268481

AQUACULTURE INFORMATION REVIEW - AN EVALUATION OF KNOWN EFFECTS AND MITIGATIONS ON FISH AND FISH HABITAT IN NEWFOUNDLAND AND LABRADOR

AMEC Earth and Environmental Limited
95 Bonaventure Avenue
St. John's NL A1B 2X5

Issuing Establishment:
Science, Oceans and Environment Branch
Oceans Programs Division
Department of Fisheries and Oceans
P.O. Box 5667
St. John's NL Canada A1C 5X1

Canadian Technical Report of Fisheries and Aquatic Sciences No. 2434

Fisheries and Oceans Pêches et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

CANADIAN TECHNICAL REPORT OF
Fisheries and Aquatic Sciences 2434

2002

AQUACULTURE INFORMATION REVIEW - AN EVALUATION OF KNOWN EFFECTS AND MITIGATIONS ON FISH AND FISH HABITAT IN NEWFOUNDLAND AND LABRADOR

by

AMEC[1]

Marine Environment and Habitat Management Division
Fisheries and Oceans Canada
Northwest Atlantic Fisheries Centre
P.O. Box 5667
St. John's, NL A1C 5X1

[1]AMEC Earth and Environmental Limited, 95 Bonaventure Avenue, St. John's NL A1B 2X5

Cat. No. Fs 97-6/2434 ISSN 0706-6457

Published by:

Fisheries and Oceans Canada
Aquaculture Collaborative Research and Development Program
This is report contribution #N-01-06-005 for the ACRDP

Correct citation for this publication:

AMEC. 2002. Aquaculture information review - an evaluation of known effects and mitigations on fish and fish habitat in Newfoundland and Labrador. Can Tech. Rep. Fish. Aquat. Sci. 2434: vii + 47 p.

TABLE OF CONTENTS

	Page
ABSTRACT	V
RESUME	VI
1.0 INTRODUCTION	1
1.1 OBJECTIVES	2
1.2 STUDY TEAM	2
2.0 PUBLIC POLICY	2
3.0 AQUACULTURE INDUSTRY IN NEWFOUNDLAND AND LABRADOR	3
3.1 SALMONIDS	4
3.2 MUSSELS	4
3.3 ATLANTIC COD	5
4.0 LITERATURE REVIEW	6
5.0 POTENTIAL AQUACULTURE EFFECTS	7
5.1 WATER QUALITY	8
5.1.1 Dissolved Oxygen (DO) Concentrations	9
5.1.2 Increased Turbidity	10
5.1.3 Release of Organic Substances	10
5.1.4 Potential Mitigations	13
5.1.5 Data Gaps	15
5.2 SEDIMENT QUALITY	15
5.2.1 Settling Of Suspended Solids	16
5.2.2 Nutrient Enrichment/Loading	17
5.2.3 Increased Bacteria Levels (Hydrogen Sulphide Production)	18
5.2.4 Benthic Macrofauna	19
5.2.5 Sediment Disturbance	20
5.2.6 Monitoring of Sediment Quality	20
5.2.7 Potential Mitigation	22
5.3 WASTE ACCUMULATION AT SITE	24
5.4 ALTERATION OF NATURAL FISH MIGRATION	24
5.4.1 Escapes	25
5.4.2 Code of Containment	26
5.5 DIRECT CHANGE OF HABITAT FOR NATURAL SPECIES	27
6.0 SUMMARY	27
6.1 THE CEAA PROCESS IN RELATION TO MARINE AQUACULTURE IN NEWFOUNDLAND AND LABRADOR	28
6.1.1 A Class-type Approach	28
6.1.2 Industry-Wide Pre-Development Activities	29
7.0 RECOMMENDATIONS	31
Acknowledgements	32
8.0 REFERENCES	33

LIST OF TABLES

Table 1. Literature Review on Aquaculture Effects in Newfoundland and Labrador Study Team ... 2
Table 2. Summary of Data Sources and their Applicable Category ... 7
Table 3. Ranges of Water Quality Parameters Suitable for Mussel Facilities ... 13
Table 4. Three Levels of Investigation (as per Hansen *et al.* 2001) ... 22
Table 5 Summary of farmed Atlantic salmon and steelhead trout captured/ identified in Conne River, 1990-2001 ... 26

LIST OF FIGURES

Figure 1. Salmonid Aquaculture Sites ... 40
Figure 2. Mussel Aquaculture Sites ... 41
Figure 3. Atlantic Cod Grow-out Sites ... 42
Figure 4 Simplified pathway showing fate of nutrients on a typical fish farm ... 43
Figure 5. Hypothetical *k*-dominance curves for species biomass and numbers, showing unpolluted, moderately polluted and grossly polluted conditions (Warwick 1989) ... 44

LIST OF APPENDICES

Appendix 1. Contact was made with the following people during the project ... 45
Appendix 2. Ranges of water quality parameters suitable for cod grow out facilities .. 46
Appendix 3. Summary of seabed categories under salmonid aquaculture operations ... 47

ABSTRACT

AMEC. 2002. Aquaculture information review - an evaluation of known effects and mitigations on fish and fish habitat in Newfoundland and Labrador. Can Tech. Rep. Fish. Aquat. Sci.: 2434: vii + 47 p.

The Department of Fisheries and Oceans (DFO) is mandated to establish a balance between enabling sustainable growth of the Canadian aquaculture industry and regulating such development in accordance with the *Navigable Waters Protection Act* (NWPA) while minimizing environmental effects on fish and fish habitat. Responsibility for the conservation and protection of fish and fish habitat is in accordance with provisions of the *Fisheries Act* and the Department's Management of Fish Habitat Policy. For aquaculture development this responsibility includes determining whether a project is likely to result in a harmful alteration, disruption or destruction (HADD) of fish habitat, thereby requiring a Section 35 (2) *Fisheries Act* authorization. In keeping with the No Net Loss guiding principal of the department's policy, aquaculture developers would have to compensate for losses in productive fish habitat. Prior to issuing an approval under the NWPA and/or a Section 35(2) *Fisheries Act* Authorization, the department is obligated to conduct an environmental assessment of the project in accordance with the *Canadian Environmental Assessment Act (*CEAA*)*.

In Newfoundland and Labrador, the biogeography, climate, oceanography and marine resources are such that the aquaculture industry faces biological and physical challenges that may have different environmental implications on marine habitat as compared to other Canadian provincial jurisdictions. DFO, as the responsible authority for the application of CEAA to aquaculture development, has the obligation to ensure that the environmental-assessment process is applied with the most current and up-to-date information. It is well recognized within industry that knowledge gaps can skew the CEAA process, causing it to act as a supporter or a spoiler. The Newfoundland aquaculture industry, recognizing the need to identify environmental issues, to provide information to address the issues, and to act responsibly, has been quick to point out the need for new knowledge towards understanding aquaculture-environment interactions and thereby pursue sound strategies towards achieving industry sustainability.

In support of its mandate, both to regulate and enable aquaculture development, DFO in conjunction with the Newfoundland Aquaculture Industry Association (NAIA), initiated an investigation of the potential environmental concerns of Newfoundland and Labrador-based aquaculture operations. Monitoring and mitigation techniques applied to other jurisdictions, as well as this province, are described for each effect where applicable. Data gaps also are outlined. This report outlines nine recommendations towards filling knowledge gaps in basic biophysical information requirements of proposed local aquaculture sites and potential mitigation techniques suitable to aquaculture development in Newfoundland and Labrador coastal marine areas.

RESUME

AMEC. 2002. Aquaculture information review - an evaluation of known effects and mitigations on fish and fish habitat in Newfoundland and Labrador. Can Tech. Rep. Fish. Aquat. Sci. 2434: vii + 47 p.

Le ministère des Pêches et des Océans (MPO) est mandaté de trouver un juste équilibre entre permettre la croissance durable de l'aquaculture au Canada et réglementer celle-ci conformément à la *Loi sur la protection des eaux navigables (LPEN)*, tout en réduisant le plus possible ses répercussions environnementales sur les poissons et leur habitat. La responsabilité en matière de conservation et de protection des poissons et de leur habitat est conforme aux dispositions de la *Loi sur les pêches* et à la politique de gestion de l'habitat du poisson du MPO. En ce qui concerne le développement de l'aquaculture, le MPO est notamment chargé de déterminer si un projet risque de détériorer, de détruire ou de perturber l'habitat du poisson (DDPHP); si tel est le cas, ce projet doit être autorisé en application du paragraphe 35(2) de la *Loi sur les pêches*. Conformément au principe directeur « aucune perte nette » de la politique du MPO, les promoteurs de l'aquaculture devraient compenser pour tout dommage causé à un habitat du poisson productif. Avant d'émettre une autorisation en vertu de la *LPEN* ou du paragraphe 35(2) de la *Loi sur les pêches*, le MPO doit effectuer une évaluation environnementale (EE) du projet conformément à la *Loi canadienne sur l'évaluation environnementale (LCEE)*.

