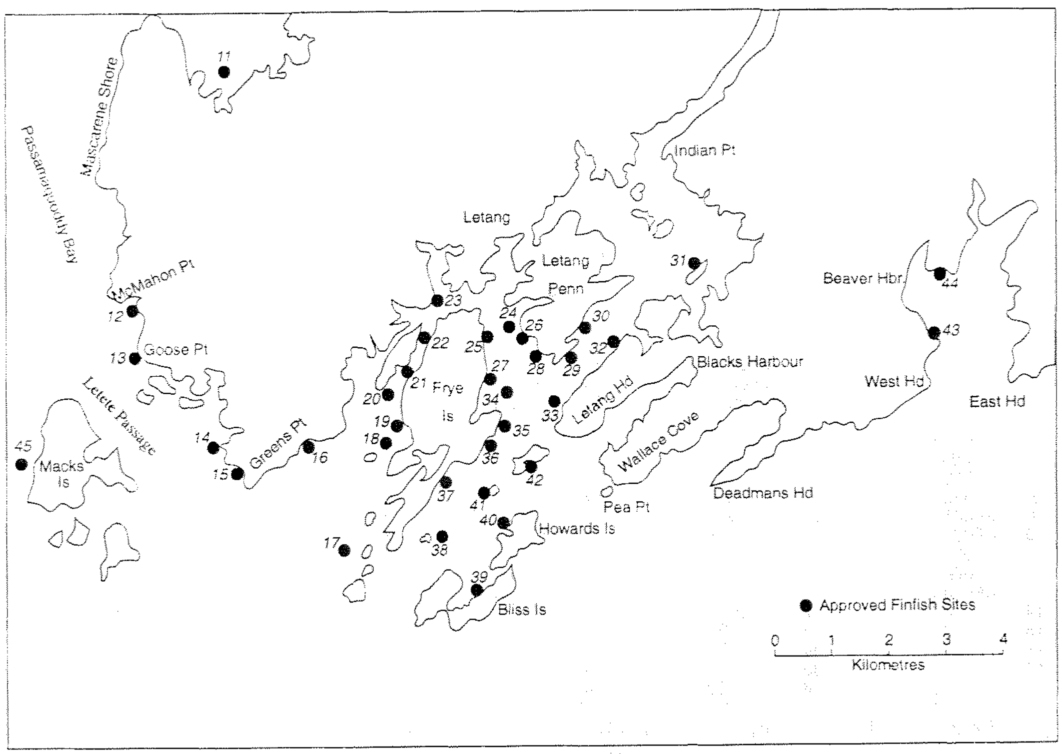

Fig 1c Letang area of Fig 1a

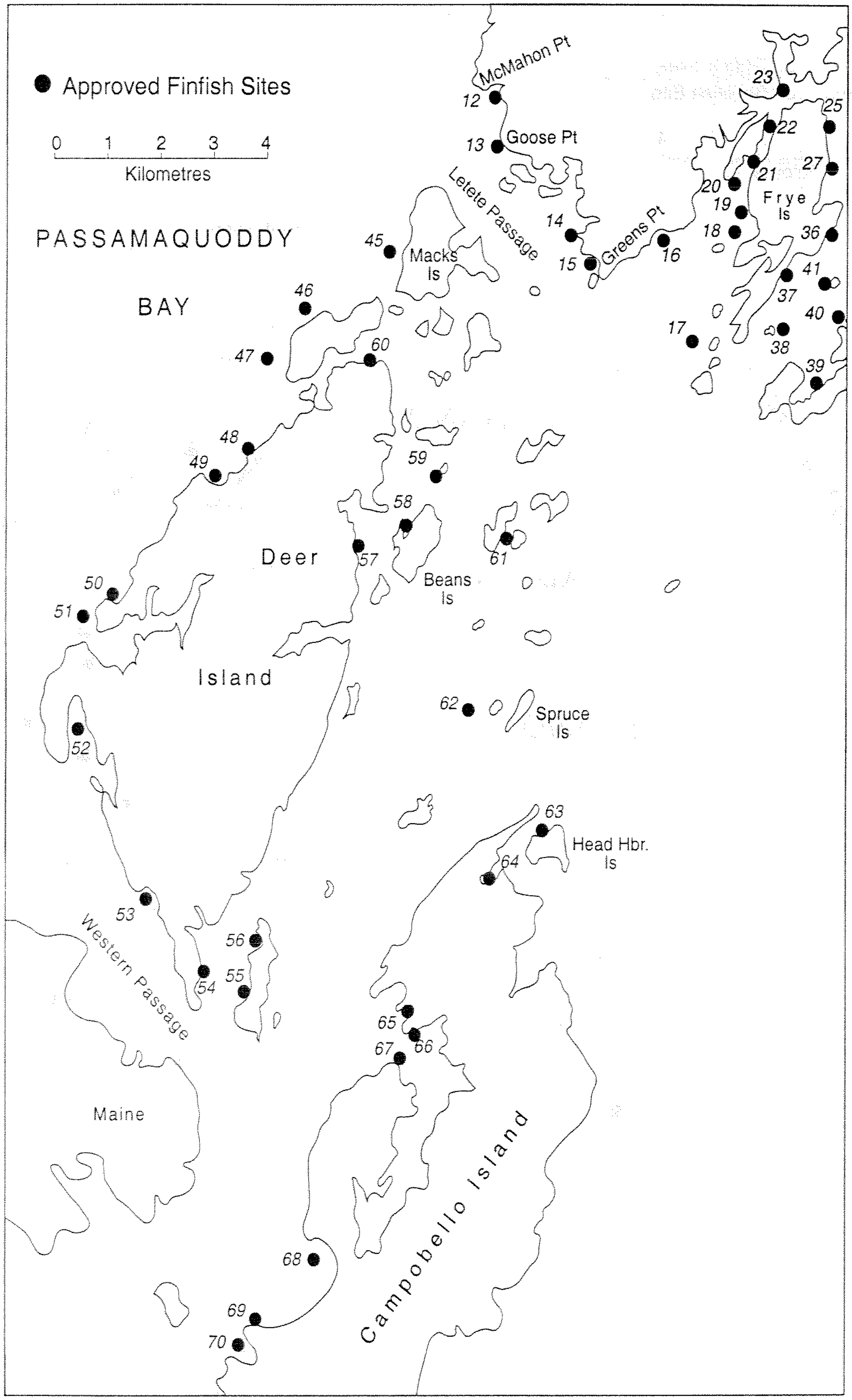

Fig 1d Deer Island and Campobello Island area of Fig 1a

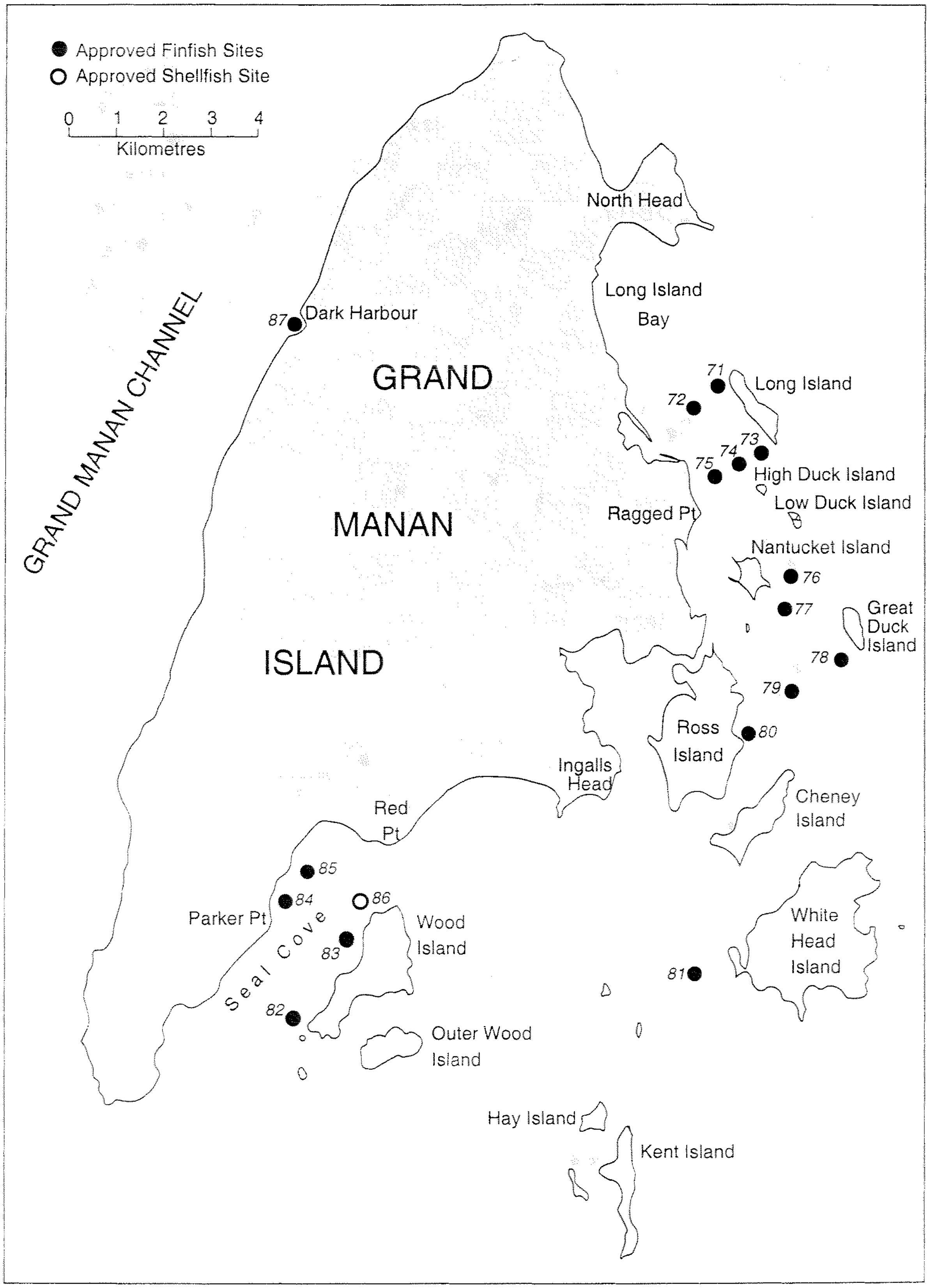

Fig 1e Grand Manan area of Fig 1a

SECTION I: SETTING THE STAGE

Brief Answers to Specific TOR Questions

1) The current status on the use of site fallowing, year class separation and distances between sites for salmon culture in Norway, Scotland, Ireland and Chile to address such questions as:

a) ***Are these mandatory for all operations?***

The relevant specific data on this question is summarized below in Table 1.

The only item which is mandatory in any of these geographical locations is the minimum distance separating sites in Chile, where a new law specifies a 2.4 km separation.

Table 1. Summary of data on distances between sites, site fallowing and year class separation for Atlantic Salmon Farm Marine Sites

	MINIMUM DISTANCES BETWEEN SITES	SITE FALLOWING	YEAR CLASS SEPARATION
Norway	Not mandatory. 1 km between farms usual. 3 km if slaughter is conducted on site.	Not mandatory. Recommended practice - widely used (1-3 months). Most use 3 months.	Not mandatory but for the last 6-7 years has been encouraged. Practiced by almost 100%.
Scotland	Not mandatory - decided on a case by case basis. Most are about 1 km apart. Prefer a minimum of at least 2 nautical miles - do not believe any of these distances are protection against disease.	Not mandatory. One month widely practiced - encouraged by regulators - industry very interested. This principle is expected to be incorporated in new guidelines or regulations on waste and production tonnages.	Not mandatory. Strongly encouraged. Industry led initiative - widely practiced.
Ireland	Not mandatory. Try to achieve 1 km.	Not mandatory. Recommended and regulators are actively pursuing the establishment of such practices. Three month period recommended.	Not mandatory. Practiced widely.
Chile	Mandatory. 2.4 km (new law).	Not mandatory. One month recommended. Practiced by a portion of the farms.	Not mandatory. Partial participation.
British Columbia	Not mandatory. 1 km guideline.	Not mandatory. Widely practiced. Believe that for full benefits one whole growth cycle is required - i.e. 12-15 months.	Not mandatory. Limited practice.

b) ***Why are fallow sites, minimum distances and year class separation required (environmental quality, fish health etc.)?***

In all of the countries the issues addressed were primarily health related. The prime objective is to break the cycle of diseases by eliminating the host biomass for a significant period thereby reducing or eliminating the disease agents with a consequent reduction of infection pressure.

Only for Norway was the additional advantage of elimination of contributions to the sediments during the period of fallowing put forward as an important, albeit, secondary objective.

c) ***Has fallowing, year class separation and minimum distances been demonstrated to be of benefit for salmon health protection?***

Fallowing and Year Class Separation: Limited proof of their effectiveness is available at the present time. In addition it is believed by both industry and regulators that the fallowing periods are effective in breaking the microbial disease and larger parasite cycles. Evidence illustrating the impact on sea lice infestations is described more comprehensively in the following discussions.

Minimum distances: There is no evidence that the distances listed in Table 1 are effective barriers to the spread of infectious diseases; there are several studies which show that none of the distances is sufficient.

d) ***Are fallowing and year class separation part of an annual site rotation process***?

Yes, where and to the extent that they have been practiced (see Table 1).

e) ***Are there any reports/information available that document the beneficial effects of fallowing, year class separation, and minimum distances between sites in terms of fish health?***

A number of reports examine and discuss various aspects of this question and draw conclusions followed by recommendations. This question is dealt with in the following more detailed discussions.

f) ***Has the use of fallowing, year class separation and minimum distances between sites proven effective in controlling the incidence of bacterial or viral pathogens?***

The industry and regulators, in most cases, believe that fallowing and year class separation coupled with Single Bay Management have been effective. None of the regulators or fish health experts spoken to in Norway, Scotland, Ireland or British Columbia felt that the minimum distances in effect control the incidence or prevalence of bacterial or viral infections. This element also is dealt with in more detail in the subsequent analysis and discussion sections.

Analysis and Discussion of Benefits

Although all those consulted regard fallowing and year class separation as beneficial it was pointed out especially by the Europeans that they have not been applied singly. In addition, they stressed that these measures (fallowing and year class separations) must be regarded as effective additional steps joined to essential basic programs already being practiced. All of these elements combined have resulted in raising the survival of the smolts transferred to the seawater farms from averages of 50 to 60% a few years ago to between 85 and over 90% observed now depending upon the year and location.

The essential basic programs to which Fallowing, Year Class Separation and Single Bay Management have been added are:

1) Healthy Smolts i.e. rapidly growing smolts shown to be free of specified diseases (a product of genetic programs designed to produce strains suitable for farming).

All smolts should be vaccinated with the available vaccines prior to transfer. To ensure the disease free state of the smolts the European Union (EU) directives call for twice annual inspection of hatcheries for smolt health. The rigour with which this is applied can be seen by the strict Norwegian requirement of a Health Certificate for smolts (good for only 10 days) before smolts can be transferred.

2) Not Exceeding the Capacities of the various areas to cope with the wastes generated at the farms thereby reducing the negative feedbacks and a source of stress on the fish as well as minimizing environmental effects.

This is achieved through prior predictive modelling of the areas and subsequent monitoring of production impacts. Specific models are discussed subsequently in relation to bottom accumulations at farm sites and the reduction over time of organic matter in these sediments.