À Terre-Neuve-et-Labrador, comparativement aux autres provinces canadiennes, la biogéographie, le climat, l'océanographie et les ressources marines font en sorte que l'industrie de l'aquaculture doit relever des défis biologiques et physiques qui peuvent avoir différentes répercussions environnementales sur l'habitat marin. À titre d'autorité responsable de l'application de la *LCEE* dans le cadre du développement de l'aquaculture, le MPO a l'obligation de s'assurer que l'évaluation environnementale est réalisée avec les données les plus à jour. Les membres de l'industrie admettent que des données incomplètes peuvent tout aussi bien fausser ce processus avantageusement que désavantageusement. L'industrie de l'aquaculture de Terre-Neuve reconnaît le besoin de cerner les questions environnementales, de fournir de l'information nécessaire pour les traiter et d'agir de manière responsable. Elle a également eu vite fait de noter l'importance d'améliorer la compréhension des interactions entre l'aquaculture et l'environnement et, de cette façon, de mettre en oeuvre de bonnes stratégies visant à assurer la durabilité de l'industrie.

Dans le cadre de son mandat de réglementer et de permettre le développement de l'aquaculture, le MPO et la Newfoundland Aquaculture Industry Association (NAIA) ont lancé un examen des préoccupations environnementales potentielles liées à l'aquaculture à Terre-Neuve-et-Labrador. Dans ce rapport, les méthodes de surveillance et d'atténuation s'appliquant à cette province, ainsi qu'aux autres provinces, sont décrites pour chaque répercussion, le cas échéant. Les lacunes dans les données y sont également présentées. Ce rapport donne un aperçu de neuf recommandations en matière de développement des connaissances sur les caractéristiques biophysiques des sites locaux proposés pour l'aquaculture et sur les méthodes d'atténuation potentielles adéquates pour le développement de cette industrie dans les zones marines côtières de Terre-Neuve-et-Labrador.

1.0 INTRODUCTION

Aquaculture in Newfoundland and Labrador is an important economic activity recognized as a priority in the strategic development plans of both the provincial and federal governments. In the interval snce the initial experiments in the 1970's, aquaculture has grown to become a well-established, diversified, viable economic sector.

The aquaculture industry in Newfoundland and Labrador is very different from that of Atlantic Canada and British Columbia. The biogeography, climate, oceanography and marine resources of Newfoundland and Labrador are such that our aquaculture industry faces different biological and physical challenges and may have different environmental effects on marine habitat as compared with other areas. There is also an emphasis within the Newfoundland and Labrador aquaculture industry to focus on further developing salmon, steelhead trout, mussels and cod aquaculture ventures.

While the growth of the aquaculture sector is positive economically, it also presents certain challenges to government agencies such as the Department of Fisheries and Oceans (DFO) that seek to find a balance between promoting sustainable growth in the industry while minimizing environmental effects to fish and fish habitat. In support of its mandate to both regulate and enable aquaculture development, DFO in conjunction with the Newfoundland Aquaculture Industry Association (NAIA) initiated a study to investigate the potential environmental effects of Newfoundland and Labrador-based aquaculture operations.

This report is broken down by the potential positive and negative effects resulting from and impacting on aquaculture operations in other parts of Canada and the world. Each effect is generally described from the literature. A description of relevant Newfoundland and Labrador material is also included as a separate sub-section. Monitoring and mitigation techniques applied in other jurisdictions as well as this province are described for each effect where applicable. Data gaps, if not obvious from the appropriate sub-sections, are also outlined. The study does not, however, assess whether mitigations used in other parts of the world would be successful in Newfoundland and Labrador. Any mitigations used in this province are specifically identified as such.

The scope of work for this study focused on habitat-based effects of aquaculture operations, therefore potential effects such as escapes and alterations to migration were included only if specific Newfoundland and Labrador data were available. The scope of work did not include potential effects that are regulated by other provincial or federal agencies such as navigable waters, disease transmission, predator attraction, or release of hazardous substances.

1.1 OBJECTIVES

The overall objectives of this study are as follows:

- To conduct a literature review to document the nature and extent of scientific information pertaining specifically to aquaculture effects in Newfoundland and Labrador; and

- To review the scientific data, along with additional information supplied by aquaculture growers throughout the province, in determining the physical and biological effects of aquaculture as currently practiced in Newfoundland and Labrador, on fish and fish habitat.

1.2 STUDY TEAM

The study team included a group of fishery and aquaculture scientists and the study was managed by AMEC Earth & Environmental Limited (Table 1).

Table 1. Literature Review on Aquaculture Effects in Newfoundland and Labrador Study Team.

Study Element	Personnel
Environmental Effects Determination	Mr. James McCarthy Dr. James Smith Mr. David Robbins Mr. Bevin LeDrew
Newfoundland and Labrador Aquaculture Sector; and, Science Issues	Dr. James Smith Mr. James McCarthy Mr. Harold Murphy Mr. David Wells

2.0 PUBLIC POLICY

Under Canadian public policy, DFO has the responsibility for aquaculture development. In Newfoundland and Labrador, a Canada/Newfoundland Memorandum of Understanding (MOU) on Aquaculture Development was signed in 1988 between the provincial and federal governments to facilitate the promotion, development and regulation of the aquaculture industry in a streamlined and efficient manner. The MOU outlines the roles and responsibilities of each government in such areas as regulation, compliance and inspection, planning, applied research and development, stock registry, education and training, statistics, and co-ordination. Also, DFO has identified aquaculture development as a priority in its strategic plan and is committed to enabling its sustainability. This dual role as both regulator and enabler of sustainable aquaculture development has led DFO to begin establishing an "enabling regulatory environment" for this sector. The goals of this process include increased clarity, efficiencies in the regulation-assessment process and technological support for the aquaculture sector.

Legislative Requirements

DFO is responsible for the conservation and protection of fish and fish habitat in accordance with provisions of the *Fisheries Act* and DFO's Policy for the Management of Fish Habitat. For aquaculture development this responsibility includes determining whether a project is likely to result in a harmful alteration, disruption or destruction (HADD) of fish habitat, thereby requiring a Section 35 (2) *Fisheries Act* Authorization. In keeping with the No Net Loss guiding principal of DFO's Policy, aquaculture developers would have to compensate for any losses in productive fish habitat. In addition, prior to issuing a Section 35(2) *Fisheries Act* Authorization, DFO is obligated to conduct an environmental assessment of the project in accordance with the *Canadian Environmental Assessment Act (*CEAA*)*.

The *Fisheries Act* also requires that aquaculture developments be reviewed by DFO to identify potential concerns with fisheries management issues including:

- Potential effects on wild stocks;
- Implications to the management of commercial and recreational fisheries; and
- Effects on primary stakeholders including commercial, recreational and Aboriginal harvesters.

While DFO, through its Canadian Coast Guard (CCG) division, also has a legislated mandate to protect navigation in accordance with the *Navigable Waters Protection Act* (NWPA), and to complete a CEAA review, the application of this act in relation to aquaculture development is not part of the mandate of this study.

DFO Policy Initiatives

While DFO, on the one hand, has responsibility for regulating aquaculture development, it also recognizes the economic importance of the aquaculture sector and is committed to enabling the sustainable growth of such developments. To this end, DFO has created an Office of Sustainable Aquaculture (OSA) that has published a series of guidelines supporting the efficient review and regulatory approval of aquaculture developments. These guidelines represent a first step in creating what DFO refers to as an "enabling regulatory environment" in support of the aquaculture sector (DFO 2002).

3.0 AQUACULTURE INDUSTRY IN NEWFOUNDLAND AND LABRADOR

This section provides a "project description" to identify the relative importance of aquaculture, its growth, potential for additional growth within the province, and concerns pertaining to such development. Also included is an overview of the geographic extent of the province's aquaculture operations and the relative composition (by species) of the industry.

3.1 SALMONIDS

Typical salmonid aquaculture operations in Newfoundland and Labrador have key characteristics that can potentially affect the aquatic environment. Sites are usually located in areas where there is a balance between protection from wave action/ice and adequate flushing characteristics. They are located in areas with temperature ranges that are most appropriate for the species being farmed. Bottom structure near sites is considered only with respect to availability of suitable substrate for anchoring of cages. Water depth at sites tends to be a compromise between having sufficient water to assist in dispersal of generated particulate matter and excess anchoring concerns. One of the current practices in salmonid operations in the province is the rotation of cages on a seasonal basis (i.e., between summer and winter locations).

Salmonid growers generally utilize circular cages of 70m circumference (some 50m cages are still in use but more farmers are switching to the larger cages) constructed of plastic. These cages are built and maintained to industry standards. Dry feed pellets are used at all sites in the province.

The salmonid sector of the aquaculture industry in Newfoundland and Labrador is located principally in the Bay d' Espoir region. It produces two species: Atlantic salmon and steelhead trout. There are 12 active winter sites and 13 summer sites, however these numbers vary by season and by the individual operators' business conditions. According to the provincial Department of Fisheries and Aquaculture (DFA), there are currently 51 Atlantic salmon and steelhead trout licenses established and/or pending in Newfoundland and Labrador (Figure 1).