3) Maximum Cage Loadings

In Ireland the recommendation is that the levels should not exceed 15 kg/m^3. In Scotland they recommend 10 to 15 kg/m^3 limits should be maintained for most of the growth period with possible exceptions rising to perhaps 20 to 25 kg/m^3 in the month or so just preceding harvest. As their water temperatures are somewhat less than those in Ireland they feel that the increased load is permissible for brief periods. In Norway the limit is 25 kg/m^3 . There are now, however, discussions taking place as to whether this limit might be raised in the future possibly to as much as 50 kg/m^3.

The maximum stocking densities are linked to site licensing and discharge consents and are not specifically controlled for disease purposes. The cage loadings, however, do have a direct effect on water quality which in turn has a direct impact on fish health.

4) Single Bay Management combined with Single Year Class Rearing followed by Fallowing

These are dealt with fully below through lengthy, but relevant, quotations from publications covering these topics.

5) Regular Comprehensive On-Site Inspections

In Europe these inspections are carried out in accordance with European Union EU) Directives which specify two visits per year to freshwater rearing facilities and once per year to marine rearing sites. An illustration of the marine farm inspection by the European countries was provided by the Scottish spokesman, Dr. A. McVicar. The inspectors attached to his organization each inspect around 150 farms/year. These inspections include:

a) an examination of the Mortality Record Book - a detailed record required to be maintained by the farmer - signed off by the inspector at the time of the inspection.

b) an examination of the farm to determine whether it is functioning in accordance with its registration specifications and licence.

c) a comprehensive examination of the farm and all of its operations and holdings. If the examination of the Mortality Record and condition of the fish stocks warrant then samples are taken for laboratory work-up.

In Ireland and Norway the approaches are similar with the difference that in Norway the inspections are contracted out to veterinary practitioners instead of being done by government inspectors. The reports of the inspections in Norway are then filed with the regional government veterinary authority.

In all cases if a disease situation is recorded or indications of a developing disease situation is perceived a local or area wide zone can be declared. The measures deemed necessary to deal with and resolve the situation are then implemented and applied to the defined zone. If warranted, disease eradication measures follow promptly. The data collected on disease and performance is available from the local authorities for collation to be used to gauge farm performances and for epidemiological diagnoses of the kind exemplified by the Jarp and Karlsen (1997) study of Infectious Salmon Anaemia, described in Section III.

Ireland and Scotland both regard the compilation of these kinds of data in a centralized and computerized data base as invaluable diagnostic tools for early detection of developing problems and epidemiological assessments which would allow early and effective interventions to avoid crisis situations. Rather similar approaches are used widely in the poultry industry within Canada.

In British Columbia the smolts are screened for Bacterial Kidney Disease and Furunculosis; the farms are examined for environmental reasons i.e. accumulation of sediments under the farms. The situation is changing somewhat there as moves are being made to collect data cooperatively on disease and farm performance (smolt survival, growth, feed conversion etc.) in a central registry to aid marine farm operations. The program, somewhat limited at this stage, is being carried out under the aegis of the Cooperative Assessment of Salmon Health (CASH) program.

6) Nutrition

Feeds specially developed and improved to ensure rapid growth i.e. fulfilment of the genetic potential and thus limiting the growth period at marine sites to the absolute minimum (now generally between 12 and 15 months but with some stocks, developed in Norway, reaching market size in 11-12 months).

7) Mortalities (Morts)

The Europeans apply strict controls the purpose of which is to remove or confine infectious or potentially infectious material as soon as possible and as completely as possible. Norway has the strictest regulations requiring examination for and removal of "morts" (i.e. fallen animals) every day in the summer and every other day in the winter.

The dead fish are placed for ensilation in tanks containing formic acid and are removed periodically by a Mort Removal Service. Much of this material is processed later (rendered for recovery of oil and to prepare food for farmed fur bearing animals).

As ensiling does not destroy the Infectious Pancreatic Necrosis (IPN) virus, this is not an approved method for destroying morts in Scotland. The EU legislation regarding disposal of morts includes rendering, burying and landfill, but not other methods. British Columbia uses acid ensilation for isolation and removal from the site of potentially infectious morts.

8) Husbandry, Hygiene and an Adequately Budgeted Farm Health Plan

All emphasized the importance of these aspects as being essential to the success of the farms in their area and that any lack of vigilance in these topic areas could offset all other measures. In this context the Scottish authority, Dr. McVicar, made the following interesting comments: As a general statement, it can be said that most overt disease problems (as opposed to infection) encountered in fish farms have a direct link to husbandry practices. For example, although the bacterium *Vibrio salmonicida* (Hitra disease agent) has been recorded in the Scottish waters it rarely causes a disease problem comparable to those experienced in Norway, a fact which is probably linked to differences in farming practices. As southern New Brunswick salmon farms had not previously experienced Infectious Salmon Anaemia (ISA) it is tempting to ask whether changes in practices have been made in southern New Brunswick which may have led to the ISA outbreak.

Interestingly, in answer to an inquiry as to whether the various regulatory measures were considered excessive and overly bureaucratic, the Scottish authority, in particular, said that to the contrary, the measures were welcomed by the industry and indeed were often led by industry. He went on to say that the Scottish industry was becoming highly professional and recognized that sound measures would reduce costs and in the end make their part of the industry that much more competitive and successful. He also stated that, far from having these measures imposed arbitrarily, they had been developed in conjunction with industry and thus had the full cooperation of most practitioners. Without the full cooperation of the industry these measures could not be enforced by the nominal numbers of regulators.

This same attitude is displayed elsewhere in Europe and is underscored in the following extended quotation taken from an article entitled "Salmon: Every picture tells a story!". The point made is that the production of farmed fish must be considered in a comprehensive manner and treated as an integrated system from beginning to end. The success of this approach over the years is particularly evident in the improving picture illustrated in Fig 2-5.

Extract from 'Aquaculture Ireland (June/July 1996)'

"Harvested tonnage now comprises a proportion of 1-2 kgm fish of just under and just over one sea-winter in age, produced in the main by Western Region farmers and a majority of fish, of 3 kgm or larger, of one sea winter in age, produced in all regions. It would appear that, as a result, the average weight of harvested fish now is about 2.6 kgm, somewhat larger than it was a few years ago when more smaller and fewer larger fish were produced.

There are three major factors involved in the reduction in the numbers of smolts transferred per tonne of salmon harvested:-

~ Improvements in smolt quality and pre-transfer and transfer techniques, for example the increasing practice of vaccinating smolts pre-transfer against vibriosis and furunculosis, leading to improvements in immediate post-transfer and longer term survival.

~ Improvements in husbandry, which have led to a better combined record in mortalities and escapes. The onset of fallowing and single bay management strategies and the availability of better, more easily administered vaccines and other therapeutants is felt to have been of particular benefit in respect of improved survival.

~ Radical upgrading of feed quality, performance and feeding techniques, in particular in the last three seasons. These changes are in two major areas; the improvement in nutritional characteristics arising from the use of fresher, LT (low temperature production methods) fishmeals with higher protein digestibility and, secondly, the increased use of higher quality fish oils to supply energy requirements. Feed changes have radically shortened the growing season for fish to the 3-5 kgm range or even bigger, such that these weights are now easily achievable in fish of one sea-winter. Shorter growing season has also had a beneficial knock-on in improving survival

Figure 5 plots estimated feed conversion rate (FCR) relative to annual production over the period 1989-1995. Again it can be seen that FCR is now almost twice as good as it was a decade ago; that means that it now takes just half as much dry-weight feed to grow a tonne of salmon relative to 1989. Another way of putting this is that the industry uses about ten times as much feed as it did a decade ago but produces almost exactly twenty times as much fish!

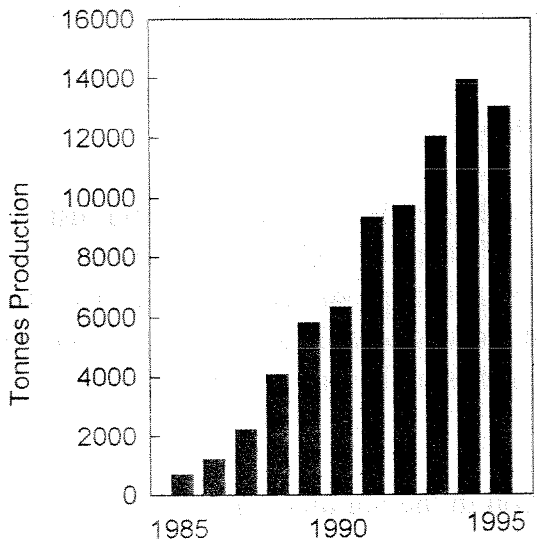

Fig. 2 Estimated Irish farmed salmon production 1985-1995

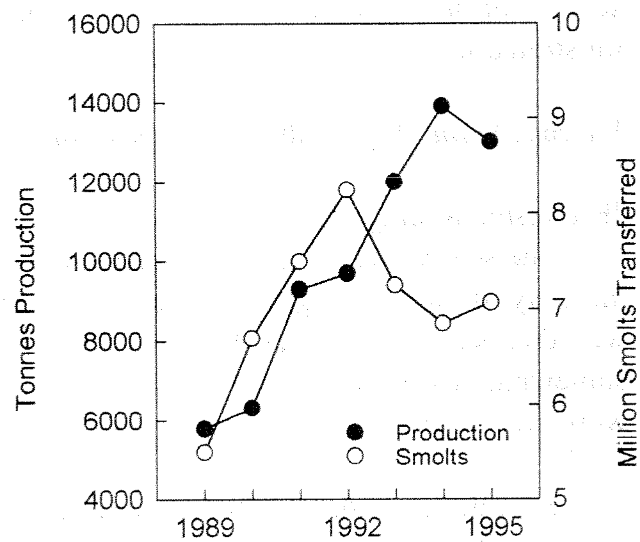

Fig. 3 Irish farmed salmon smolt transfers to seawater farms relative to total production 1989-1995

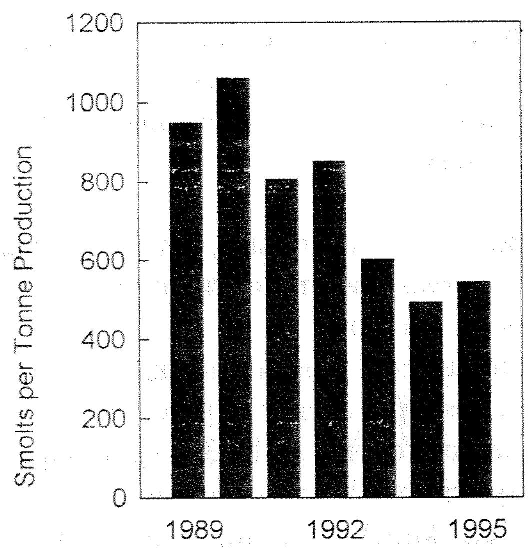

Fig. 4 Irish farmed salmon smolts transferred to seawater farms per tonne of production 1989-1995

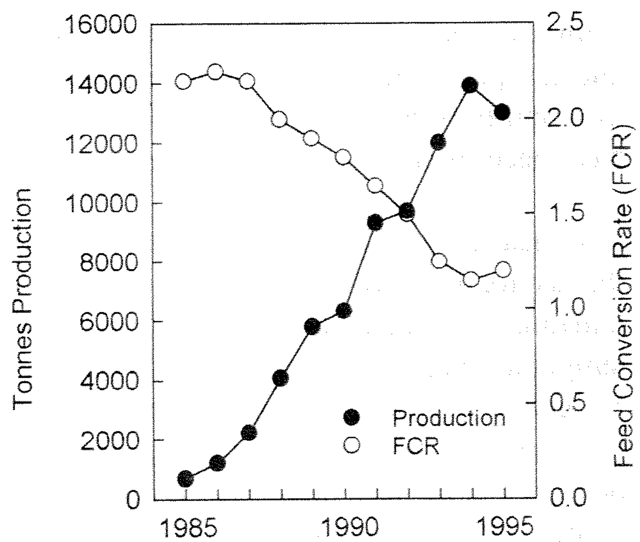

Fig. 5 Estimated total Irish farmed salmon production relative to approximate feed conversion rates 1985-1995

(Fig. 2-5 redrawn from Aquaculture Ireland, June/July 1996)

Although improvements in feed formulation may be seen as the major influence on improved FCR, improved husbandry and very much better survival have also had their part to play. In addition, whilst we may complain that, on the face of it, a tonne of feed costs very much more than it did a decade ago, it is clear that across the board improvements in performance have resulted in only a slight increase in feeding costs as a proportion of overall production costs. This is despite the fact that commodity prices in general have soared in that time. Feed producers have been trying to convince the industry of this for years!

The combined benefits of these improved operating conditions on the industry's performance are manifold:-

~ Lower proportion of production costs arising from smolt and smolt transfer costs, particularly relevant in the production of fish in the 1-2 kgm range but still a large factor in the costs of producing larger fish.

~ Less individuals and lower standing biomass per tonne of fish produced, arising both from better husbandry and improved feeds, resulting in more growth per unit fish per unit time.

~ Lower standing biomass has offered the opportunity for lower stocking densities in the cage space available, itself contributing to more rapid and even growth.

~ Lower numbers of hosts and therefore host surface area for parasite infestation per tonne of fish produced.

~ Lower costs for applications of vaccines and oral therapeutants.

~ Reduced environmental impact arising from excretory products due to improved feed digestibility, reduced standing biomass and more efficient therapeutant usage.

~ Shortened production cycle, improving survival and increasing efficiency of cage and staff utilisation.

All these factors have a beneficial effect on margins and are all signs of the industry continuing to innovate and to move up the learning curve at a rapid rate. Indeed statistics from Norway, Shetland and mainland Scotland suggest that average production costs in Ireland have been maintained broadly comparable with those of our industry neighbours. These observations should also give a very positive message, both to the industry regulators and to the anti-fishfarming lobby. Irish salmon farmers and the companies that serve them are proving very proactive in the application of management and science to improve the commercial and environmental performance of the industry.

The overall result is the prospect of a larger, more efficient industry, able to meet the objectives of the Fisheries Operational Programme. Irish salmon farming will also be able to offer more jobs in our coastal communities and increased export earnings, without a pro-rata increase in environmental impact. This bodes well for the industry's future security, despite its small size in world terms.

In closing, it is worthy of note that the rigorous collection and collation of data from across the industry can give us very strong indicators of how we are performing, as illustrated by the four graphs above. As the song says, 'Every picture tells a story'; collection and processing of such data should be strongly encouraged....." (Aquaculture Ireland, June/July 1996).

SECTION II: SINGLE BAY MANAGEMENT AND FALLOWING

Single Bay or Single Area Management

This is practiced in British Columbia to a limited extent largely where a single company owns all the farms in the inlet or area. Because Chile, to date, has not had the lice and disease problems experienced elsewhere Single Bay Management has not been practiced widely; additionally their coast is more open and the bays are less well defined and thus application is more difficult. In Europe Single Bay Management is practiced widely and combines year class separation and fallowing in an effort to break disease cycles, initially, and especially for sea lice. Sea lice, *Caligus elongatus* and more particularly *Lepeophtheirus salmonis*, are extremely insidious copepod crustacean parasites for farmed Atlantic salmon. The life cycle of *L. salmonis* consists of 10 stages: two free swimming non-parasitic naupliar stages, one free swimming infectious copepodid stage, 4 attached chalimus stages, 2 pre-adult stages and the adult (Fig. 6). As the infective free swimming copepodid is the first parasitic stage it must attach to a host within a few days of its formation or it will break the life cycle by dying. These parasitic crustaceans cause severe economic losses by damaging the fishes' integument and causing localized haemorrhaging and necrosis. Mortalities may result from osmotic shock as well as through secondary infections acquired as a result of the integumental damage. The *C. elongatus* is a non-specific parasite of at least 73 species of fish while *L. salmonis* is largely restricted to the Salmonidae. The large numbers which give rise to the massive infestations are a direct function of the biomass of the host species (farmed fish) and the time of occupation of the site.

Treating the fish with chemical agents such as organophosphates must be done carefully so as not to damage the fish severely or cause mortalities, but at sufficient concentrations to kill those lice at the susceptible stages of their life cycles i.e. only the pre-adult and adult stages are killed by the organophosphates. Following organophosphate treatment the larval forms attached to the fish survive and grow to the pre-adult and adult stages. Thus the basis for rapidly re-establishing the infection at high levels persists despite the treatment and leads to the need for subsequent regular chemical treatments as well as the potential problem of development of lice resistance to the chemical agents. In addition, there is the problem of controlling the anti-parasite agent so that desirable crustaceans in the vicinity are not affected. The intent then of the three measures (single bay management, single year class separation and fallowing) is to leave the bay, inlet or area fallow for a period of at least 4 weeks, and preferably 2-3 months, as the parasite does not survive without a host for prolonged periods. According to Johnson and Albright (1991) the mean time at 10°C for development from the egg through the free swimming

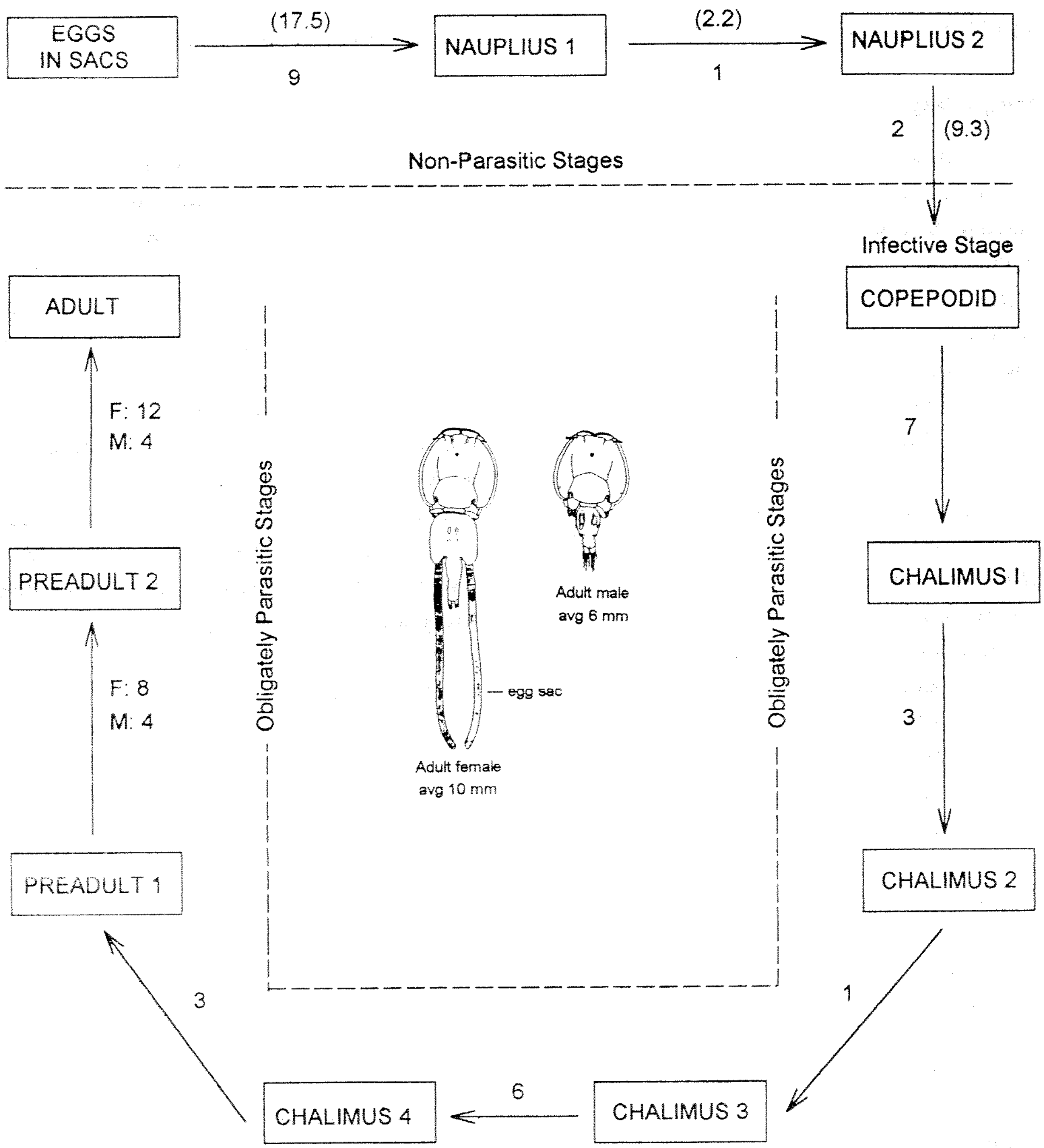

Fig. 6 Life cycle of *Lepeophtheirus salmonis* drawn from Johnson & Albright, 1991 plus outline drawings of a female and a male from Schram, 1993.

Bracketed numbers beside arrows indicate mean development time in days at 5C; unbracketed numbers indicate minimum development time in days at 10C.

F = female; M = male

nauplius stages to the infectious and obligately parasitic copepodid stage of *L. salmonis* is about 12.3 days (range 12-22 days); the mean time for this development at 5°C is about 29 days and by extrapolation the range at that temperature should be between 29 and 50 days (see Fig. 6). Because of the colder waters of the Bay of Fundy, the fallowing times chosen should be at least two months.

Once the sea lice life cycle has been broken the population recedes to a very low level and requires time and a large host biomass to raise the sea lice population to troublesome levels. Re-stocking the farms in the area with a single year class following fallowing ensures that the re-establishment of the sea lice population has available for hosts only or mainly the uninfected smolts. This re-establishment of troublesome lice levels will take a significant period, as noted initially with the early farms in the Passamaquoddy area. Single Bay or Single Area Management aids this process by arranging for all fallowing to occur simultaneously, and for a sufficient period so that re-establishment of the lice populations is confined to a single year class of fish.

Impact of Fallowing on Sea Lice

Fallowing has been practiced largely as a means to deal with and reduce the problems of sea lice although it is also believed to have benefits in reducing microbially caused diseases as well. An examination of the impact only on sea lice is described below. Costello (1993) has provided an excellent and comprehensive review of all the methods used to control sea lice on salmon farms; this is recommended reading for anyone wishing to have a more complete picture of control options.

Grant and Treasurer (1993) reported at length specifically on control of sea lice by fallowing. Two trials were reported:

1) Loch Eil, Scotland: Fallowing

"Loch Eil farm was stocked in April 1989 with smolts. Lice control became necessary on a routine basis from September and mean numbers of lice rarely fell below 40. On 3 May 1991 a small number (15,000) of smolts was stocked alongside the 100,000 older 1989 year class. Within 3 days copepodids of *L. salmonis* were seen on the smolts and the fish quickly acquired a significant infestation (mean of eight mobiles per fish). Treatment with Aquagard was required within 4 weeks of stocking and thereafter at 4-weekly intervals through the summer. The farm was fallowed from 15 January 1992 along with the rest of the farms in the loch before restocking during April 1992. No treatment has been required to date (October, 1992). Only *C. elongatus* was present in any number and did not pose a threat."

2) Loch Sunart, Scotland: Fallowing and Management Agreement

"Loch Sunart had been farmed continuously for several years prior to 1991 without a fallow period extending to the whole loch. The three companies farming in the loch, Marine Harvest, McConnell Salmon and Mingarry Fish Farms, agreed to remove all fish from the water in February 1991. After 6 weeks, restocking commenced in April 1991 with smolts of the same generation. The total number of fish stocked in the loch was also reduced. Significant infestation with *L. salmonis* did not occur until June 1992 when the fish were first treated, and treatment has continued since then. Consequently the use of dichlorvos has been substantially reduced."

The Loch Eil example shows how quickly a fresh uninfected batch of smolts stocked alongside fish carrying the lice become infested and require treatment i.e. within 4 weeks of stocking. Fallowing for 10-12 weeks on the other hand allowed stocking with smolts which up to 8 months later (the time of publication) still did not require treatment. In the second instance 6 weeks of fallowing allowed Loch Sunart to be stocked with smolts for 14 months before treatment for sea lice was required.

As dispersal stages of the lice can occur over large distances, the authors, Grant and Treasurer (1993), suggest that to achieve maximum effect, the areas to be fallowed should be extended to all farms in the sea loch through management agreements. The relevant clauses of a management agreement for the authors' employers, Marine Harvest, are:

"1) The area within a management agreement is defined.
2) The fallow period for the loch is specified.
3) Single generation (year class) stocking.
4) All fish in - all fish out.
5) The lice population is monitored and, where possible, treatments on farms are coordinated."

Clearly, fallowing combined with single bay or area management and single year class separation can be highly effective in reducing the impact of sea lice on Atlantic salmon farms.

Irish Progress Report on Single Bay Management

The following extract is taken from an Irish report on Single Bay Management (Jackson 1997) where the local farms had been blamed for the genesis of the problem of massive sea lice infestations of sea trout, a prime angling fish in the Irish coastal zone. Irish authorities point out, however, that although the farms were blamed there was, in fact, no evidence of a cause and effect relationship. The major reduction of the sea trout and thus the reduction in angling was a direct result of the sea lice. This report illustrates the approach taken and underscores the need to arrange alternative sites for fallowing.

"Progress Report on Single Bay Management
Dr. David Jackson
10th October 1997
Introduction

The original concept of single bay management was first utilised in Scotland in the late 1980s. The strategy was put in place by a number of salmon farms in a sea loch on the west coast of Scotland to deal with two intractable problems, which were threatening to put the farms out of business, sea lice and multi-resistant furunculosis. As a management strategy it was very successful and enabled the farmers both to control their lice problem and to get rid of the multi-resistant furunculosis.

The idea was imported into Ireland by salmon farmers. With the encouragement of the Department of Marine it was introduced progressively, on a voluntary basis, from 1992 to 1994. Initially the implementation of the single bay management concept consisted of a move to single generation sites and the early harvest of two sea winter fish combined with effective co-ordinated lice treatments.

The driving force behind the implementation of Single Bay Management in Ireland was the need to control lice on farmed salmon. This is expressly laid out in two recommendations of the Sea Trout Task force, 10.36 and 10.37. Following a pilot study in Kilkiaran Bay single bay management proposals were prepared for every salmon farming area in Ireland. The components to the single bay management concept as implemented on salmon farms include: information exchange, an agreed code of practice, single generation sites, early harvest of two sea winter fish, fallowing.

The information exchange includes regular formal exchanges of information on lice numbers, disease status etc. between fish farmers and the exchange of information amongst the participants in the Single Bay Management Groups. The agreed code of practice covers a range of animal husbandry issues which impact on both disease and lice control. The limiting of stocking at each site to fish of only one age class or generation prevents the vertical transmission of lice infestations or diseases and the early harvesting of two sea winter fish reduces the overall lice burden in the spring. Fallowing involves the synchronous removal of fish from adjacent sites for a period of one or more months to break the cycle of infestation with parasites or diseases.

Single Bay Management is all about an integrated approach to management. As a tool it is not specifically designed to simply tackle one problem (e.g. lice) rather it has the potential to lead to improvements over a whole range of husbandry issues. It (is) a particularly useful tool in the control, and in some cases elimination, of disease. It is the gateway to more efficient production by optimising conditions within the bay and it lays the foundations for co-operative ventures between hitherto "rival" operators in the same bay.

The mechanics of the process are quite simple. The individual operators come together under the auspices of the Dept. of Marine/Marine Institute and draft a plan reconciling their various production plans. This "draft" is then taken to a regional group, the Single Bay Management Group, who meet and discuss the merits of the plan and any perceived difficulties with it. These groups are comprised of representatives from the Dept. of Marine, each salmon farm in the area, the Irish Shellfish Association, the Regional Fisheries Board and other inland fisheries interests. Once the draft plan has been modified to take into account the concerns of the group it is put in place. The implementation of the plan is then overseen by the group and any proposed modifications to it are discussed by the group.

Single Bay Management is just as applicable to shellfish farming as it is to finfish farming. It offers the opportunity of an integrated management plan for all aquaculture operations within a bay together with a forum for discussing any potential areas of conflict and coming to a resolution at a local level. There are also more specific areas where there are direct benefits to be obtained. For example, in the southwest, plankton samples from salmon farms in the outer approaches to the shellfish areas of Kenmare and Bantry Bays have been used as an early warning of the arrival of *Dinophysis* spp. in the bays and the subsequent onset of toxicity in shellfish. This process has recently been extended. From the 1st of October 1997 phytoplankton samples are being collected at all sites visited as part of the lice monitoring programme. This operation is piggybacking on the existing programme at no extra cost. It has already supplied samples to allow the assessment of a reported potentially harmful bloom in Connemara. On the subject of disease, the successful management of an occurrence of serious diseases in shellfish such as brown ring disease or *Bonamia* in an area requires an integrated and coherent approach to the management of fisheries and aquaculture in that area.

In short the way forward is to develop an integrated management plan for aquaculture in each area. This plan should be geared towards achieving sustainable growth and development hand in hand with environmental protection. Such a plan would then form the basis for the aquaculture section of a new Coastal Zone Management initiative. The development of holistic Single Bay Management plans at this stage gives the industry the opportunity to be proactive rather than reacting to EU Directives.

General Considerations

The main planks of the process are as follows:

~ Single Generation sites
~ Fallowing of sites for a minimum of one month each year
~ Implementation of husbandry practices to minimise lice levels
~ Synchronous treatments for lice
~ Synchronous fallowing of production sites in bays
~ Mechanisms of information exchange

In general the practice of single generation sites has been implemented throughout the industry. In some cases the separation between sites may not be as great as would be ideal but every effort is being made to separate generations in a meaningful way. Similarly the annual fallowing of sites is being practised throughout the industry. A number of key husbandry developments have aided in the rational control of lice numbers including; improved harvesting practices, shorter production cycles, new types of lice treatment and improved disease management. The synchronising of the fallowing process in all adjacent sites is proving somewhat more difficult. While it has been achieved in a number of bays, notably those where the sites are operated by the same company, full synchronisation has yet to be achieved in a number of areas.

There are two major obstacles to the achievement of synchronisity in fallowing:

1. different production targets/requirement by different companies.
2. the lack of fallowing sites.

The first obstacle is gradually being overcome as companies work towards a holistic approach to site management. The question of fallowing sites can only be fully addressed in the context of the commencement of the new aquaculture licensing processes as laid down in the 1997 act. In the absence of these procedures the provision of fallowing sites in key areas will remain problematic.

The production of fish for market after ten months in the sea has been rendered uneconomic by current pricing structures. This means that that segment of the industry which achieved annual fallowing by utilising a ten month production cycle can no longer operate in this way and have to move to a 14 to 18 month cycle incorporating both a production and a fallowing site. This in effect means that all salmon farm production units require a production and a fallowing site to implement SBM."