The primary species produced in the province is steelhead trout. The sector is comprised of six companies: one producing Atlantic salmon and five producing steelhead. The annual production of salmonids was 2,500mt in 1999, 1,500mt in 2000 and 2,800mt in 2001. It is projected that production will retain the 2001 level or increase slightly in 2002 depending on market conditions.

There are indications that the sector may be ready for growth. It has the experience and skills to move forward with expansion, though such expansion will depend on market conditions and available capital. Generally, an overall goal of development is to reach production levels of 5,000mt. Recent capacity studies indicate that this level is attainable and sustainable. Any expansion will be commercially driven and subject to environmental requirements. It is difficult to tie any increased production trends to an established timeline since market conditions and operational capital have become limiting factors in the growth of the sector. Sector challenges include attaining a higher market value and the high cost of importing juveniles. Supply of local juveniles also factors into this.

3.2 MUSSELS

Typical mussel aquaculture operations in Newfoundland and Labrador have key characteristics that potentially can affect the environment. Mussel farms in the province are sited based on various conditions, all of which may vary in importance depending on the individual site. These parameters may include:

- exposure and fetch length;
- flushing rate;
- bottom type for anchorage;
- average yearly water temperatures, extremes in temperatures and thermal stability (does it fluctuate with tidal, wind and wave action?);
- salinity and proximity to fresh water outflows;
- ice – both land fast and Arctic (e.g,, is there a shoal at the site that prevents Arctic ice from entering?);
- gear-type used; and,
- species to be cultured.

Mussel long lines or rafts typically are anchored to the sea bottom. Sites typically are harvested and reseeded within the same year, hence no true fallowing of sites occurs. Some operators may reseed an area in the following season, thereby effectively leaving the location fallow for some time.

Mussel farms are distributed through much of Newfoundland's coastal zone with significant concentrations in the Green Bay/Notre Dame Bay area and the Connaigre Peninsula on the South Coast. Figure 2 presents the current and pending sites registered with the provincial DFA. The mussel industry has experienced good growth over the past two years and is expected to have continued good potential for long-term growth. Burke Consulting Inc. (2000) suggests that Newfoundland and Labrador's potential for growth exceeds that of the other Atlantic provinces.

Mussel production increased by 80% from 1998 to 1999 and had an export value of $3.8M in 1999. The establishment of secondary mussel production facilities in Newfoundland and Labrador has reduced some of the competitive disadvantages that are present in fresh production.

Currently, there are over 100 established and pending mussel growing sites/operations in Newfoundland and Labrador of which 19 are new/pending operations. Additional new license applications are expected in the coming months. It is currently estimated that demand for mussels far outweighs supply in North America (C. Couturier, pers comm.).

3.3 ATLANTIC COD

Typical cod grow-out operations in Newfoundland and Labrador have key characteristics that potentially can affect the marine environment. Sites generally are located near open sea habitat that provides flushing and optimal temperature regimes for growth. This is balanced with suitable protection against high winds and waves that are prevalent in the fall. Suitable depths are chosen under cages to allow for adequate dispersal of food and faeces.

Cages are smaller than those used in salmonid aquaculture and generally are filled with fewer fish. Raw fish (herring, mackerel, and capelin) is used as food as opposed to dry pellets.

Atlantic cod grow-out from wild stock is viewed as having potential for industrial growth in Newfoundland and Labrador. This sector had a farm gate value in excess of $500,000 in 2001. Cod aquaculture from egg to market is emerging from the R&D stage and represents an additional sector growth opportunity.

Year	# of Farms	Production (HOG lbs.)	Farm gate Value C$
1997	8	72,600	72,500
1998	4	68,200	92,775
1999	7	35,400	344,500
2000	18	416,300	578,677
2001	17	480,000	552,000

Cod fed raw fish can double their weight in approximately 100 days. These fish then are sold on an "as ordered" basis late in the season when prices are traditionally higher. Cod-grow out typically is a seasonal operation, lasting approximately three to four months during the summer and fall, after which the site is left fallow for the remainder of the year.

Trap harvesters are in a unique position to take advantage of this opportunity as many have the boats, possess gear construction and handling skills, and much of the equipment required. A simple, low-tech approach that is not heavily dependent on scientific skills or costly infrastructure has shown to have good prospects for success. In addition, the numerous coves and inlets along the coast of Newfoundland offer significant site opportunities. Currently there are 85 new/pending site licence applications and renewals for cod farming with the provincial DFA (Figure 3). Renewals for 2002 make up 50 of these licence applications. Challenges for the sector include reliable and timely sources of wild stock and consistency in market prices.

4.0 LITERATURE REVIEW

Many literature sources were reviewed for this report. All databases and periodicals at the Queen Elizabeth II Library at Memorial University, the Marine Institute, and DFO were searched. Team members also searched the library of the provincial DFA in Grand Falls.

In addition to searching databases, communications were undertaken with researchers, growers, associations, and experts in the aquaculture industry. Appendix 1 lists those individuals contacted and their affiliation. Each was asked for information or to provide comments based on their experience. Most provided input in the form of referrals to others, references to literature, and some verbal information. The latter was provided mainly by growers.

Literature used in the report has been archived in a Microsoft Access database and deposited with the Marine Environment and Habitat Management division of DFO in St. John's. Literature not specifically included in the report is also included in the database as it may be applicable to other users of the archive. Table 2 below presents the literature in the database by geographic location and topic.

Table 2. Summary of data sources and their applicable category (as of March 31, 2002).

Topic	Location of Study			
	Newfoundland	Maritimes	Canada	International
Water Quality	2	3	4	75
Sediment/Benthos	1	11	2	52
Possible Effect On Natural Populations	0	2	8	12
Disease	0	0	1	3
Antibacteria/Bio-Fouling	0	1	1	3
Ecosystem Interactions	12	3	0	17
Overall Effects (General)	3	11	13	60
Methods and Mitigations	19	6	18	46
Siting	5	0	2	5
Other (Diet, Genetics, Terminology, Drugs, Predation)	2	0	4	51

5.0 POTENTIAL AQUACULTURE EFFECTS

Potential effects, both positive and negative, of aquaculture on fish and fish habitat may be attributed to physical, biological, or chemical processes. Figure 4 depicts a simplified pathway showing fate of nutrients on a typical fish farm.

These processes can lead to:

- effects on fish habitat (both positive and negative) through changes in physical and geo-chemical conditions, including the water column and benthic components of the environment (Smith 2001);
- effects on fish habitat (both positive and negative) through changes in ecological conditions, including primary and secondary production in the water column and benthos (Smith 2001);
- effects on local fish and aquatic species (both positive and negative) near aquaculture operations through changes in nutrient cycles and inputs; and
- direct acute or sub-lethal toxicity of resident species (Smith 2001).

The information on each potential effect (i.e., mitigations to reduce the overall negative intensity, frequency, and duration) can be reviewed by appropriate managers or regulatory agencies to determine whether it may have a significant impact on fish and fish habitat. The literature specifically from Newfoundland and Labrador will assist in determining whether adequate local information regarding a potential effect or mitigation is available and whether the effect may occur as a result of local operating regimes (e.g., fallowing), farm sizes, siting practices, or local environmental and species considerations.

It should be noted that potential effects that do not directly affect fish habitat, and which are under the authority of other agencies, have been excluded from this report such as disease transmission and control, predator attraction, and release of hazardous substances.

This section outlines the potential aquaculture (i.e., finfish, shellfish) effects that may have an impact on fish and fish habitat based on information gathered. It presents an overview of each effect based on research and information from various aquaculture locations throughout the world. As well, this section outlines research that has been conducted in Newfoundland and Labrador on the subject and provides a summary of the results.

Each effect is described, to the extent possible, in terms of:

- The type of effect (i.e., physical, chemical, biological);
- The potential cause (e.g., fish feeding, bio-fouling control, offal disposal, accidental spills);
- Duration of effect (i.e., short-term/seasonal, long-term/year-round);
- Zone of influence (near-field/under cage, far-field/surrounding environment); and,
- Potential recovery time (i.e., if impact has ceased).

The section also presents identified **mitigation techniques** (literature, communication, ongoing research) applied at various sites in Newfoundland and Labrador, and elsewhere, and their effectiveness in minimizing potential effects. Any mitigation techniques utilized by the Newfoundland and Labrador aquaculture industry are clearly differentiated from other national/international techniques that have not yet been utilized and/or documented locally.

Each mitigation is described, to the extent possible, in terms of its:

- Effectiveness;
- Extent of influence (i.e., temporal and spatial); and
- Limitations.

Based on the above descriptions, **data gaps** also will be discussed as they pertain to Newfoundland and Labrador.

5.1 WATER QUALITY

Effects of aquaculture operations on water quality can be both physical and biological. Uneaten food (organic and inorganic nutrients), faecal and excreted material resulting from the digestive and metabolic activity of the stock (organic and inorganic nutrients), and removal of fouling organisms from cages and equipment can affect water quality within and near sites. Water quality encompasses several specific parameters that are outlined in detail below.