More technically detailed accounts of the problems of sea lice with Irish cultivated salmon and their amelioration have been published by Jackson and Minchin (1993) and Jackson et al. (1997). In Jackson and Minchin (1993) the incidence of the most frequent sea lice species *L. salmonis* varied during the year with the age class and site farmed; smolts had the smallest load and two-sea-winter fish the greatest. Jackson et al. (1997) evaluated the performance of various sea lice management strategies applied on the west coast of Ireland and found the variations directly linked to changing husbandry practices.

SECTION III: DISEASES AND DISTANCES BETWEEN SITES

The question was asked - what is the appropriate distance between farm sites to provide protection against the spread of infectious diseases? The short answer is that unfortunately, as all authorities consulted agreed, none of the distances specified in Table 1 is adequate to the task. The guiding principle which covers this issue best is summed up in the maxim enunciated by the Scottish authority, Dr. McVicar: "If you share the water you share the disease risks".

As all marine waters are contiguous what is meant by sharing the waters and how can this maxim be applied in practical terms? The risks involved in sharing the waters will be highly area specific and will depend upon the dilution of the infective agent, infective dose and the length of time the infective agent can survive away from the host. Although risks clearly would decrease with increasing distance, minimum effective distances have not been determined for the various agents nor has the role of vectors such as escaped infected fish or parasites carrying infective agents been examined or evaluated with regard to the transfer and transmission of disease agents over distance.

To attempt to answer the complex question of what is involved in the disease aspects of shared waters a stepwise approach has been used. First the infectious disease agents recorded for the southern New Brunswick area are listed followed by a brief synopsis of diseases of salmon experienced elsewhere. This is followed by a discussion of diseases generally with relation to fish farming with emphasis on the diseases experienced in New Brunswick and emphasizing features related to transmission and transmissibility. Thirdly the available relevant literature on what are essentially natural experiments or models dealing with distances and farm practices is discussed and finally data available on the mixing and sharing of waters in the Passamaquoddy area is presented.

Disease Agents or Diseases Recorded for Southern New Brunswick Atlantic Salmon Farms

Protozoan

- Proliferative Kidney Disease - one case recorded

Bacterial

- *Vibrio anguillarum*
  - several serotypes giving rise to vibriosis
- *Vibrio salmonicida*
  - the cause of the form of vibriosis known as Cold Water Vibriosis or Hitra Disease

Aeromonas salmonicida
- the agent causing Furunculosis

Renibacterium salmoninarum
- the causative agent of Bacterial Kidney Disease

Viral

Infectious Pancreatic Necrosis Virus (IPNV)
Infectious Salmon Anaemia Virus (ISAV)
Hemorrhagic Kidney Syndrome (HKS)
- apparently virally caused and may be related to or identical with ISAV - this question is still being resolved.

Sea Lice

Caligus elongatus
- has been recorded as a parasite on 73 species of marine fish including Atlantic salmon and is not regarded as being as troublesome as the following related species

Lepeophtheirus salmonis
- primarily found on Salmonidae. This sea louse is the scourge of salmon farming generally. (See Fig. 6 for its life cycle and information on infectious states).

Disease Problems of Norway, Ireland, Scotland, British Columbia and Chile

Vibriosis, the disease caused by *V. anguillarum* is rare in Scotland and occurs as a production problem attributed largely to a failure of husbandry and hygiene which can be rectified by improving care and attention as well as by not overloading the system. In Norway it is regarded in much the same light and is dealt with through improved practices and by the use of vaccines. The Norwegians use the same approach for dealing with Hitra Disease i.e. vaccination of smolts prior to transfer to seawater farms and improved husbandry after transfer.

Furunculosis, sea lice, IPN and ISA have been the most troublesome diseases or infestations in Norway. In Scotland the major disease problems have been furunculosis and sea lice while in Ireland they have been plagued mainly by sea lice. In 1997 the Irish also had a serious problem with Amoebic Gill Disease in Atlantic salmon; this infection and losses may possibly stem from the warmer temperatures experienced in 1997. In British Columbia, although they do not consider their problems with diseases to be major, they have had more trouble among Atlantic salmon with Bacterial Kidney Disease than with furunculosis.

In Chile producers have had relatively few fish health problems to date. Average Atlantic salmon mortality levels from smolt introductions to harvest are about 10% with about half these losses due to a rickettsia, *Piscirickettsia salmonis*, the first rickettsial pathogen of fish to be fully characterized and a possible serious new factor in fish diseases (Fryer and Mauel 1997). Interestingly, this rickettsial pathogen, *P. salmonis*, has been recorded now also in Norway where it was diagnosed as the probable cause of a low mortality systemic disease on 51 farms (Olsen et al. 1997). For the remainder of the Chilean losses, Bacterial Kidney Disease is the next most frequent cause of mortality; sea lice are endemic to the area. Furunculosis has not been a problem previously, but a new atypical strain has been isolated recently.

Fish Diseases

Before discussing the merits of distance in reducing or controlling diseases it is worth noting a few salient facts about the disease agents noted above. Infections among fish or any other animal do not occur simply or inevitably because a host has collided with an infectious agent; the development of an overt disease is a complex product of the interaction involving the host (fish), pathogens and the environment.

Stress

If the fish is a healthy vigorous specimen kept under good to excellent conditions it will usually resist infection by opportunistic pathogens. If however, it has been stressed by transportation, presence of predators, poor diet, adverse temperatures or salinity or overcrowding this will result in a markedly reduced capacity for disease resistance, impaired development of immunity, impaired reproductive capacity and reduced growth rates (Barton and Iwama 1991, Pickering et al. 1982, Pickering and Stewart 1984, Pickering and Pottinger 1989, Pickering 1997, Thompson et al. 1993). The elements contributing to stress and thus immunosuppression are considered so dominant that Smith (1997) in his discussion of furunculosis argues that the infectious agent itself, although essential, is actually a minor player in the overall infection. In this view the major reasons for the disease are the precipitating factors giving rise to stress and these should receive at least as much attention as specific infective agents; this view emphasizes that there is no substitute for good husbandry in reducing occurrences of and the impacts of infectious diseases. An immunosuppressed animal is extremely susceptible to all infectious agents and requires a considerable time to recover its various immune and resistance capabilities even after removal of the causes of the stress, i.e. a month or more; growth is impaired for even longer periods.

Vibriosis

The bacteria causing vibriosis are ubiquitous in the marine environment and are not a problem for fish in peak condition. When the fish are stressed by such abuses as those listed in the previous paragraph they become susceptible and succumb in large numbers to these otherwise innocuous bacteria. The problem is overcome by application of good husbandry supported by vaccination of the smolts prior to transfer from the hatchery. *Vibrio salmonicida* which causes Hitra Disease is usually associated with fish farms and is frequently found in the fish farm sediments, which may act as a reservoir for this bacterium (Enger et al. 1989); it too can be dealt with by vaccination and good husbandry.

Infectious Pancreatic Necrosis Virus

The Norwegians in past years have had a particular problem with IPNV-affected fish. Many of the smolts coming from the hatcheries were latent carriers, having survived IPNV infections in the hatchery. Losses ranging from 15 to 50% were experienced in the first couple of months following the stress of transfer to sea water and for a time it was the most serious problem in Norwegian salmon farming. They found a high proportion of the smolts were carriers. As the virus is transmitted both vertically (from the female through the eggs to her progeny) and horizontally (to other interacting fish) the approach to control was to eradicate it at the brood stock level. Emphasis was placed on ridding the broodstock of IPNV with the gratifying result that the number of smolts which were latent carriers dropped and the losses immediately following transfer to seawater declined. The Norwegians are now also vaccinating their smolts with an IPN vaccine; success with the vaccine has been variable. A point worth noting which adds to the attractiveness of reducing showers of IPNV in and around aquaculture facilities is that IPNV has been shown to be highly pathogenic to halibut. The isolation of IPNV was associated with 100% mortalities in metamorphosed halibut fry in Scotland and is considered a serious threat to the development of halibut culture in that country (Wood et al. 1996).

Infectious Salmon Anaemia Virus

The first case of infectious salmon anaemia (ISA) was diagnosed in 1984 among Atlantic salmon parr in Norway; mortalities reached 80% over the course of several months (Thorud 1991 cited in Jarp and Karlsen 1997). The most serious problems since have occurred periodically in sea farms where mortalities vary from insignificant to serious. In the course of their studies Thorud and Djupvik (1988) showed the disease could be transmitted to healthy fish by intraperitoneal injection of liver homogenate from diseased fish and or transmitted to healthy fish by their cohabitation with ISA diseased fish.

Because of the importance of this new disease considerable effort in Norway has been devoted to its study especially on mechanisms of transmission and possible reservoirs.

Studies focused on mechanisms of transmission showed that Atlantic salmon exposed to organic material i.e. blood or blood products which contained the ISA virus or equally to sea lice from ISA infected Atlantic salmon suffered high mortalities attributable to ISA (Nylund et al. 1994). These authors also demonstrated that the ISA agent was still infectious after 20 h in seawater, or 4 days in blood or kidney tissue kept at 6°C; they concluded that sea lice may be an important vector for transfer of the ISA agent in epidemic and endemic phases.

These findings were extended by Totland et al. (1996) who showed that short term (48 h) exposure (cohabitation) of healthy Atlantic salmon smolts to ISA-inoculated cohort smolts resulted in transmission with 100% mortalities from day 7 post-inoculation and onwards. The transmission occurred more than one week before the inoculated (ISA infected) fish themselves showed any overt signs of the disease. Skin mucus, faeces, urine and blood, isolated from ISA inoculated smolts transmitted the disease to healthy smolts with variable efficiency depending on how the inoculum was administered. Intraperitoneal injection (i.p.) was best with all sources; blood homogenates gave a slightly shorter LT50* (16 days) than did skin mucus or faeces (18 days). Urine from the same fish used as an ISA source produced a higher LT50 (32 days). When applied to gills of healthy animals the blood homogenates and skin mucus from the infected animals gave LT50 values which were only slightly longer than those for i.p. injections i.e. blood homogenates = 19 days, skin mucus = 21 days, urine = 28 days and faeces = 31 days. When these same materials were introduced into the stomachs of healthy fish no mortalities attributable to ISA were observed in 3 consecutive trials leading to the conclusion that, although coprophagy among smolts was observed, transmission via the digestive system was not an effective means of transmitting the virus. Of major importance was the finding that skin mucus from non-inoculated cohabitants exposed to ISA inoculated smolts for 2 days transmitted the disease, with close to 100% efficiency, to healthy cohort smolts when injected intraperitoneally indicating the infectious agent is water borne and absorbed by skin mucus rather than being secreted with the skin mucus. Apparently the virus is replicated continuously in the fish, a fact which indicates seemingly healthy fish may be carriers and perform as reservoirs from which virus is shed over long periods of time. From their studies the authors offer the working hypothesis that the most likely ISA portal of entry is the gills.

*Number of days from infection of the fish to 50% mortality.

Subsequently Nylund et al. (1997) found that after experimental ISA infection of the rainbow trout, *Oncorhynchus mykiss*, the virus was still present 28 days later. The ISA virus was able to propagate in *O. mykiss*; but did not cause any significant observed mortalities in the rainbow trout. Thus these fish could act as disease free carriers (reservoirs for infection). Similarly Rolland and Nylund (1998) have shown that the virus could be propagated in sea run brown trout, *Salmo trutta*, without causing any gross pathological change enabling sea run brown trout to act as disease free carriers of the virus. An earlier speculation that ISA virus could be transferred from infected brown trout to Atlantic salmon with sea lice as a transfer mechanism, or by cohabitation independently of sea lice, was substantiated. These authors also refer to studies in which the virus was detected in the trout up to seven months following challenge raising the possibility of life long disease-free carrier status.

To summarize, the ISA virus appears to be propagated continuously in infected fish and is present in their blood, skin mucus, urine, faeces and other tissues. It is shed apparently continuously even by seemingly healthy, but infected, fish. The virus contributed to the water column through slaughter wastes (blood, viscera and other tissue), shed by infected Atlantic salmon or possibly by others such as disease free carriers (sea run brown or rainbow trout) appears to be water borne and can be transmitted directly, through cohabitation or via transfer mechanisms such as sea lice. The gills are considered the most likely tissue for passive transmission of the ISA virus.

The current practice in Norway for dealing with ISA among farmed salmon is to institute a restricted zone of 3-5 km radius (depending upon water currents and other factors) around farm sites diagnosed as infected with the ISA virus. The fish within the zone can be maintained until it is appropriate to slaughter them and market the products. If, however, mortalities within the cages increase (by a minimum of 0.5 fish/1000/cage/day) an order to slaughter the fish immediately can be issued on a cage by cage basis. No fish can be introduced to the restricted zone until all farm fish within are slaughtered and cleared out. Slaughter and transport must be carried out in facilities and under conditions approved by veterinary authorities; the process water must be disinfected and the viscera acidified to give a pH value below 4 for at least 24 hr to inactivate the virus. The waste material can then be processed in a special plant for the recovery of oil and the residue prepared as food for the rearing of fur bearing animals. Following the removal of all farm fish the area must be fallowed for one month before re-stocking is allowed. A discussion is taking place in Norway regarding the merits of the current procedures versus an approach in which an order to slaughter would be issued immediately upon positive diagnosis of ISA and would be independent of increasing mortalities.

Bacterial Kidney Disease

Renibacterium salmoninarum the causative agent of bacterial kidney disease is spread through the female to her progeny via the eggs; in addition it can also be transmitted to other susceptible fish through the water. After infection, death can result in a few months or can occur years later when a latent infection is activated by adverse environmental conditions, secondary infections or reproductive stress. Since for the most part *R. salmoninarum* is slow growing in infected fish, treatment with antibiotics can be ineffective as the antibiotic will be eliminated from the fish before the bacterium completes the necessary generational period (antibiotics are only effective against actively dividing bacteria). In addition, the bacterium can survive intracellularly in the fish phagocytes resulting in intracellular preservation (Gutenberger et al. 1997). Thus as no vaccines are available, broodstock and egg clean-up are the only profitable avenues to follow in attempting to eliminate this pathogen.

Furunculosis

Furunculosis, caused by the bacterium, *Aeromonas salmonicida*, is passed from fish to fish in both freshwater and marine environments. Mortalities can be quite high if the environmental conditions are poor and the fish are stressed; in other cases mortalities may be low, but smolts perform poorly. The disease can be transmitted horizontally via fish, farm equipment, birds and blood sucking parasites e.g. lice (Bruno et al. 1997) or vertically through the broodstock where infection of progeny by the parent can take place in the hatchery and thus introduce covertly infected smolts to the farm. Additional reservoirs of *A. salmonicida* are sediments from fish farms (Husevåg and Lunestad 1995), sea lice and marine plankton (Nese and Enger 1993). Nese and Enger detected *A. salmonicida* in Atlantic salmon farm sediments and isolated it in large numbers from surface disinfected sea lice (*L. salmonis*) originally picked from fish suffering from furunculosis i.e. 10,000 *A. salmonicida* cells/louse. The sea lice apparently are vectors for the transmission of furunculosis. Measures to reduce the problem of furunculosis include an emphasis on using, smolts free of *A. salmonicida*, vaccines, improved husbandry, elimination of furunculosis at farm sites, and fallowing to rid the area of an apparent vector, the sea lice (Bernoth et al. 1997). Jarp et al. (1993) concluded the main risk factors for infection with furunculosis in hatcheries were 1) migration of anadromous fish into the freshwater supply, 2) sharing of personnel with other fish farms, and 3) a high concentration of fish farms infected with *A. salmonicida* near the hatcheries. In the seawater farms it was determined that much of the problem resulted from the bacterium being transmitted between farms by humans.