5.1.1 Dissolved Oxygen (DO) Concentrations

A potential effect of aquaculture, particularly from species such as salmonids, is a reduction in the DO concentration of the surrounding aquatic environment. This effect can occur around many different types of aquaculture operations due to increases in biological oxygen demand (BOD) brought on by microbial breakdown of uneaten feed, excess faeces, and overall increases in organic input (Wu 1995). Sites that experience low flushing, low currents or excessive estuarine influence may also experience problems with phytoplankton blooms. Under certain oceanographic conditions, dying phytoplankton may kill or stress both farmed and native fish through DO reductions in water (SCCDC 1998, Novotny and Pennell 1996).

Brown *et al.* (1987) found that DO concentrations can range from 35–70% saturation at distances of 3m from marine salmonid cages and 50–85% saturation at distances greater than 15m. These results indicate that waters near intensive aquaculture operations, with relatively high ambient DO levels, could experience severe DO decreases as a result of fish respiration alone. This is similar to freshwater farming conditions as Axler *et al.* (1996) estimated that 64–74% of the DO demand in lakes containing aquaculture operations could occur directly from fish respiration.

Most studies have shown that marine fish farms do not have a significant adverse impact on DO levels (Pitts 1990). In general, increases in BOD occur in the water column around salmonid fish farms, but have been shown to return to normal approximately 30m away from the pens (Beveridge and Muir 1982, Phillips and Beverage 1986, Gowen and Bradbury 1987). In an Environmental Impact Statement (EIS) on fish culture in floating net-pens produced for the State of Washington, it was stated that DO consumption by fish and microbial decomposition of fish wastes and excess food could reduce DO concentrations near fish farms (Pitts 1990). However, the EIS found that the DO requirements of salmon raised in farms limits the impact the farm itself can have on the surrounding environment since salmonids require water with high levels of DO in order to maintain rapid oxygen delivery to the blood. Therefore, low DO concentrations are more likely to affect the farm than the converse (Pitts 1990). It should be noted that DO can be a chronic rather than acute problem for both the farm and the environment. This problem, however, can be mitigated by proper fish/cage densities, clean cages, and possibly aeration (J. Smith pers comm.).

Newfoundland and Labrador

In Newfoundland and Labrador, the potential effect of aquaculture on DO levels in the surrounding aquatic environment has been monitored for both salmonid and shellfish operations in selected areas. No information could be found on potential changes in DO resulting from cod grow-out operations, however growers interviewed did not identify it as a potential problem.

In Bay d'Espoir, one of the potentially limiting factors of productivity is availability of safe over-wintering sites that offer good water quality, protection from ice, and accessibility to aquaculture cages (Tlusty *et al.* 1999). Roti Bay has been identified as one of these locations (ADB 1998). During the winter of 1997, Roti Bay was monitored for various water quality parameters including DO. Monitoring was conducted in the immediate vicinity of over-wintering salmon cages and at distances greater than 50m away. In general, aquaculture operations had little or no effect on water quality (Tlusty *et al.* 1999).

In shellfish operations, monitoring of water quality has been conducted at various aquaculture sites around the Island (Clemens *et al.* 2000). This study indicated that there was very little variation in DO concentrations near aquaculture sites that could be attributed to oxygen depletion resulting from stocking with shellfish. There was some evidence of subsurface oxygen depletion in early summer near the halocline (i.e., depth where sharp change in salinity occurs) where oxygen levels were measured below 80% saturation. This typically appears to happen, however, after the spring algal bloom (Clemens *et al.* 2000). There was also some evidence of oxygen depletion near the sediment surface at some sites where saturation dropped to approximately 70% in late summer. It was suggested that this could be due to sediment oxygen consumption by microbes and benthic fauna (Clemens *et al.* 2000).

5.1.2 Increased Turbidity

Although aquaculture operations may cause increased turbidity within surrounding waters (Pitts 1990), this typically has been associated with net/cage cleaning and high levels of fine particulates in feeds, especially bulk feed systems. This activity (physical removal of organisms) has not been shown to affect aquatic organisms adversely in the nearby ecosystem based on work conducted in Washington (Pitts 1990). Although local measurements of the potential impact of aquaculture on turbidity were not found, Wells (1999) recommends that turbid water be avoided for initial cod grow-out operation set up.

Newfoundland and Labrador

Growers in Bay d'Espoir have their nets cleaned at one location within the Bay by a company with equipment specifically designed for this purpose. Nets are not cleaned at farming sites (H. Murphy pers comm.).

5.1.3 Release of Organic Substances

Organic nutrients that can be generated from aquaculture operations include orthophosphates and nitrogenous nutrients (such as ammonia). These remain dissolved within the water column rather than settling and affecting the sediment and/or benthos and therefore affect water quality near aquaculture facilities. These soluble organics are natural excretory wastes produced by aquatic organisms, however, intensive farming can overload local ecosystems. The potential for toxicity or impacts on water quality is greatest from the increased production of dissolved nitrogen (including ammonia) that typically is associated with fish farms (Pitts 1990).

In other jurisdictions, high concentrations of orthophosphate and nitrogenous nutrients have been observed in surface waters adjacent to aquaculture operations (Hansen *et al.* 2001). However, concentrations decline rapidly with distance from the net cages as a result of dilution and assimilation by phytoplankton or algae growing on the cages (Wildish *et al.* 1993, Aure *et al.* 1988).

Investigations have been conducted to determine if variations in feeding frequency could alter effluent loadings (Bergheim and Forsberg 1993). This study involved both periodic and continuous feeding frequencies (2-4 and 170-250 feedings/day, respectively) of adult Atlantic salmon in tanks. They found that feeding frequency had no influence on effluent loadings, growth rates or feed conversion ratios (Bergheim and Forsberg 1993). Values of effluents measured were (expressed per kilogram of fish/day):

- 0.5-1.4g suspended dry matter;
- 0.01-0.05g total phosphorous;
- 0.15-0.30g total nitrogen;
- 0.1-0.2g total ammonia nitrogen; and
- feed conversion ratio of 1.0-1.2kg dry feed: 1kg fish gain.

In freshwater salmonid aquaculture facilities, monitoring regimes have been developed to assess the impacts of effluents on receiving waters. Environmental effects induced by intensive fish farming on receiving water bodies often are difficult to assess because of the high rate of waste dilution (Lee et al. 1995, Oberdorff and Porcher 1994). The Index of Biotic Integrity (IBI) has been used which measures stream fish population metrics in order to detect changes in fish assemblage attributes. The assumption is that population attributes change in a characteristic fashion with stream degradation. The technique was developed in the mid-western United States and confirmed in several regions of North America and Europe as being useful, however, metrics used in the index must be modified with respect to regional differences in fish assemblage structure. Oberdorff and Porcher (1994) used IBI to assess the impact of salmonid farm effluents on receiving waters in the Brittany region of France. They found that IBI could detect longitudinal changes in fish farm effluents from upstream to downstream.

Newfoundland and Labrador

In continuing research on the potential carrying capacity of Bay d'Espoir for salmonid aquaculture, Tlusty *et al.* (1998) assessed the potential environmental impacts of over-wintering salmon cages in protected bays. Maintaining cages in specific over-wintering areas is the normal practice in Bay d'Espoir in order to protect the cages and fish from winter-ice damage caused by the freezing of the upper freshwater layer of the bay. Typically, these winter locations have slower moving water and longer flushing times. Often these winter sites are located over naturally accumulating bottoms that are prone to deposition of wastes (Tlusty *et al.* 1998). While salmonids require less feed at lower water temperatures, their digestive efficiency decreases with decreased water temperatures such that faeces will have a higher overall organic matter content. The long-term impact of overwintering activity within these protected areas was unknown in Newfoundland and Labrador (Tlusty *et al.* 1998). This study assessed the water quality at three bays within Bay d'Espoir, each with varying winter use. Fresh, transition, and near bottom (tidal) water quality was surveyed at each site (over 2,000 samples in total). There was no indication of increased nutrification as a result of aquaculture operations (i.e., all aquaculture sites had levels similar to control sites).

Another study in Bay d'Espoir by Tlusty *et al.* (2000a) attempted to estimate the theoretical maximum capacity of Roti Bay and Voyce Cove for over-wintering salmonids using a model developed by Silvert (1994). This was carried out in order to determine the total amount of fish that can be over-wintered in each area without causing adverse environmental effects. In Bay d'Espoir, two main areas meet the requirements for over-wintering fish and accordingly are used for this activity. Voyce Cove (2,500,000 m^3), that holds market-sized fish, is a shoal bay adjacent to a 100m deep basin of the upper Bay d'Espoir system. The flushing time is estimated at five days (Tlusty *et al.* 2000a). Roti Bay (51,637,000 m^3) is more enclosed. This over-winter site holds approximately 85% of all pre-market fish (Tlusty *et al.* 2000a). Roti Bay has an estimated flushing time of 20 days. During the winter of 1997, Roti Bay carried 595 tonnes of fish (Tlusty *et al.* 1999).