Sea Lice

Sea lice constitute a hazard somewhat different from those caused by viruses, bacteria and rickettsia. They are large parasites with a complicated life cycle which has two non-parasitic stages followed by eight obligately parasitic stages; the lice can move from fish to fish. The life cycle has been outlined in Fig. 6 together with the information that the stages vulnerable to such chemicals as organophosphates are the pre-adult and adult stages only. Killing these stages leaves the remainder on the fish to mature and produce more eggs and thus provide more lice on a continuing basis ensuring that repeated chemical treatments will be required. If the cycle can be broken at the first obligately parasitic stage, the copepodid, by extended absence of the host (i.e. fallowing) a lengthy, essentially parasite free period can follow (see discussion under Single Bay Management in Section II). The problem with sea lice is not only the mortalities they cause directly, but also the wounds they create allowing other infectious agents to enter the fish. In addition they take up infectious agents themselves while feeding on infected fish. These disease agents can be passed then to other fish when the parasite moves to its next host. Thus the sea lice are potential and apparent vectors for transfer of diseases from fish to fish and from site to site.

Vectors

As noted above, sea lice have been identified clearly as apparent vectors for the transfer of *A. salmonicida* (Nese and Enger 1993) and Infectious Salmon Anaemia Virus (Nylund et al. 1993). Additionally, Nese and Enger (1993) showed *A. salmonicida* can be carried around the area on marine phytoplankton.

Adding to these hazards is the fact that the lice can be transported from site to site by fish outside the cages. The sea louse, *Lepeophtheirus salmonis* has been pinpointed not only as a probable vector within the fish farm cages, but also has been shown by Bruno and Stone (1990) to infest pollock (*Pollachius virens*) in the vicinity of salmon cages. These authors in a series of experiments also showed the *L. salmonis* could transfer from salmon to pollock and from pollock to salmon; moribund salmon and pollock appeared to attract more lice that did the healthy fish.

While *Caligus elongatus* is not as feared as *L. salmonis* as a direct parasite of salmon, its possible role as a vector for the onward transmission of diseases needs to be examined. If it can function as a vector the fact that it can be carried by as many as 73 different species of marine fish would make it more effective than *L. salmonis* in establishing reservoirs of infection in other species and transferring the agents over widely separated geographic areas. The roles of both species of sea lice as vectors need to be resolved as early as possible.

General

The ingredients for dealing with diseases generally are first and foremost avoidance of introducing disease agents initially by concentrating on eliminating them from the broodstock and by always vaccinating the smolts with appropriate vaccines. The vibrio diseases can be avoided by a combination of husbandry and vaccines - an approach that would be beneficial also in dealing with furunculosis. Elimination of the build-up of sediments under the cages will also remove a reservoir for those agents such as *A. salmonicida* (furunculosis) which can persist in the sediments. Where and when sea lice are a problem, fallowing for 2-3 months would appear to be the best line of defence; this will not only reduce the direct impact of the parasitism, but will also reduce the number of vectors in the area.

When a disease becomes established at a site, it is necessary to take all measures to confine it and eradicate it immediately. Massive numbers increase the chances of development of enhanced virulence of the infectious agent and will ensure its continuing release to the surrounding area. All the farms which share those waters will also be at risk and stand a good probability of sharing the disease.

Share the Water Share the Disease

There are limited data available to flesh out this maxim in practical terms. For obvious reasons it is not feasible to conduct widespread experiments with disease over extended geographic areas. The alternative is to study "natural experiments" i.e. disease experiences for arrays of fish farms or to undertake modelling studies using the best available data. The work described by Jarp and Karlsen (1997) on Infectious Salmon Anaemia (ISA) can also be considered a model of or proxy for Hemorrhagic Kidney Syndrome (HKS) as HKS apparently follows a similar course and may or may not, in fact, be wholly ISA, a question that is still being resolved for southern New Brunswick.

Jarp and Karlsen (1997) conducted a study of Infectious Salmon Anaemia risk factors in sea cultured Atlantic salmon in which they followed matched pairs of sea sites consisting of 37 ISA positive sites and 37 ISA negative sites. In their analysis they found "that the proportion of ISA negative sites located outside the zone fell markedly when the zone boundary was extended from 5 to 6 km from such a unit (an ISA positive site). Based on these results, a cut-off value for distance of less than or equal to 5 km was chosen in all further analyses of the risk associated with location".

Using this approach Jarp and Karlsen calculated odds associated with location. Location within 5 km of a salmonid slaughterhouse produced an ISA odds ratio of 13:1 compared to a location farther away; the risk of infection increased by an odds ratio of 8:1 if the site was situated closer than 5 km to another ISA positive farmstead compared to farms more than 5 km away. Disinfecting the waste water from slaughtering and processing seemed to prevent transmission of ISA. The risk of ISA was also associated with the number of hatcheries delivering smolts to the sites; this risk increased if hatcheries were located outside the site's home county. Overall results indicated that ISA was transmitted to new sites from infected sites mainly through sea water. Their recommendations included minimizing the risk of transmission by shortening the time between diagnosis of ISA and the elimination of positive sites, establishment of a 5 km minimum distance between sites, disinfection of wastes from slaughter and processing and implementation of good sanitary practices at farm sites. In Norway all ISA-positive fish have to be slaughtered in slaughterhouses following sanitary procedures and standards approved by the veterinary authorities; there is a requirement in Norway that disinfecting systems for the effluents from salmonid slaughterhouses and processing plants be installed along lines described by Torgersen and Håstein (1995).

Earlier Jarp et al. (1994) had studied the risk factors for furunculosis and Infectious Pancreatic Necrosis (IPN) and had concluded that, among other factors, mixing smolts from many different hatcheries increased the risk of IPN infections similar to the results with ISA. The reasons for this are at least twofold. One is that fish from different sources will have varying susceptibilities to a specific pathogen and another is that smolts from one hatchery may be carrying a pathogenic agent not found at the other hatcheries.

Turrell and Munro (1988) modelled the dispersal of soluble and infectious wastes from Atlantic salmon cages set in an hypothetical Scottish sea loch. The loch was 10 km long and 1 km wide; the farm of 70-700 tonnes annual production (being treated with 70 g oxytetracycline/day) was located 500 m from the upper end of the loch. Their calculations indicated that, given normal farm operations, the ammonia release from the farm would not affect existing ammonia levels, nor would the antibiotic release significantly affect biological activities in the loch. The constant shedding of *A. salmonicida*, however, even with the insertion of a logical decay factor, would result in numbers of viable infective particles in the loch such that all other farms established in the loch would be at risk, on a continuing basis, of contracting furunculosis.

In a somewhat different, but related study Wheatley et al. (1995) used epidemiological techniques to determine associations between farm management practices and mortality rates using data collated from 11 marine Atlantic salmon farms in Ireland over the period

1988-1992. "Analyses of the data base indicated that total mortality was significantly higher in years where sites were not fallowed ($P<0.05$), where more than one generation of fish were reared on site ($P<0.05$), where slaughtering of fish occurred on site ($P<0.05$) or where farm staff moved between farm sites ($P<0.05$). The individual effect of each of these practices on mortality rates could not be determined as farmers generally practice all four methods in conjunction. There was no association between mortality rates and the number of years of production on site, site depth or net clearance of the sea bed. The results suggest that the interruption of parasitic life cycles and/or the reduction in pathogenic organism load on site by fallowing, single generation rearing, and the practice of basic hygiene methods could be used as significant control measures for reducing the severity of disease outbreaks in populations of Irish farmed Atlantic salmon".

Movement of Waters in Passamaquoddy Bay Region

It is obvious from the foregoing that distances of 1 km are not effective barriers to the spread of disease. In fact, the few studies in which distance has been one of the risk factors examined, distances of 5 and 10 km, depending on circumstances, were not considered proof against the transmission of disease. When vectors such as marine plankton or sea lice transported by fish outside the cages are included in the equation it is obvious that there are no specific practical distances which can be delineated.

Thus the consideration of what can be considered a single or separate site for the purpose of management of diseases must turn to a consideration of the degree of water mixing. After consultations with B. Petrie, D.A. Greenberg and G. Bugden of the Bedford Institute of Oceanography, it was apparent that the best way to convey this information was graphically using simulations of the most important component i.e. tidal excursions in the Passamaquoddy Bay region (Fig. 7). This has been followed by a simulation of the dispersion of a single injection of particles over a single tidal cycle (Fig. 8). Dr. Greenberg and his associates kindly supplied the representations of the tidally driven dispersion patterns shown in Fig. 7 and 8 (note that wind and freshwater runoff components have not been included in the model). A dynamic display of these data is even more effective and informative; a computer-animated display is available on the World Wide Web at the following address: http://dfomr.dfo.ca/science/ocean/passamaquoddy/ under the title Passamaquoddy Bay Tidal Animations and can be observed using Microsoft/Explorer or Netscape/Java.

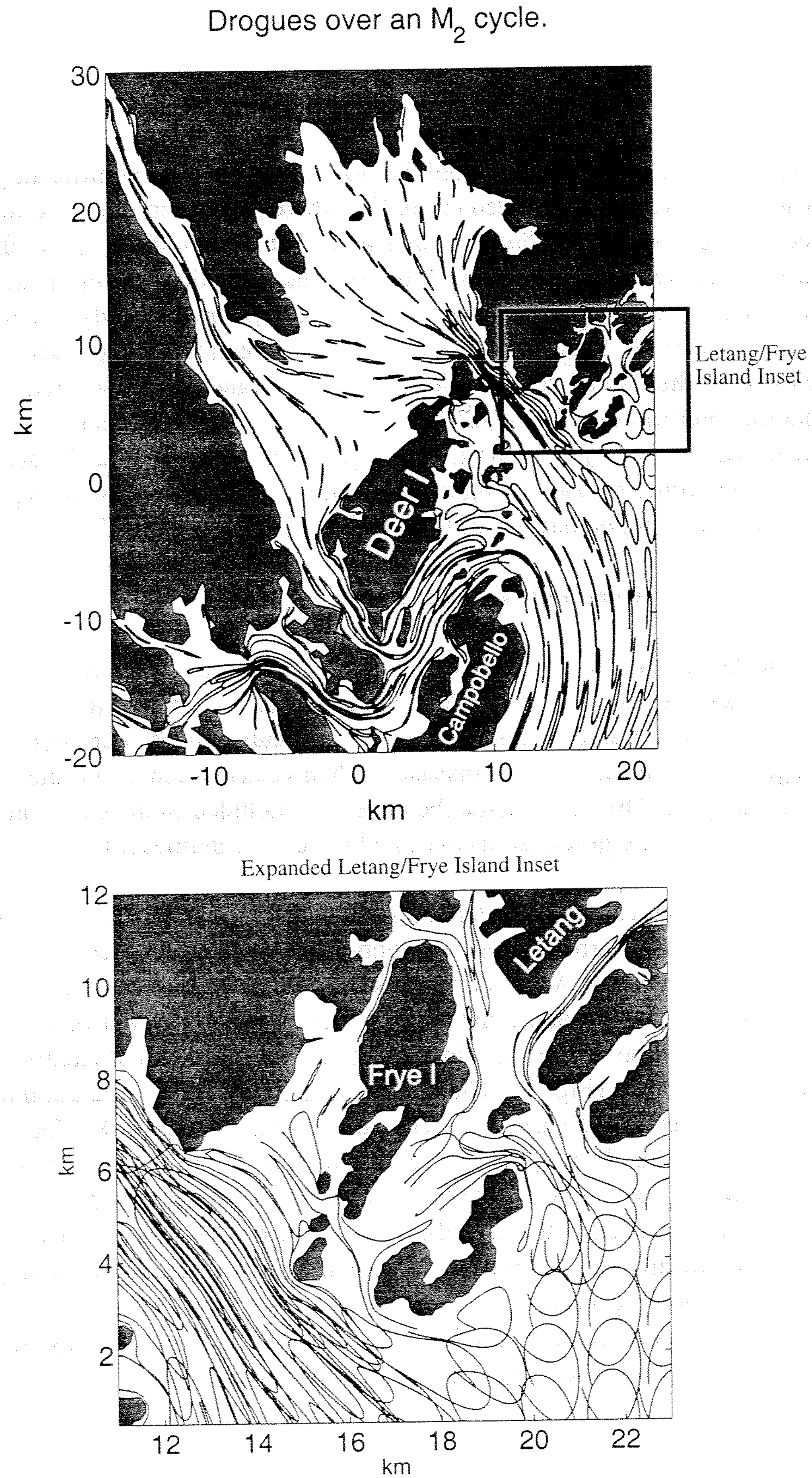

Fig.7. Simulated single tidal excursion particle trajectory plots for the Passamaquoddy region of New Brunswick. Lines represent trajectories and distances travelled by hypothetical particles over one complete tidal excursion (*flood tide to flood tide;* from Greenberg, Shore and Shen, 1998).

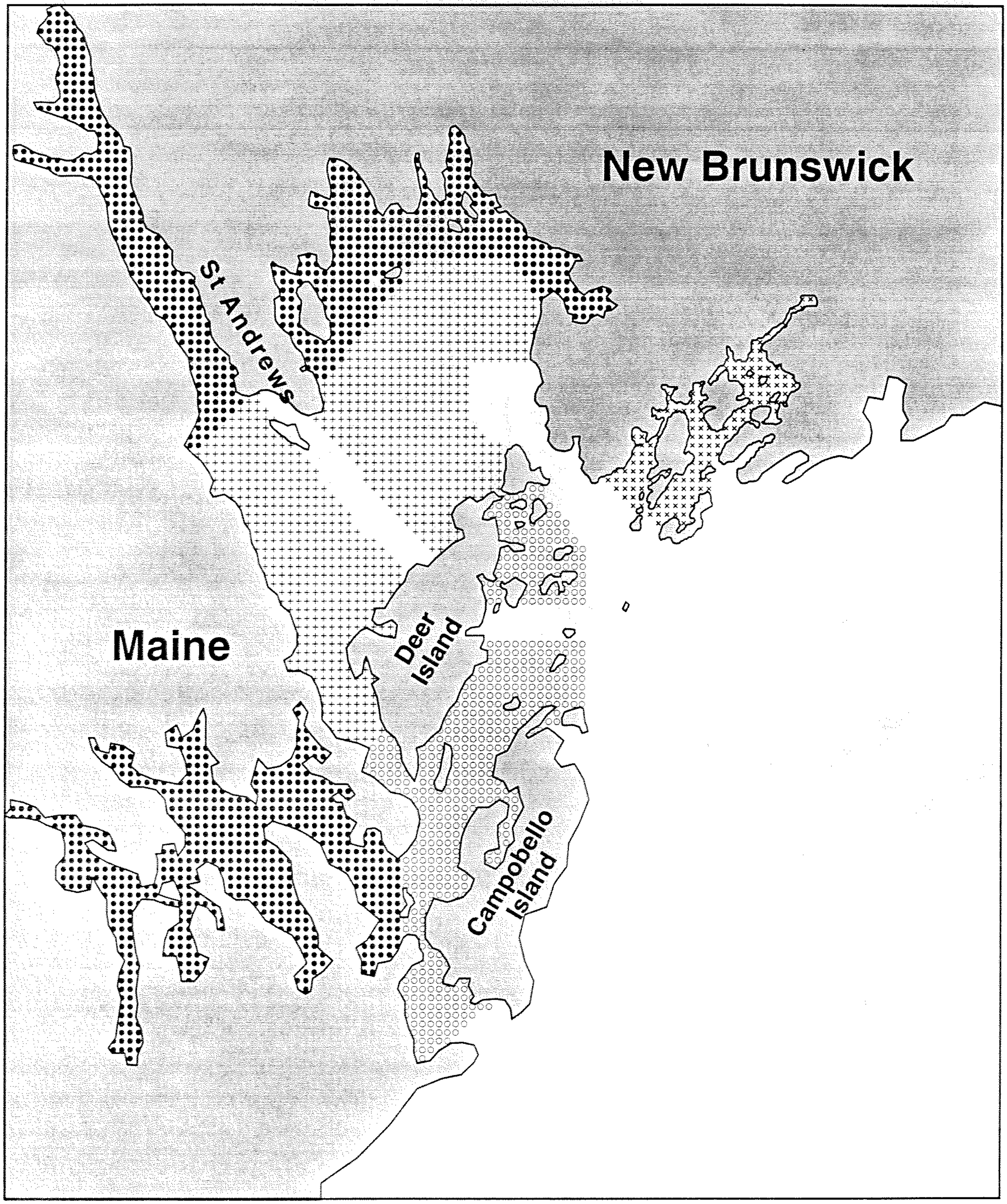

Fig. 8a. Zero time in the simulation of the dispersion of particles over 1 tidal cycle in the Passamaquoddy Bay region of New Brunswick beginning with a single injection of particles initially uniformly distributed. Note: contrary to appearances none of the particles have been removed through the course of the simulation, some have coalesced or have been superimposed on one another as would occur in reality (from Greenberg, Shore and Shen 1998).