The following assumptions were made in undertaking this maximum capacity estimate:

(a) salmonid nutrient releases under a winter thermal regime are less than during summer temperatures;
(b) winter feeding regimes are 1/10 to 1/20 the amount fed in summer; and,
(c) the ameliorative effect of six months fallowing may be mediated in either a linear or non-linear manner in the models.

With this approach, estimates for Roti Bay ranged from 103.3 to 8,261.9 tonnes and Voyce Cove ranged between 20 and 1,600 tonnes (Tlusty *et al.* 2000a). These calculations imply that Roti Bay carried approximately 7% of its theoretical maximum in 1997 and Voyce Cove carried over 50% of its maximum. Unfortunately, there is considerable uncertainty inherent in these estimates. The management implication of these estimates is that it appears to be conservative, as the minimum capacity of each site has been exceeded yet no water column impacts have been observed. It should be noted that the Silvert model has received criticism in that its calculations tend to over-estimate effects by orders of magnitude (J. Smith, pers comm.). In fact, Roti Bay was stocked five times more densely in 1997 than the recommended density to prevent environmental degradation in British Columbia (Levings 1994). There was no evidence of increased nutrient load or increased primary productivity in the water column (Tlusty *et al.* 1999).

Shellfish and cod grow-out operations appear to receive less monitoring in terms of water quality than salmonid aquaculture operations. Very little monitoring/research has been conducted in Newfoundland and Labrador apart from water quality measures that may affect the operation as opposed to the converse. Most of this is associated with initial site location (Newcombe 1995, Brown *et al.* 1998, Wells 1999). While not directly related to impacts, Newcombe (1995) summarized recommended water quality parameters for mussel sites (Table 3).

Table 3. Ranges of water quality parameters suitable for mussel facilities (abstracted from Newcombe (1995)).

Parameter	Description
Water Quality	- Sites should be located away from residential areas to avoid contamination of product
Salinity	- 25-33 ppt
Temperature	- $\leq 20^{O}C$
Depth	- At least 30 feet (9m)

Wells (1999) outlines ranges of water quality parameters suitable for cod grow-out facilities. No criteria were outlined for reducing effects of grow-out operations on the environment. Appendix 2 summarizes the ranges of parameters from Wells (1999).

Brown *et al.* (1998) outline numerous techniques for maximum growth and production in mussel farms. They state that environmental monitoring may be too expensive for growers to conduct on their own. They found that only 17% of the growers surveyed measured environmental parameters. It should be noted, however, that since 1998 most farm operations do conduct some monitoring with respect to temperature (C. Couturier pers comm.).

5.1.4 Potential Mitigations

It is critical to ensure that the physical capacity of an area does not exceed its biological functioning (Tlusty *et al.* 2000a). Otherwise, excess nutrients beyond the assimilative capacity of the area can cause waste build-up, oxygen depletion, and possibly hydrogen sulphide production that can lead to fish mortality (Gowen and Bradbury 1987). As stated earlier, salmonids require high levels of DO in order to maintain the oxygen gradient across the gill epithelium needed for rapid oxygen delivery to the blood (Deveau 1997). An assessment of potential aquaculture sites within Economic Zone 13 (Coast of Bays Region) of Newfoundland indicates that DO in the range of 7-12 ppm should be available year round (SCCDC 1998). In the Bay of Fundy, farmers try to avoid saturations lower than 90% (SCB Fisheries 1992). However, they regularly encounter saturations of 70-80% with no detected problems in production (J. Smith pers comm.).

High flushing rates benefit aquaculture operations by keeping DO levels close to air saturation levels (Boghen 1995). High flushing rates also carry away wastes and uneaten food. Aquaculture of salmonids, shellfish and cod grow-out is best suited to areas where water exchange (or the time it takes for the whole bay or cove to replenish itself with a new volume of water) is measured in days rather than weeks (SCCDC 1998, Wells 1999, Newcombe 1995).

There have been policies developed for the Bay d'Espoir system to facilitate optimal use of areas available for various aspects of salmonid operations (ADB 1998). One of the potentially limiting factors in Bay d'Espoir is the availability of over-wintering sites that offer good water quality, protection from ice, and accessibility. Roti Bay has been identified as one of these locations (ADB 1998). A management plan for Roti Bay has been developed to avoid water quality and fish health problems (ADB 1998). Elements of the plan include:

- the minimum distance between farms in over-wintering sites is 100m;
- all operators must feed using approved winter rates to avoid excess feed loss to the environment;
- cages can be placed in Roti Bay for over-wintering of fish between November 15 and May 15 only; and,
- the entire Bay will remain fallow for the remainder of the year.

It is unclear whether these elements are transferable to other over-wintering sites around the province as they are based on data specifically collected from Roti Bay. For instance, it was found that the freshwater layer on the surface of Roti Bay assists in flushing excess nutrients from the bay as rainbow trout and brook trout spend a significant amount of time in this layer. Limited mixing between this layer and the more saline lower layer allows the transport of nutrients away from the site quicker than tidal flushing alone (Tlusty *et al.* 2000a).

Salmonid aquaculture in Newfoundland and Labrador appears to have a "built in" mitigation for most sites since summer and winter cage locations are different. Over-wintering areas may be more protected (i.e., depositional basins), however, they are used only between November and May and then left fallow (G. Herritt pers comm., J. Kealey pers comm.). Water quality monitoring of the over-wintering sites in Bay d'Espoir to date has revealed no measurable effect due to cages. The use of video surveillance of the cage bottom during feeding assists with managing feed application. The bottom of the cage is monitored while feeding. Once excess food is observed reaching the bottom of the cage, feeding is discontinued (H. Murphy pers. comm.). This was established more as a cost-saving measure but it may be an important mitigation to avoid excess nutrients from entering the ecosystem. Other mitigations include feed tables and good records to avoid feed wastage. Potential effects on sediment quality and benthic community structure are presented in Section 5.2.

In marine environments, studies elsewhere have looked at the possibility of dual cultures to reduce overall nutrient release from salmonid aquaculture. For example, culturing bivalves near salmonid farms so they can feed on and filter organic wastes and possible algal blooms has been investigated (Pei-Yuan *et al.* 2001). Locally, a preliminary examination into the efficiency of native seaweed species to assimilate ammonia (unionized NH_3 and ionized NH_4^+) and oxidized nitrogen (NO_2^- and NO_3^-) from the excretory wastes of salmonid operations also was conducted (Clarke 2000). This polyculture approach could potentially reduce water quality impacts and add another marketable product to the operation. The results indicated that the three species tested (*Laminaria digitata*, *L. longicruris*, and *Alaria esculenta*) could uptake between 0.082-0.086mg/l/day of ammonia (NH_4^+) produced by steelhead, which was significant. Uptake of oxidized nitrogen by these species was not significantly different from controls. This suggests that local seaweed species could be grown near salmonid sites and potentially reduce wastes released into the environment. This technique also is being evaluated in

New Brunswick (J. Smith pers comm.). Neither the feasibility nor the potential effect the seaweed could have on circulation patterns and flushing rates near cages was determined. This may be a potential concern as Hatfield Consultants Ltd. (1990) and Pennell (1992) recommend siting salmon farms away from kelp in order to reduce fouling of cages.

In Nova Scotia, settling ponds for effluent treatment of freshwater salmonid operations were assessed in order to determine whether they were reducing total suspended solids and total phosphorous concentrations (UMA Engineering Ltd. 1989). Two settling ponds were used to treat effluent prior to re-release into the receiving stream (i.e., effluent flows through the first pond then the second). The first pond had an average inflow from the farm of $6.36m^3/s$, a flow velocity in the pond of 0.005m/s, and a retention time of 134 minutes. The second pond had an average inflow from the farm and a small diverted stream of $7.27m^3/s$, a flow velocity of 0.005m/s, and a retention time of 160 minutes. These two ponds were found to reduce total suspended solids and total phosphorus to acceptable provincial regulatory levels.

Mitigation techniques for shellfish facilities to reduce water quality impacts were not found. Most shellfish operations appear to have little effect on water quality, however some growers have noticed their operations provide food for lobsters, urchins and star fish (C. Loveless pers comm.). There is currently some mussel mitigation and monitoring being conducted in Prince Edward Island and at Dalhousie University (J. Smith pers comm.). Investigations are continuing.

Cod grow-out facilities, for the most part, operate from mid-June to the end of October (Fisher 1988). The fish are then harvested and the site is left fallow until the following June (W. Williams pers comm., A. Bailey pers comm., S. Butt pers comm., R. Hedderson pers comm.). Also, sites for cod grow-out typically are in areas of higher wave and current energy than mussel and salmon farms. Flushing of such sites would be higher (D. Wells pers comm.).

5.1.5 Data Gaps

1. While the spatial extent of potential DO effects has been identified, the temporal extent was not. With the noted limited spatial effects, temporal effects also maybe limited. This has not been confirmed. Additional information is required in order to determine whether the temporal extent of changes in DO are significant near aquaculture operations and whether such changes significantly affect fish or fish habitat.
2. Most information regarding the potential effects of aquaculture operations have been from salmonid and shellfish operations. Very little information, specifically from cod grow-out facilities, appears to exist apart from growers' experiences.

5.2 SEDIMENT QUALITY

Effects on sediment quality probably are the most direct impact that aquaculture operations have on fish habitat. Any excess feed, non-soluble faecal matter, and settling of natural suspended particles due to changes in current patterns have the ability to affect the benthic environment and ecosystem in the vicinity of aquaculture operations. The spatial extent and intensity of the impact will relate to the sensitivity of the sediments and ecosystem, the amount of organic material deposited, and the ability of the environment to assimilate excess nutrients.

Sediment impacts can be both physical and chemical. Settling of particles can smother habitat, rendering it less usable for local fish species (i.e., spawning habitat or interstitial spaces for predator avoidance) as well as benthic organisms that provide a food source for fish. In addition, an increase in organic enrichment can shift the sediment decomposition process from aerobic to anaerobic and thus alter the benthic community. This can alter food sources and habitat quality for species that may not be able to utilize the habitat to the same extent as they could prior to enrichment. It can also have a positive effect whereby native species feed on excess food particles that pass through the cages.

The main effects of aquaculture operations on sediment quality include: increased settling of suspended solids; nutrient enrichment/loading; alteration of bacteria levels (e.g., aerobic to anaerobic decomposition); alteration of the benthic macrofauna; and, physical sediment disturbance. A description of the potential impacts on the benthic community and sediment are described below from studies conducted outside the province. There is limited literature from Newfoundland and Labrador regarding sediment alteration. Most Newfoundland and Labrador information pertains to potential mitigation and is outlined where appropriate.

5.2.1 Settling Of Suspended Solids

Deposition around aquaculture sites has been shown to range from two to twenty times that of background (i.e., control) levels (Findley *et al.* 1995). This variation may be a result of siting considerations. For example, cages in areas with higher flushing rates will have less organic deposition than cages sited in natural depositional areas (Tlusty *et al.* 2000b). In finfish aquaculture operations, cages also can affect local currents if improperly positioned or if they are overly abundant in any given area, thereby altering sediment transport and deposition patterns (Faris 1987).

A substantial accumulation of bottom sludge, irregular settling patterns of suspended particles, and impaired water movements were recorded under a salmon cage operation in an enclosed bay in New Brunswick (Rosenthal and Rangeley 1989). The farm cage was located in a well-protected bay in the Bay of Fundy where there was a unique tidal effect (i.e., the tidal flow into the bay took only three hours, while its retreat took nine hours). This slower outflowing of water from the bay meant decreased current and reduced physical flushing of particulate matter. The number of fish being raised during the study was estimated at approximately 120,000 in a total of 64 cages (area of bay estimated at 545,500m^2).

Bivalves feed on natural phytoplankton and organic input to the sediment is composed largely of rapidly settling bio-deposits such as faeces and pseudofaeces (Hatcher *et al.*

1994, Rosenthal *et al.* 1988). Misdorp *et al.* (1984) estimated the rate of sedimentation caused by mussel culture as 10mm/year in the eastern Scheldt.

Newfoundland and Labrador

Very little information was found from Newfoundland and Labrador regarding the physical settling of suspended solids. Tlusty *et al.* (2000b) conducted studies on the relative potential for soluble and transport losses of salmonid aquaculture wastes. Waste was collected at four junctures between introduction and the culmination of settlement, including samples of feed, faeces, particulate matter in the water column, and in the benthos. Soluble losses were examined by measuring change in organic matter content while the samples were in a stationary water field. The potential for transport losses was examined by determining if light and heavy fractions of a sample differed in their amount of organic matter. The results indicated that faecal matter had a very high solubility potential, losing approximately 50% of its organic matter in 12 days. No other sample had losses greater than 10%. In terms of transport losses, no discernible trend could be detected. However, lighter material generally was found to settle out of the water column last and further afield (Tlusty *et al.* 2000b). It should be noted that some salmon growers in Bay d'Espoir have identified an immediate "imprint" under some of their summer cages as well as enhanced productivity around their sites for other fish species that feed on waste feed and/or faeces (C. Collier pers comm.). Fallowing the site through the winter apparently mitigates this affect seasonally.

5.2.2 Nutrient Enrichment/Loading

Nutrient enrichment/loading occurs when excess feed and faeces settle to the substrate and accumulate faster than natural processes can assimilate (e.g., erosion, decomposition, digestion). This process is difficult to separate from other coincident processes when organic enrichment occurs (e.g., increased bacteria levels, changes in benthic macrofauna). Therefore, overlap occurs between these sections.

Gowen and Bradbury (1987) estimated that the deposition of organic waste beneath a fish farm might be as high as $10kg/m^2/yr$ directly beneath the cages and $3kg/m^2/yr$ in the immediate vicinity of the farm. While improved husbandry practices over the past fifteen years most likely have reduced these values, a recent study found that carbon flux to the seabed below net cages could be several orders of magnitude higher than natural fluxes in adjacent waters (Hansen *et al.* 2001).

The environmental effects on sediment are less dramatic for mussel culture than finfish culture (Hatcher *et al.* 1994). Suspended mussel culture in Nova Scotia has been shown to have little effect on sediment phosphorus dynamics. However, Hatcher *et al.* (1994) did find that ammonium release, under mussel lines was higher at all times of the year. Throughout the course of the year, sediment at reference sites served as a net sink for total dissolved nitrogen, while sediment under the mussel lines was a source.

Newfoundland and Labrador

Research on how over-wintering of salmon in protected bays can affect water and sediment quality has been ongoing in Bay d'Espoir (Tlusty *et al.* 1998). Due to the more depositional nature of over-wintering sites compared to summer locations and the fact that fish digestion is slower in colder water, one would expect increased organic deposition on the bottom in and around these sites. Sediment cores were collected at 25 stations and analyzed for percent solids and organic matter (percent loss on ignition) in the top 1cm of sediment in three over-wintering bays in Bay d'Espoir (i.e., Roti Bay, Voyce Cove, Northwest Cove). The effect of aquaculture operations on the benthic environment differed at each sample location (Tlusty *et al.* 1998). The apparent impact was inversely proportional to the amount of effort and length of time each area had been utilized. The main reason that aquaculture had the most pronounced effect in North-west Cove was because this area was not fallowed during the previous two winters. Even though this was the most impacted area examined, it would still be categorized as a "low impact" site when compared to those in New Brunswick (Tlusty *et al.* 1998). However, it was noted in this study that the organic material/content under cages can be highly variable due to the fish-pen location. This research has lead to several key questions regarding benthic processes. These questions have been the topic of ongoing research in Newfoundland and Labrador, particularly near mussel operations; however, the results are not yet available for inclusion in this study (R. Anderson, DFO St. John's, pers comm.). Salmonid operators from Placentia Bay West and Fortune Bay East expressed some concern regarding sediment quality and possible disease transmission if aquaculture operations in their area became very large (such as that in certain congested areas in British Columbia, New Brunswick or Maine) (M. Anstey pers comm.).

Many local cod grow-out operators have indicated that any excess food near cod cages is quickly consumed by native species such as cod, urchins, and lobster (W. Williams pers comm., O. Bailey pers comm., S. Butt pers comm., R. Hedderson pers comm.). Additionally, due to site characteristics such as high flushing and deep water, sediment accumulation is unlikely and natural processes remove any sediment that accumulates during the fallowing period (W. Williams pers comm.). One cod grow-out operator actually harvests the urchins attracted to his cages and views this as an additional benefit to his operation.

5.2.3 Increased Bacteria Levels (Hydrogen Sulphide Production)

Increasing the amount of organic material in the sediment tends to shift decomposition processes from aerobic to anaerobic, and sulphate reduction may begin to predominate (Holmer and Christensen 1992). Typical features of such sediments are substantially lowered redox potentials, presence of hydrogen sulphide in pore waters, mats of sulphide-oxidizing bacteria and severe disturbance of the macrobenthic community (Brown *et al.* 1987, Hargrave *et al.* 1993). In sediments with severe organic enrichment, methanogenic bacteria proliferate causing gas ebullition and a lowering of pH (Hansen *et al.* 2001). Analyses of gas released from such sediments have shown that it contains methane with up to 1,800 ppm of hydrogen sulphide (Hansen *et al.* 2001).

In cases of high organic input the sediment may become destitute of any vestige of animal life (i.e., azoic) but such an effect is usually limited to the seabed directly beneath the culture structures (Rosenthal *et al.* 1988). At a greater distance, generally greater than 30m, the effects are manifested by a proliferation of opportunistic species and a loss of many species intolerant of the physical and chemical consequences of organic enrichment (Rosenthal *et al.* 1988).

At salmon cage locations in Norway that had been abandoned for a period of four years or more, the sediments were considerably less reducing than when the site was active (Frogh and Schaanning 1991). Many of these sites had strong tidal effect, therefore particulate matter was dispersed over a large area and to a lesser extent under the cages. This favours aerobic degradation and faster turnover time for waste (Frogh and Schaanning 1991).