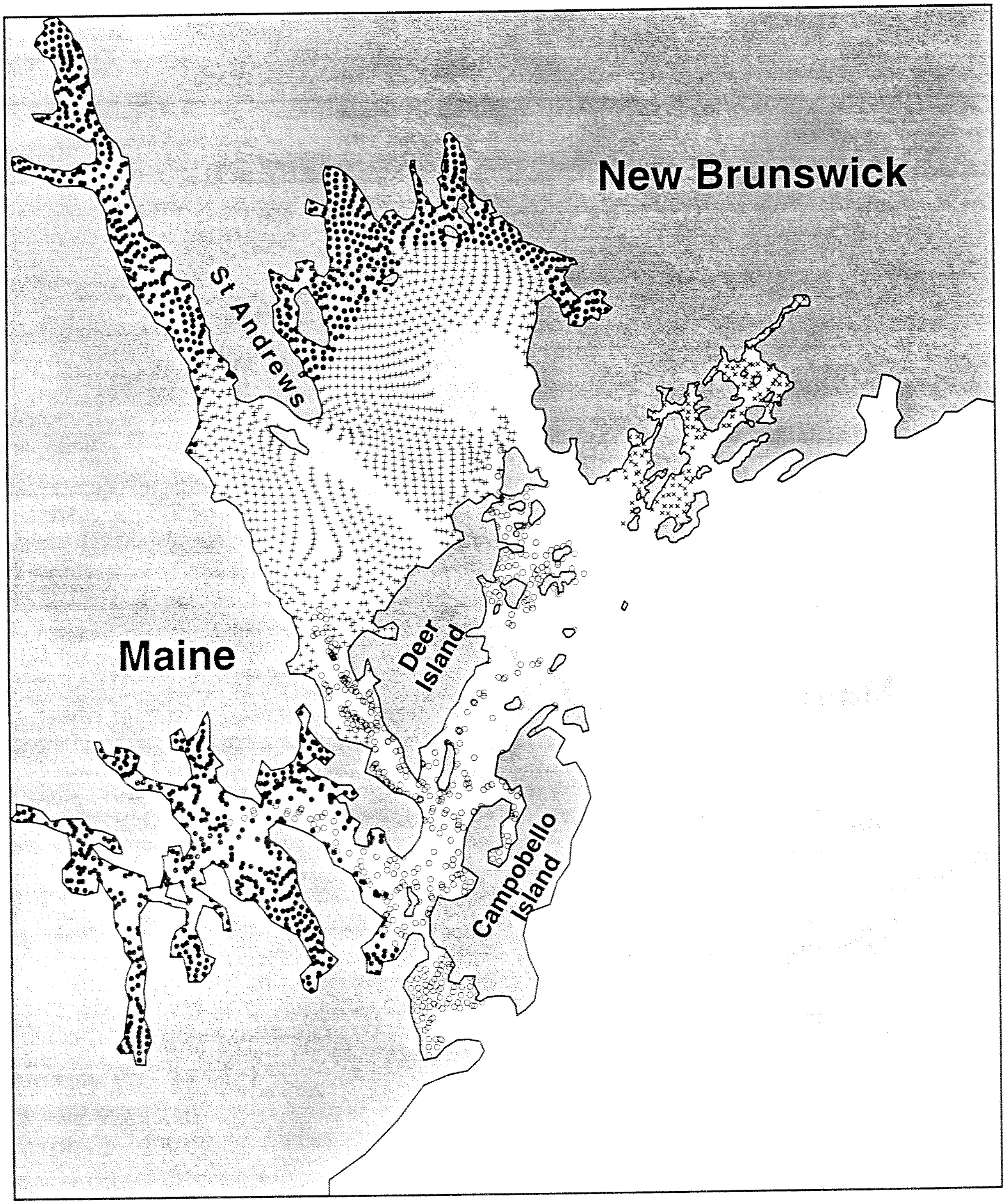

Fig. 8b. Completion of one quarter tidal cycle in the simulation of dispersion of particles in Passamaquoddy Bay (from Greenberg, Shore and Shen 1998)

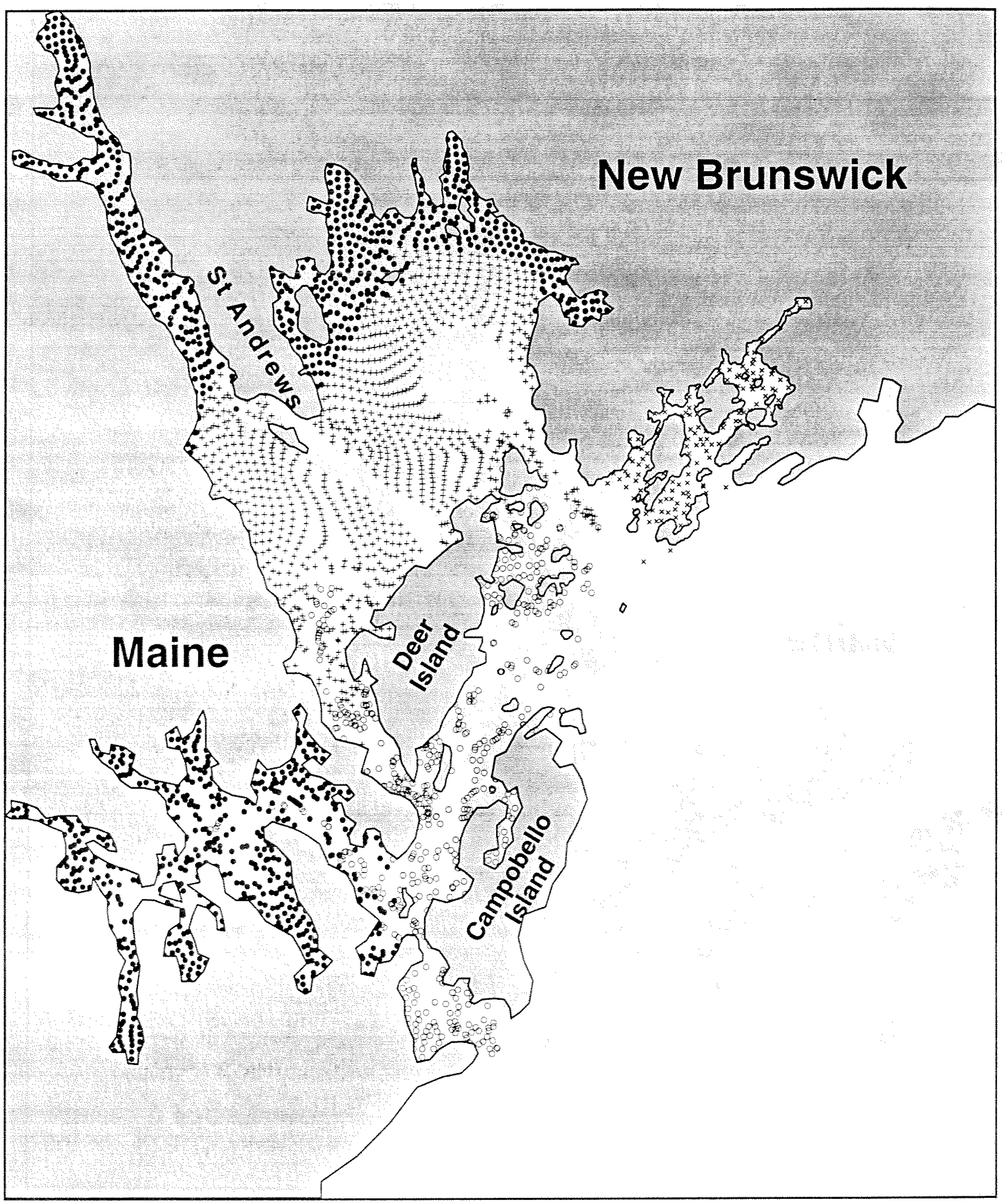

Fig. 8c. Completion of one half tidal cycle in the simulation of dispersion of particles in Passamaquoddy Bay (from Greenberg, Shore and Shen 1998).

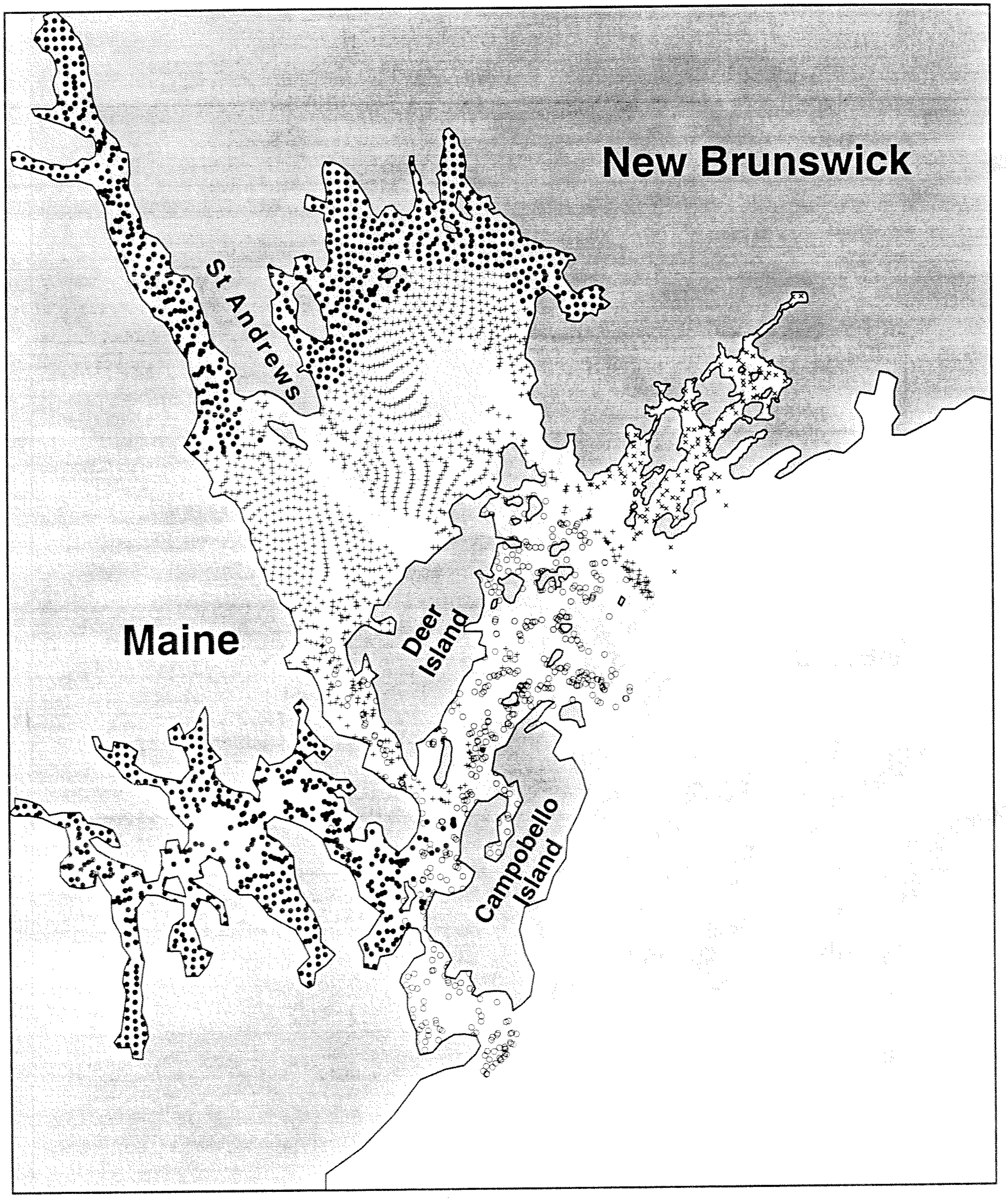

Fig. 8d. Completion of three quarters of the tidal cycle in the simulation of dispersion of particles in Passamaquoddy Bay (from Greenberg, Shore and Shen 1998).

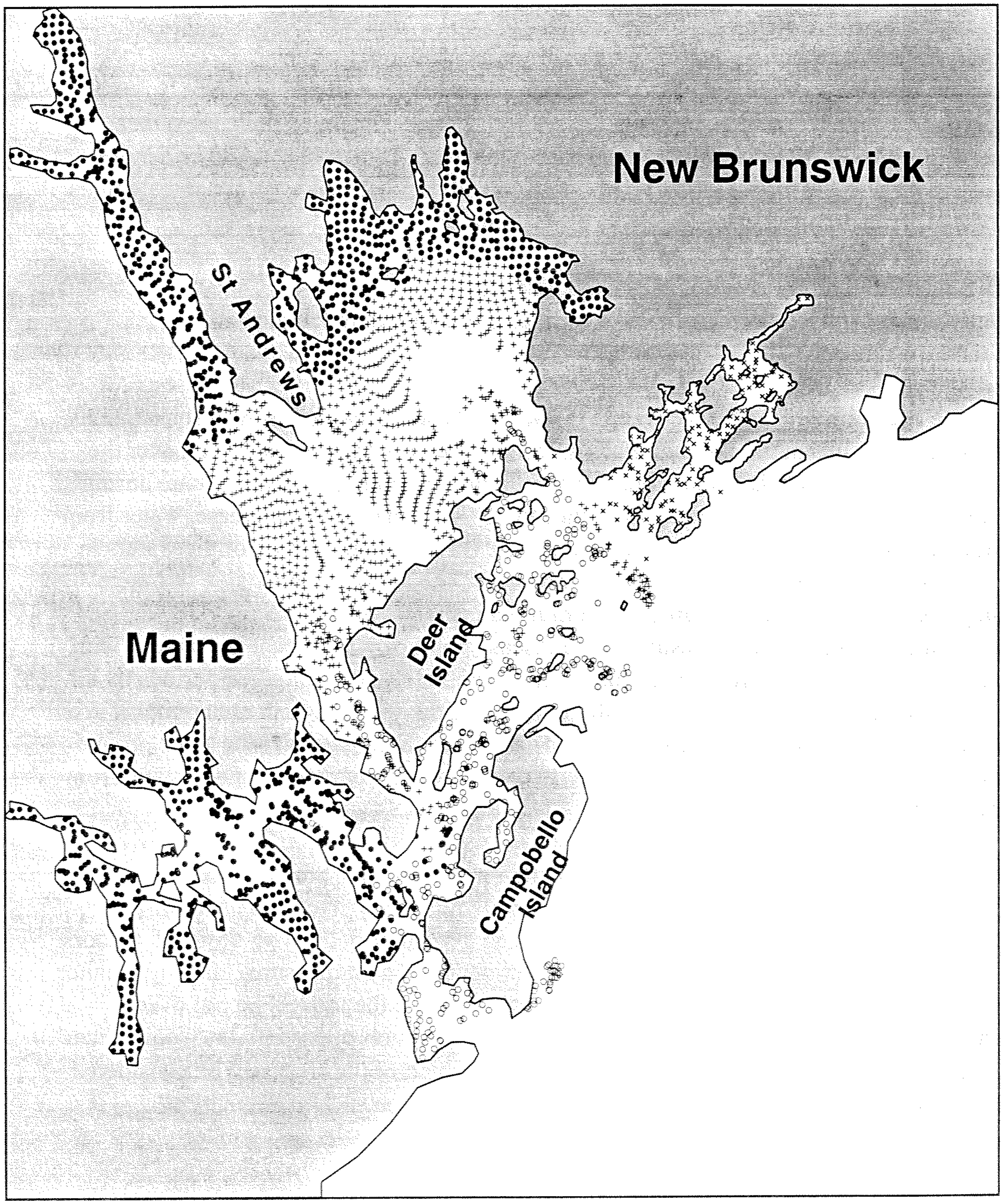

Fig. 8e. Completion of one full tidal cycle in the simulation of dispersion of particles in Passamaquoddy Bay (from Greenberg, Shore and Shen 1998).

As can be deduced from Fig. 7 and 8, the mixing of the waters in and around Passamaquoddy Bay are such that with the array of farms (Fig. 1a-e) there are at best, 3 separate sites based on infectious disease considerations. These areas could be Single Management Areas which it might be possible and advisable to manage as separate units to cope with health problems. The areas are in general:

1) The inner or northern part of Passamaquoddy Bay
2) Deer Island/Campobello Island plus the Letang side of Letete Passage
3) Grand Manan

As can be seen in Fig. 7 and 8 the waters in each of these 3 areas are moved substantially as a block, with substantial internal mixing, from one end of the area and back over the same ground on every tidal excursion. Very little mixing with new water occurs during the early tidal excursions. As time and hence number of tidal cycles increase, water from outside the area is slowly introduced resulting in a very gradual dilution of the waters in the areas identified above. Because of their position, the areas on either side of Letete Passage experience earlier and greater dilution than is recorded for the inner Passamaquoddy Bay. The net result from a disease point of view is that the waters, with disease agents entrained, are shared more or less completely for prolonged periods by all the farms in that specific area. Essentially the bulk of the water in each area remains in a relatively confined space in which it moves back and forth mainly over the same ground as the original water is being replaced slowly by new water from adjacent areas and from the Bay of Fundy.

The resolution of the precise areas which should be the basis for Single Area Management requires a simulation based upon realistic disease agent survival times; depending upon the agent, these survival times can exceed periods of 45 days. If vectors are considered the periods used should be greater depending on measures taken to counter the diseases. For all these considerations it is essential that the models be run over a much larger number of tidal cycles using continuous insertion of particles as would occur in a real disease situation; the ultimate decisions on which of the areas can be considered sufficiently separated for health purposes should be based on such mathematical modelling exercises.

SECTION IV: ENVIRONMENTAL

Carrying Capacity of Aquaculture Areas

In European and in British Columbian salmon farming, load limits are determined using mathematical models to assess the carrying capacity of the area, usually on the scale of an entire inlet. The farms are monitored after their establishment to check on the validity of the prediction and also the operation of the farm. The Norwegians use the comprehensive LENKA (Kryvi 1994, Stewart et al. 1993) and MOM (Ervik 1994, Ervik et al. 1997) systems for these purposes. The Scottish limits are established using models devised by Ross and associates; applications of these are described in Ross et al. (1993a and b) and Ross et al. (1994). The Scottish model incorporates the major physical and biological elements of the fjordic ecosystem and allows clear identification of the mechanisms underlying its behaviour and the impact that new loads imposed would have. Dr. B. Petrie, an oceanographic modeller (Bedford Institute of Oceanography) upon examination stated that the Scottish model was eminently suitable for this side of the Atlantic and could be readily applied to determining carrying capacities or load limits for the aquaculture areas of Atlantic Canada. In addition, Gillibrand and Turrell (1997) have described a suite of simple box models for the assessment of the relative impact of new and existing farms on the water quality of the entire loch. The potential enhancement of nutrient levels due to fish farms is predicted; the models have been tested using data on the dispersion of dichlorvos used in treatments against sea lice. Strain et al. (1995) have described a similar model involving nutrient loadings and oxygen demand which they applied to the Letang Inlet, New Brunswick and concluded that wastes from salmon aquaculture and fish processing were the dominant anthropogenic inputs. These models, however, will not predict impacts of farms on sea bed sediments; mathematical models describing the impacts on the benthic ecosystems beneath the farm cage sites are available (e.g. Silvert 1992, Hargrave 1994).

Accumulation and Dispersion of Sediments

Discussion of carrying capacities and load limits for aquaculture areas leads directly to consideration of organic matter accumulation in sediments under fish farm cages. This also raises the question of the period of time required for the accumulated sediments to disperse and the site to return to its original state.

Fortunately B. Hargrave and G. Phillips of the Marine Environmental Sciences Division, Bedford Institute of Oceanography were able to offer assistance. The team led by Dr. Hargrave had made a detailed 6 year study of a salmon site originally occupied (1990-1992) and then abandoned (1993-1996) in the Western Isles region of the Bay of Fundy (Bliss Harbour) (see also Hargrave et al. 1997). Measurements made for the Western

Isle site were compared with the mean values for the same variables derived from 11 non-farm or reference sites. The most sensitive measures are recorded in Table 2 and represented graphically in Figure 9. Although there was a marked improvement in the benthic conditions of this depositional site by the end of the first year of its abandonment it is clear that it had not returned completely to a pristine state even after 4 years. A casual observation from Scotland was that sediments appeared to accumulate more rapidly upon subsequent occupations of previous farm sites, indicating a possible long term effect; the data in Fig 9 may be an indication of which factors could be involved.

Farm sediments are regarded as an environmental problem as within the shadow of the fish farm cage the benthic ecology is affected; the area immediately below the cage can become azoic and anaerobic and the area surrounding the cages for 50 m or so is affected to varying degrees. As noted earlier the sediments have been shown to harbour *A. salmonicida*, the causative agent of furunculosis and because of their anaerobic nature will produce volatile gases such as methane, hydrogen sulphide and carbon dioxide which in shallow areas will be vented through the cages above. Although there is a wealth of information on the nature and composition of these outgassings (ebullition) there is little information on the effect these volatiles have on the farmed fish or on other biota in the vicinity, an omission that needs to be rectified. It can be assumed that these volatiles will add significantly to the stress levels experienced by the fish in the cages and thus contribute to immunosuppression resulting in increased susceptibility to infectious diseases.

According to Dr. Hargrave, studies his group conducted in the Annapolis Basin showed that when fish farm cages were placed in erosional areas sediment accumulation was rarely if ever noted. He advised that determining which sites would be erosional and which depositional could be done through a relatively simple set of calculations based upon a) current velocity, b) water depth and c) bottom shape in and around the proposed sites.

An alternative and rapid means to determine which areas are erosional and which are depositional (i.e. where the wastes would be expected to accumulate) can be accomplished also through prior survey and analysis of the bottom sediments. This is an accurate, straight-forward and relatively simple procedure. The basis for it is amplified in somewhat more technical language in the following paragraph supplied by T.G. Milligan:

"The aggregation dynamics of the particulate material and the hydrodynamics within any body of water will control the fate of surface-active contaminants. The formation and deposition of large, fast sinking aggregates by flocculation, which occurs in all saltwater

Table 2. Geochemical measurements in surface sediment at a single location at the Frye Island salmon aquaculture sites (Bliss Harbour) in the Western Isles region of the Bay of Fundy from 1990-1996. Means for each year are plotted as bar graphs in Figure 9.

Date	Eh (mV)	S= (mM)	C org (%)	N (%)	O_2 Uptake ($mM/m^2/hr$)	CO_2 Release ($mM/m^2/hr$)
1990						
May-16	-57	31	8.06	0.24	2.51	
Jun-06	45	7.1	7.70	0.24	3.40	
Jul-04	57	32.5	7.32	0.92	3.15	
Aug-01	-32	29.2	9.01	1.20	3.89	
Sep-05	-64	342.3	5.56	0.73	4.85	
Oct-03	-18	14.1	6.81	0.70	1.46	
Nov-05	-74	7.9	10.2	1.16	2.17	
Mean	-20	66.3	7.80	0.74	3.06	
Std. Dev.	48	113	1.39	0.36	1.05	
1991						
Feb-26	-31	5.5	11.31	1.27	1.75	
1992						
Sep-24	-31	4.0	4.14	0.67		
Sep-25	-53	6.5	4.94	0.66		
Mean	-42	5.3	4.54	0.67	4.89(n=5)	11.75(n=5)
Std. Dev.	11	1.3	0.40	0.01	1.26	8.21
1993						
May/June	-42		2.40			
Sep-27	26	0.20	2.08	0.27		
Sep-27	109	0.18	3.83	0.57		
Mean	31	0.19	2.77	0.42	1.39(n=5)	4.88(n=5)
Std. Dev.	62	0.01	0.76	0.15	0.19	1.37
1994						
Mar	-95		2.25			
Jun-29	84	0.19	1.69	0.18	0.85(n=3)	1.73(n=3)
Jun-29	-21	1.00	2.88	0.36		
Sep-27	54	0.42	2.19	0.31	1.22(n=6)	2.87(n=6)
Sep-27	52	0.42	2.27	0.31		
Mean	15	0.51	2.26	0.29	1.10(n=9)	2.49(n=9)
Std. Dev.	65	0.30	0.38	0.07	0.24	0.86
1995						
Jun-16	-141	5.40	3.31	0.42		
Jun-16	-128	5.80	4.71	0.60		
Sep-19	89	0.05	2.75	0.42		
Mean	-60	3.75	3.59	0.48	0.91(n=5)	1.68(n=5)
Std. Dev.	105	2.62	0.82	0.08	0.12	0.49
1996						
Sep-04	122	0.22	2.08	0.32		
Mean					1.22(n=5)	2.33(n=5)
Std. Dev.					0.13	1.41

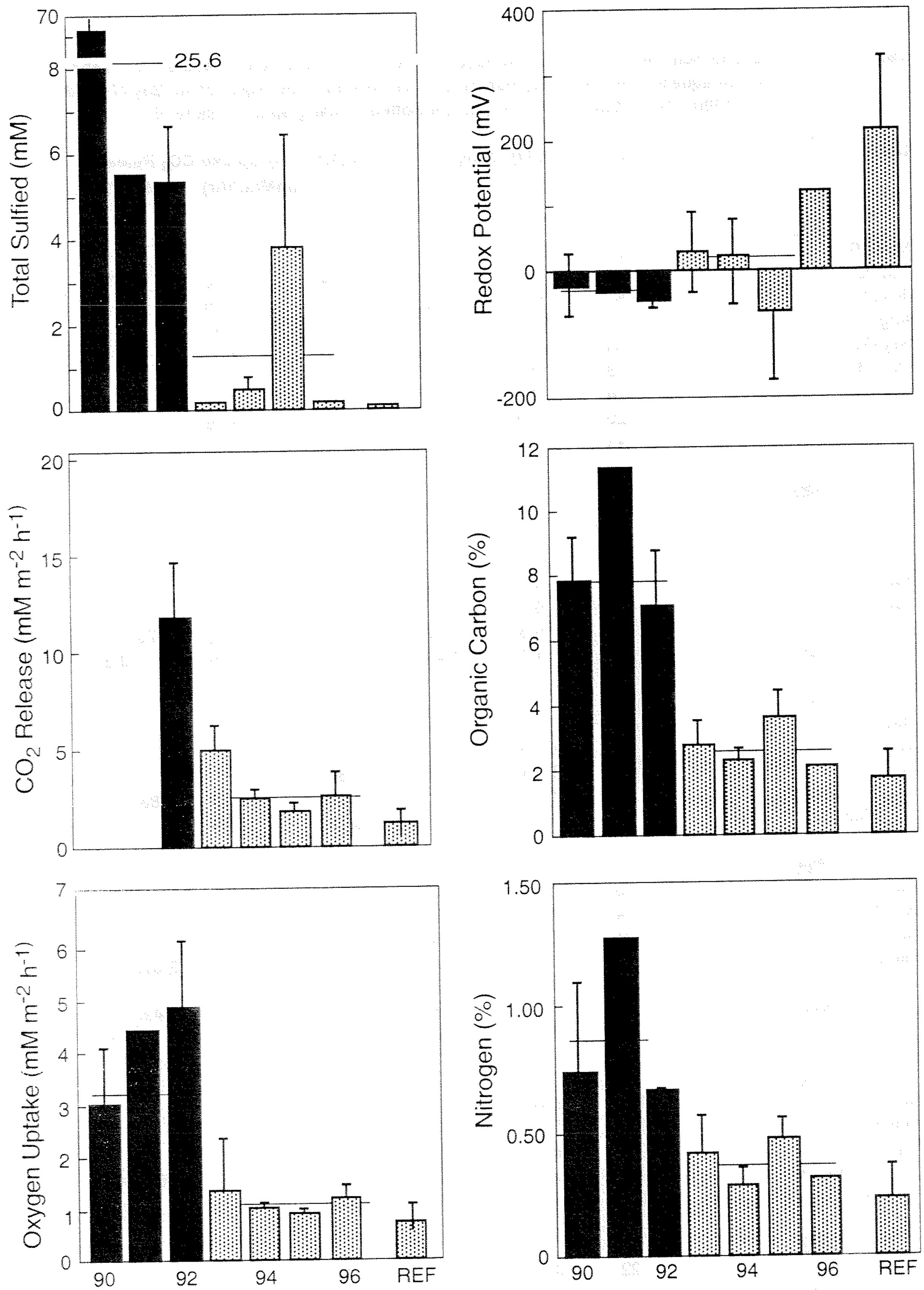

Fig. 9. The period of occupation is denoted by solid bars and the unoccupied period by hatched bars.

and most freshwater environments, governs the distribution of fine particulate material within the coastal zone (Milligan and Loring 1997, Kranck 1993). Aggregation models such as those of Jackson (1995) and Hill and Nowell (1995) contain three major terms to describe the development of a flocculated suspension: 1) particle number or concentration, 2) particle adhesion efficiency or stickiness and 3) particle break-up, most often due to an applied shear. The equilibrium size distribution of a flocculated suspension can be considered a balance between particle aggregation and disaggregation, hence changes to turbulence, composition or concentration can affect the distribution of fine particulate material and contaminants (Milligan and Loring 1997, Milligan and Hill, In Press). The introduction of waste feed, faecal material, and their resulting degradation products from aquaculture operations will likely increase both particle concentration and particle stickiness. Intense aquaculture could also be expected to decrease turbulence. As a result, the natural flocculation and depositional equilibrium could become unbalanced toward increased deposition of particulate material and the sequestering of contaminants within the surficial sediment."