Newfoundland and Labrador

No relevant information on this topic was found from Newfoundland and Labrador sources, however, no evidence of hydrogen sulphide production (i.e., gas ebullition) under cages was identified by growers.

5.2.4 Benthic Macrofauna

Benthic fauna are sensitive to organic loading (Pearson and Rosenberg 1978) and is considered sensitive enough to detect subtle impacts (Ritz *et al.* 1989, Weston 1990, Johannessen *et al.* 1994, Hansen *et al.* 2001).

Benthos near a salmon farm in a fjordic sea loch on the west coast of Scotland was examined to determine the spatial extent and overall effect of wastes associated with the operation (Brown *et a*l. 1987). The farm consisted of six cages covering an effective area of 2,160 m^2. During the study (February to August 1985), the cages held 35 tonnes of mature salmon with a mean daily input of feed at 142 kg. The water depth beneath the unit was 20m and the mean current velocity at the site was 0.037m/s. Quantitative macrofauna samples were obtained from stations in the range of 3 to 1,400m away. Core samples also were obtained for measurement of organic carbon and nitrogen content. Profiles of sedimentary redox potentials also were measured. Results indicated that the benthic fauna showed marked changes in species number, diversity, abundance, and biomass in the region of the fish farm, with four zones of effluent identified. Directly beneath, and up to the edge of the cages, there was an azoic zone. A "highly enriched" zone occurred from the edge of the cages out to approximately 8m. A slightly enriched "transitional" zone occurred between 8 and 25m, and a "clean" zone extended beyond 25m from the cages. The study illustrated that salmon farming had a similar effect on the benthos as other forms of organic enrichment, but the effects were limited to a small area in the immediate vicinity of the cages. There was a decrease in carbon content in the sediment with increasing distance from the cages, the level at 3m (9.35%) being more than double that at 15m (3.99%) (Brown *et al.* 1987). In addition, at a distance of greater than 15m from the cages, redox values were positive throughout the sampling period. At a distance of 11m, they became highly negative in May. Three metres from the cages, redox values were highly negative throughout the sampling period, reaching minimum levels in May. Seasonal variation in sedimentary redox potential at all stations was apparent with minimum values measured in May.

Similar to Brown *et al.* (1987), the impact of organic enrichment on the benthic community due to salmon farms was investigated in the Bay of Fundy (Lim 1991). Monthly bottom samples were collected from two farms along two transects. Results from the first eight months showed that at one site a "transition zone" was established 55m from the net-pens. The transition zone was considered to be the region where both species diversity and biomass peaked. High numbers of *Capitella* and high microbial biomass were detected at the sampling station closest to the cages, indicating organic enrichment had occurred in the vicinity of the farm.

At salmon cage sites, degradation of the macrobenthos was observed three months after start up (Rosenthal *et al.* 1988). When cages were removed from a site after aquaculture activities ceased, an improvement in the benthos was recorded within three months of removal. However, the macrofauna community continued to show evidence of substantial alteration relative to reference stations even after eight months (Rosenthal *et al.* 1988).

Mattson and Linden (1983) monitored the recovery of macrobenthos in a relatively enclosed bay (currents approximately 3cm/s) after removal of a mussel longline that had been in production for three years in Sweden. Deposition of organic matter created several centimeters of sediment each year, resulting in H_2S production in the uppermost layer. They found no change in the bottom after six months and very little recovery after one and a half years.

Newfoundland and Labrador

No relevant literature on this topic was found from Newfoundland and Labrador sources. Interviews with growers indicated that some finfish operators in the Bay d'Espoir area have noticed a reduction in biodiversity directly below some cages, however, a gain in biomass of certain species such as lobster also has been recorded (J. Moir pers comm.).

5.2.5 Sediment Disturbance

No literature was found regarding physical sediment disturbance at or near aquaculture facilities. However, the only physical contact with the bottom would be associated with anchoring. In Newfoundland and Labrador, movement and re-location of anchors is limited as growers will mark (using rope and visible buoys) anchors for re-use rather than removing and redeploying (D. Wells pers. comm.). Anchors are generally designed so that they do not move on the bottom, hence scouring or dredging of benthos is considered minimal.

5.2.6 Monitoring of Sediment Quality

Monitoring investigations of various degrees of complexity have been employed in various jurisdictions in order to minimize the potential harmful effects of aquaculture activities (e.g., Henderson and Ross 1995, Wildish *et al.* 1999). Hansen *et al.* (2001)

outline three types of investigations of increasing complexity and accuracy which are applied more frequently with increasing environmental impact. Emphasis is on benthic impacts but also focuses on the area close to the operation, where the impact would be most pronounced. The three investigation types are described in Table 4.

Wildish *et al.* (2001) reviewed two monitoring methods of organic enrichment for salmon farms: macrofaunal community structure and sediment geochemistry. A comparison was conducted based on scientific and cost-effectiveness criteria. The macrofaunal community structure technique identifies and estimates the abundance of all macrofaunal taxa. The sediment geochemistry technique measures redox and sediment sulphide levels. Both techniques produced significant differences between farm and reference sites and were able to categorize sediment organic impact as normal, hypoxic, and anoxic. However, the macrofaunal technique takes considerably more time to complete due to the required identification of macrofaunal taxa and cannot be completed in the field like the sediment techniques.

Table 4. Three levels of investigation (as per Hansen *et al.* 2001).

Investigation Type	**General Description**
1	- A simple measure of the rate of sedimentation of organic matter below the fish farm. - Sediment traps are deployed under the cages for two weeks and sedimentation rates are recorded.
2	- Combines three groups of parameters that are measured in the local impact zone (i.e., under and/or between pens). - Measurements include biological (macrofauna), chemical (pH and redox), and sensory (sediment colour, odor, consistency, thickness, ebullition).
3	- Investigates benthic community structure along transects drawn from farm towards sedimentation areas or sensitive part of the intermediate and regional impact zones. - Three sites per transect are sampled (near, mid and far) with respect to the farm.

A method to assess the pollution status of a marine macrobenthic community without reference to a temporal or spatial series of control samples also was described by Warwick (1989). Theoretical considerations suggest that the distribution of numbers of individuals among species should behave differently than the distribution of biomass among species when influenced by pollution-induced disturbance. Figure 5 illustrates the hypothetical k-dominance curves for species biomass and numbers that was used for this analysis.

This method was tested by Ritz *et al.* (1989) to assess the response of infaunal macrobenthic communities beneath salmon sea cages to solid organic wastes. The method proved to be a sensitive indicator of community health. Under a normal feeding regime, the macrofaunal community structure indicated a moderately disturbed condition. Only seven weeks after the cage was harvested, species richness had increased markedly and the community adopted an undisturbed condition. Further improvement was apparent fourteen weeks post-harvest. Similarly, a decline to a moderately disturbed condition was apparent seven weeks after restocking, at which time species richness had declined. No such changes occurred under a cage that contained fish continuously over the same period.

A technique using video assessment of environmental impacts also has been developed (Crawford *et al.* 2001). Videotaping beneath cages is a common practice. However, this approach usually is qualitative and hence provides no way of analyzing whether significant impacts have occurred over time. Crawford *et al.* (2001) developed a quantitative method of video assessment that uses multivariate statistics to detect major organic enrichment. In their appraisal of the technique, however, they state that it is not as sensitive as benthic infaunal data and the methodology has to be tailored to different environmental conditions (Crawford *et al.* 2001). The technique does not show promise for long-term monitoring programs on a wide-scale as video generally is very costly and limited to certain situations (J. Smith pers comm.).

5.2.7 Potential Mitigation

To minimize the effects of excess organic wastes, it is advantageous to locate farms so as to provide maximum dispersal of organic wastes and utilize the natural assimilative capacity of water bodies (Levings *et al.* 1995). A study of 57 salmon farms in Scotland has shown that acute organic enrichment, usually accompanied by sediment outgassing, occurred beneath most cages (Lumb 1989). Development of these conditions is likely to occur with "self pollution" of a fish farm, resulting in reduced growth and increased susceptibility to disease. In order to avoid this situation, surveys were conducted to correlate the degree of organic enrichment to the seabed type and water depth on the site.

A simple assessment of the seabed type at a site provided an index of the exposure to water movement, thereby enabling prediction of the response of the site to organic loading. Use of minimum depth guidelines alone was shown to be inadequate in preventing acute organic enrichment and sediment outgassing. The importance of avoiding sites with low water movement was also demonstrated. The correlation between seabed type and organic enrichment was used to establish siting guidelines for farms based on seabed characteristics (a surrogate value of current). It was concluded (Caine et al. 1987) that fish farms should not be sited over a mud seabed unless site rotation (with the necessary fallow period required) is possible, acceptable and planned. Fish farms sited over sand and gravel seabeds will result in lower intensities of organic enrichment, reduce the risks of "self pollution" and have increased site longevity. This study linked an easily assessed variable (seabed substrate) to the potential for acute organic enrichment. A summary of the six major categories of seabed type and associated biological community are provided in Appendix 3. The seabed types are ranked in order of increasing exposure to water movement. It should be noted that these characterizations were recorded under ongoing salmonid aquaculture operations and not in "control" or pre-operation situations.