SECTION V: STRATEGIES

Given the limited number of well sheltered areas in and around the desired high tidal range (6 m) areas of southern New Brunswick it is difficult to see how new alternative sites could be made available for fallowing and single year class separation and rearing. If it is necessary to hold fish year-round in well sheltered areas then the provision of production sites and alternate fallow sites can probably be accomplished mainly by reducing the number of farm sites now occupied on a year round basis.

There might be merit in considering offshore sites for all or part of each growth cycle. In Ireland, the bulk of the farming is done off their western coast within a mile or two of the shore in more or less open waters in large Bridgestone cages. Fish are reared there for the full cycle. According to the Irish authorities the weather in winter only occasionally prevents them from servicing the farms and then only for a couple of days at a time.

About 5 to 10% of the Scottish farms now occupy offshore sites for the warm weather periods of the year. Their weather is much more severe than that in the Irish areas and if the cages are left out in severe weather the fish would be damaged in the cages, impairing growth and providing wounds which would act as portals of entry for infectious agents. They use smaller net cages than the Irish, because at the end of the warm weather season they must tow them into the sheltered, relatively shallow lochs. In these instances, they plant the smolts offshore in April and tow the cages ashore in and around October. In addition, they are attempting to reduce their marine growth periods to as short a period as possible (currently it is 12-15 months); this is being accomplished by strain selection and improved nutrition. They have major concerns over the impact of towing on the fish as it can be quite stressful and they emphasize that they try to keep handling to the absolute minimum in all of their farming practices to reduce stress and consequent mortalities.

It is possible the fish farmers of southern New Brunswick may be able to devise regimes in which planting of smolts offshore allows a 2-3 month fallowing or rotation of fallowing sites inshore coupled with Single Year Class Rearing and Single Area Management at the several separate rearing sites now occupied; 1) the inner or northern Passamaquoddy Bay area, 2) Deer Island/Campobello Island, Letang Inlet and approaches and 3) Grand Manan. If such a regimen were to be attempted it obviously would require the maximum degree of cooperation and coordination of all concerned farmers, regulators and technical support staff.

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REFERENCES

Barton, B.A. and G.K. Iwama. 1991. Physiological changes in fish from stress in aquaculture with emphasis on the response and effects of corticosteroids. Ann. Rev. Fish Dis. 1: 3-26.

Bernoth, E.-M., A.E. Ellis, P.J. Midtlyng, G. Olivier and P. Smith (eds.). 1997. Furunculosis: multidisciplinary fish disease research. Academic Press, San Diego, 529 p.

Bruno, D.W., D.J. Alderman and H.J. Schlotfeldt. 1997. What should I do? A practical guide for the marine fish farmer. European Association of Fish Pathologists, 64 p.

Bruno, D.W. and J. Stone. 1990. The role of saithe, *Pollachius virens L.*, as a host for the sea lice, *Lepeophtheirus salmonis* Krøyer and *Caligus elongatus* Nordmann. Aquaculture 89: 201-207.

Costello, M.J. 1993. Review of methods to control sea lice (Caligidae:Crustacea) infestations on salmon (*Salmo salar*) farms. *In* G.A. Boxshall and D. Defaye (eds.). Pathogens of wild and farmed fish: sea lice. Ellis Horwood Ltd., New York, p. 219-252.

Enger, Ø., B. Husevåg and J. Goksøyr. 1989. Presence of the fish pathogen *Vibrio salmonicida* in fish farm sediments. Appl. Environ. Microbiol. 55: 2815-2818.

Ervik, A. 1994. Modelling and monitoring internal impact from fish farms. *In* A. Ervik, P.K. Hansen and V. Wennevik (eds.). Proceedings of the Canada-Norway workshop on environmental impacts of aquaculture. Institute of Marine Research, Bergen, p. 69-75.

Ervik, A., P.K. Hansen, J. Aure, A. Stigebrandt, P. Johannessen and T. Jahnsen. 1997. Regulating the local environmental impact of intensive marine fish farming. I. The concept of the MOM system (Modelling - Ongrowing fish farms - Monitoring). Aquaculture 158: 85-94.

Fryer, J.L. and M.J. Mauel. 1997. The rickettsia: an emerging group of pathogens in fish. Emerging Infectious Diseases 3: 137-144.

Gillibrand, P.A. and W.R. Turrell. 1997. The use of simple models in the regulation of the impact of fish farms on water quality in Scottish sea lochs. Aquaculture 159: 33-46.

Grant, A.N. and J.W. Treasurer. 1993. The effects of fallowing on caligid infestations on farmed Atlantic salmon (*Salmo salar L.)* in Scotland. *In* G.A. Boxshall and D. Defaye (eds.). Pathogens of wild and farmed fish: sea lice. Ellis Horwood Ltd., New York, p. 255-260.

Greenberg, D.A., J. Shore and Y. Shen. 1998. Modelling tidal flows in Passamaquoddy Bay. *In* Burt, M.D.B. and P.G. Wells, (Eds.) 1998. Coastal Monitoring and the Bay of Fundy. Proceedings of the Maritime Atlantic Ecozone Science Workshop, held in St. Andrews, New Brunswick, November 11-15, 1997. Huntsman Marine Science Centre, St. Andrews, NB. p. 58-64.

Gutenberger, S.K., J.R. Duimstra, J.S. Rohovec and J.L. Fryer. 1997. Intracellular survival of *Renibacterium salmoninarum* in trout mononuclear phagocytes. Dis. Aquat. Org. 28: 93-106.

Hargrave, B.T. (ed.). 1994. Modelling benthic impacts of organic enrichment from marine aquaculture. Can. Tech. Rep. Fish. Aquat. Sci., Dartmouth, Nova Scotia, No. 1949. 125 p.

Hargrave, B.T., G.A. Phillips, L.I. Doucette, M.J. White, T.G. Milligan, D.J. Wildish and R.E. Cranston. 1997. Assessing benthic impacts of organic enrichment from marine aquaculture. Water, Air and Soil Pollution 99: 641-650.

Hill, P.S. and A.R.M. Nowell. 1995. Comparison of two models of aggregation in continental-shelf bottom boundary layers. J. Geophys. Res. 100 (C11): 22,749-22, 763.

Husevåg, B. and B.T. Lunestad. 1995. Presence of the fish pathogen *Aeromonas salmonicida* and bacteria resistant to antimicrobial agents in sediments from Norwegian fish farms. Bull. Eur. Ass. Fish Pathol. 15: 17-19.

Jackson D. 1997. Progress report on Single Bay Management. 4 p.

Jackson, D., S. Deady, Y. Leahy and D. Hassett. 1997. Variations in parasitic caligid infestations on farmed salmonids and implications for their management. ICES J. Mar. Sci. 54: 1104-1112.

Jackson, D. and D. Minchin. 1993. Lice infestations of farmed salmon in Ireland. *In* G.A. Boxshall and D. Defaye (eds.). Pathogens of wild and farmed fish: sea lice. Ellis Horwood Ltd., New York, p. 188-201.

Jackson, G.A. 1995. Comparing observed changes in particle size spectra with those predicted using coagulation theory. Deep Sea Res. II, 42: 159-184.

Jarp, J., A.G. Gjevre, A.B. Olsen and T. Bruheim. 1994. Risk factors for furunculosis, infectious pancreatic necrosis and mortality in post-smolt of Atlantic salmon, *Salmo salar* L. J. Fish Dis. 18: 67-68.

Jarp, J. and E. Karlsen. 1997. Infectious salmon anaemia (ISA) risk factors in sea-cultured Atlantic salmon *Salmo salar*. Dis. Aquat. Org. 28: 79-86.

Jarp, J., K. Tangen, F.V. Willumsen, H.O. Djupvik and A.M. Tveit. 1993. Risk factors for infection with *Aeromonas salmonicida* subsp. *salmonicida* in Norwegian freshwater hatcheries. Dis. Aquat. Org. 17: 81-86.

Johnson, S.C. and L.J. Albright. 1991. Development, growth, and survival of *Lepeophtheirus salmonis* (Copepoda:Caligidae) under laboratory conditions. J. Mar. Biol. Ass. UK 71: 425-436.

Kranck, K. 1993. Flocculation and sediment particle size. Arch. Hydrobiol./Suppl. 75: 299-309.

Kryvi, H. 1994. Coastal zone management in Norway - LENKA and its applications. *In* A. Ervik, P.K. Hansen and V. Wennevik (eds.). Proceedings of the Canada-Norway workshop on environmental impacts of aquaculture. Institute of Marine Research, Bergen, p. 19-27.

Milligan, T.G. and P.S. Hill. In Press. A laboratory assessment of the relative importance of turbulence, particle composition, and concentration in limiting maximal floc size and settling behaviour. J. Sea Res.

Milligan, T.G. and D.H. Loring. 1997. The effect of flocculation on the size distributions of bottom sediment in coastal inlets: implications for contaminant transport. Water Air Soil Pollution 99: 33-42.

Nese, L. and Ø. Enger. 1993. Isolation of *Aeromonas salmonicida* from salmon lice *Lepeophtheirus salmonis* and marine plankton. Dis. Aquat. Org. 16: 79-81.

Nylund, A., T. Hovland, K. Hodneland, F. Nilsen and P. Løvik. 1994. Mechanisms for transmission of infectious salmon anaemia (ISA). Dis. Aquat. Org. 19: 95-100.

Nylund, A., A.M. Kvenseth, B. Krossøy and K. Hodneland. 1997. Replication of the infectious salmon anaemia virus (ISAV) in rainbow trout, *Oncorhynchus mykiss* (Walbaum). J. Fish. Dis. 20: 275-279.

Nylund, A., C. Wallace and T. Hovland. 1993. The possible role of *Lepeophtheirus salmonis* (Krøyer) in the transmission of infectious salmon anemia. *In* G.A. Boxshall and D. Defaye eds.). Pathogens of wild and farmed fish: sea lice. Ellis Horwood Ltd., New York, p. 367-373.

Olsen, A.B., H.P. Melby, L. Speilberg, Ø. Evensen and T. Håstein. 1997. *Piscirickettsia salmonis* infection in Atlantic salmon *Salmo salar* in Norway - epidemiological, pathological and microbiological findings. Dis. Aquat. Org. 31: 35-48.

Pickering, A.D. 1997. Husbandry and stress. *In* E.-M. Bernoth, A.E. Ellis, P.J. Midtlyng, G. Olivier and P. Smith (eds.). Furunculosis: multidisciplinary fish disease research. Academic Press, San Diego, p. 178-202.

Pickering, A.D. and T.G. Pottinger. 1989. Stress responses and disease resistance in salmonid fish: Effects of chronic elevation of plasma cortisol. Fish Physiology and Biochemistry 7: 253-258.

Pickering, A.D., T.G. Pottinger and P. Christie. 1982. Recovery of the brown trout, *Salmo trutta* L., from acute handling stress: a time-course study. J. Fish. Biol. 20: 229-244.

Pickering, A.D. and A. Stewart. 1984. Acclimation of the interrenal tissue of the brown trout, *Salmo trutta* L., to chronic crowding stress. J. Fish. Biol. 24: 731-740.

Rolland, J.B. and A. Nylund. 1998. Sea running brown trout: carrier and transmitter of the infectious salmon anemia virus (ISAV). Bull. Eur. Ass. Fish Pathol. 18: 50-55.

Ross, A.H., W.S.C. Gurney and M.R. Heath. 1993a. Ecosystem models of Scottish sea lochs for assessing the impact of nutrient enrichment. ICES J. Mar. Sci. 50: 359-367.

Ross, A.H., W.S.C. Gurney and M.R. Heath. 1994. A comparative study of the ecosystem dynamics of four fjords. Limnol. Oceanogr. 39: 318-343.

Ross, A.H., W.S.C. Gurney, M.R. Heath, S.J. Hay and E.W. Henderson. 1993b. A strategic simulation model of a fjord ecosystem. Limnol. Oceanogr. 38: 128-153.

Schram, T.A. 1993. Supplementary descriptions of the developmental stages of *Lepeophtheirus salmonis* (Krøyer, 837)(Copepoda:Caligidae). *In* G.A. Boxshall and D. Defaye (eds.). Pathogens of wild and farmed fish: sea lice. Ellis Horwood Ltd., New York, p. 30-47.

Silvert, W. 1992. Assessing environmental impacts of finfish aquaculture in marine waters. Aquaculture 107: 67-79.

Smith, P. 1997. The epizootiology of furunculosis: The present state of our ignorance. *In* E.-M. Bernoth, A.E. Ellis, P.J. Midtlyng, G. Olivier and P. Smith (eds.). Furunculosis: multidisciplinary fish disease research. Academic Press, San Diego, p. 25-53.

Stewart, J.E., E.C. Penning-Rowsell and S. Thornton. 1993. The LENKA Project and coastal zone management in Norway. *In* OECD documents: Coastal Zone Management Selected Case Studies. OECD, Paris, p. 257-281.

Strain, P.M., D.J. Wildish and P.A. Yeats. 1995. The application of simple models of nutrient loading and oxygen demand to the management of a marine tidal inlet. Mar. Poll. Bull. 30: 253-261.

Thompson, I., A. White, T.C. Fletcher, D.F. Houlihan and C.J. Secombes. 1993. The effect of stress on the immune response of Atlantic salmon (*Salmo salar* L.) fed diets containing different amounts of vitamin C. Aquaculture 114: 1-18.

Thorud, K.E. 1991. Infectious salmon anemia. Thesis Dr Scientiarum, Norwegian College of Veterinary Medicine, Oslo.

Thorud, K. and H.O. Djupvik. 1988. Infectious anaemia in Atlantic salmon (*Salmo salar* L.). Bull. Eur. Ass. Fish. Pathol. 8: 109-111.

Torgersen, Y. and T. Håstein. 1995. Disinfection in aquaculture. Rev. Sci. Tech. Off. Int. Epizoot. 14: 419-434.

Totland, G.K., B.K. Hjeltnes and P.R. Flood. 1996. Transmission of infectious salmon anaemia (ISA) through natural secretions and excretions from infected smolts of Atlantic salmon *Salmo salar* during their presymptomatic phase. Dis. Aquat. Org. 26: 25-31.

Turrell, W.R. and A.L.S. Munro. 1988. A theoretical study of the dispersal of soluble and infectious wastes from farmed Atlantic salmon net cages in a hypothetical Scottish sea loch. ICES. CM 1988/F:36, Mariculture Committee, 20p.

Wheatley, S.B., M.F. McLoughlin, F.D. Menzies and E.A. Goodall. 1995. Site management factors influencing mortality rates in Atlantic salmon (*Salmo salar* L.) during marine production. Aquaculture 136: 195-207.

Wood, B.P., D.W. Bruno and K. Ross. 1996. Infectious pancreatic necrosis virus (IPNV) mortalities among farmed Atlantic halibut, *Hippoglossus hippoglossus* L., in Scotland. Bull. Eur. Ass. Fish. Pathol. 16: 214-216.