For seabed categories A-C, water depth appeared to have little influence on intensity of enrichment, although organic loading per unit area of seabed must decrease with increasing depth due to increased dispersion. At sites with the D-type seabed, there was a general decrease in intensity of enrichment with increasing water depth. Seabed types E and F showed limited enrichment.

It is important to note that, although siting cages in macro-tidal environments may reduce the environmental impact of the industry on benthic communities at the farm site, the potential exists for accumulation of farm wastes nearby in sedimentary sinks albeit not directly under cages (Frid and Mercer 1989). Additionally, the longer residence time of wastes in the water column has the potential to lead to phytoplankton blooms.

Some Norwegian salmon farmers have found it necessary to disperse accumulated sediments under cages with propellers, or rotate cages among several different sites, thereby allowing time for recovery of enriched sediment (Rosenthal *et al.* 1988). Recommended changes to a salmon farm in an enclosed bay in New Brunswick included changing cage arrangements, reducing total biomass of fish in the area, and adapting operational conditions such as switching from wet to dry feed. These were identified as strategies to assist in remediating the effects of salmon farming on the benthic community beneath the cages (Rosenthal and Rangeley 1989).

One study evaluated the use of single-point moorings (SPMs; see Beveridge 1987 for a description of mooring systems) and drifting cages to mitigate the environmental effects of mariculture (Goudey *et al.* 2001). SPMs allow the cages to move in response to the environment (e.g., currents, waves). The cage has a larger "zone of influence" and hence the accumulation of organic matter is spread out rather than overwhelming a more localized environment. A preliminary analysis indicates a two to seventy-fold reduction in deposition of waste on the seabed depending on mooring geometry and current type (Goudey *et al.* 2001).

The increased dispersive potential of single-point moorings also was examined by Lumb (1989). He observed that four established sites within areas of seabed Type-C showed reduced sediment organic loadings compared with equivalent fixed-mooring sites. How this technique would apply to Newfoundland and Labrador and specifically to the requirements of the *Navigable Waters Protection Act* is unknown. The use of SPMs may be considered a significant business risk and would probably not be used in today's market environment (J. Smith pers comm.).

Clam (*Anadara* spp.) growers in Japan have adopted a strategy of bed rotation after harvest; a period of 1.5 years is required before the beds are reseeded. During this time the beds are traveled repeatedly (i.e., raked) to accelerate remineralization (Rosenthal *et al.* 1988).

Newfoundland and Labrador

As stated in Section 5.1.4, the Aquaculture Development Branch, Department of Fisheries and Aquaculture has implemented a management plan for Roti Bay, Bay d'Espoir so that optimal use of the bay for over-wintering is realized without major environmental effects (ADB 1998). In addition, Tlusty *et al.* (2000a) suggest that areas having more than 50% of their theoretical estimated maximum capacity utilized should be subjected to intense monitoring programs to ensure impacts are detected and caution is used when increasing further prosecution of an area's production potential. Such monitoring provides a baseline from which to pursue adaptive management so that changing conditions that may arise over time can be interpreted as to their potential consequences, both on the aquaculture operation and the environment.

There were no outlined mussel or cod mitigations found from any Newfoundland and Labrador literature.

5.3 WASTE ACCUMULATION AT SITE

This section deals with the possibility of accumulating debris (e.g., plastics, ropes, bags, and anchors) from aquaculture operations in the marine environment.

No literature was found regarding this aspect of aquaculture from any jurisdiction. Some growers identified the fact that a loss of gear is possible in any marine operation (B. Carter pers comm.). However, it was stated also that all gear is expensive and, whenever possible, lost gear is retrieved and repaired.

5.4 ALTERATION OF NATURAL FISH MIGRATION

The presence of cages in the water has been found to disrupt the migration patterns of fish due to physical structures interfering with flow patterns (Silvert and Sowles 1996). While not directly associated with aquaculture operations, it also has been shown that oxygen depletion below natural levels has the ability to restrict salmon migrations (Wells *et al.* 1987).

The North Atlantic Salmon Conservation Organization (NASCO) has protocols for the introduction and transfer of salmonids (NASCO 1994). One important protocol is the minimum allowable distance for a commercial salmon ranching operation from a natural salmon river. The distance is determined by several factors such as species being ranched, whether the species is reproductively incapacitated, and the classification of the salmon river as determined by NASCO. This restriction applies to Zone One areas of the province only. This zone is identified as northern Quebec, Labrador, Anticosti Island and the major salmon-producing rivers in Newfoundland north of Cape Ray and west of Cape Saint John (NASCO 1994). While there are no minimum distances for Zone Two rivers (the remainder of the island of Newfoundland), non-native stocks cannot be used unless functionally reproductively compromised (e.g., the approval for female only diploid steelhead).

As NASCO is an international protocol, a national code has been drafted recently by the Canadian Council of Fisheries and Aquaculture Ministers (CCFAM) to address introductions and transfers in Canada (CCFAM 2002). While no protocols are included in the Code, it outlines an evaluation process involving appointed committee members and a consultation and risk assessment review. The Code currently is under an 18-month review and comment period; therefore assessment processes are not yet finalized.

However, all introductions and transfers of aquatic organisms must be in compliance with all other national and provincial legislation, regulations, and policies (CCFAM 2002).

Newfoundland and Labrador

There was no information found regarding the possibility that aquaculture operations may interfere with migrations of native fish. This may be regarded as a data gap since it is plausible that large, intensive aquaculture operations located near river mouths could mask the cues required for wild fish when homing to their natal river(s).

5.4.1 Escapes

Some research on the movements of escaped salmonids has been conducted in Bay d'Espoir using a combined acoustic and radio telemetry system (Bridger *et al.* 2001). This study was conducted to simulate the escape of cultured steelhead trout from a commercial aquaculture site so that possible escapee behaviour may be incorporated into a recapture procedure. These studies were conducted under both summer and winter conditions. Summer releases involved fish released directly from a grow-out site (cage) and releases from a cage towed approximately one kilometer from the usual grow-out location. Winter trials also involved releases from both grow-out and off-site locations. Winter trials, however, used off-site releases directly from a boat at 200m and 1,000m from the grow-out location. The results suggest that there is a relatively high degree of initial fidelity to the grow-out site as most fish released either stayed near the grow-out site (for those released at the site) or quickly returned to their grow-out site (for those released off-site). All tagged fish eventually displayed a directed movement toward the Bay d'Espoir hydroelectric outflow at the head of the bay.

DFO also has monitored local rivers in the Bay d'Espoir system for the presence of escapees. There has been a counting fence on the Conne River for a number of years, from which DFO has procured data on fish migrations into that watershed. Snorkling surveys also have been conducted to locate any escaped farmed fish. A summary of the total number of escaped salmonids identified in Conne River from aquaculture operations is provided in Table 5.

Table 5. Summary of farmed Atlantic salmon and steelhead trout captured/identified in Conne River, 1990-2001 (from Dempson *et al.* 1999, 2000, 2001).

Year	Farmed Species Captured	
	Atlantic salmon	Steelhead trout*
1990	0	3
1991	0	47
1992	0	3
1993	1 adult	11
1994	2 adult, 12 smolt	12
1995	0	39
1996	59 smolt	41
1997	14 adult	71
1998	2 adult	25
1999	1 adult	137
2000	5 adult	25

* total of weir-trap counts and snorkling observations.

5.4.2 Code of Containment

A Code of Containment Plan was developed by the Newfoundland Salmonid Growers Association (unpublished) as a condition to use non-local diploid strains of salmonids in Newfoundland and Labrador. The objective is to facilitate access to the best performing strains while minimizing the risk to wild salmonid populations. It came into effect in Bay d'Espoir in 1999 with the approval from government to use a non-local, all-female diploid strain of steelhead trout. The Code of Containment adopts the measures that were previously outlined in an Industry Code of Practice (1997 draft). These codes of practice were outlined previously as a guide for proper farm operations and were not adopted as compulsory until 1999, with the introduction of diploid steelhead trout. Included are contingency measures for the control of non-native fish should they escape.

The contingency measures include inventory monitoring and recapture plans. As per the Code of Containment, DFA provides a semi-annual inventory review, including numbers introduced, mortalities, removals and escapes. DFA, DFO and Industry have conducted recapture trials to determine the most effective fishing gear for rapid recapture. To date, it has been determined that escaped fish will tend to stay in the immediate vicinity of their cages for several days (Bridger *et al.* 2001) and the most effective and rapid means of recapture is the use of gillnets of various mesh size. In 2002, DFO supplied gill nets to a third party agency, Newfoundland Aqua Services Ltd., that has a trained crew ready to respond rapidly to any farm reporting losses/escapes in the Bay d'Espoir system. In addition, individual growers can also apply for a license to recover their own losses. The condition of this license from DFO is the procurement of a specific number of gill nets of varying mesh size [minimum 8 nets with moorings] and demonstrated ability to use the gear. Fish recaptured from the wild are to be either discarded by incineration or sold commercially. It should be noted that some implementation measures, including contingency components, are being developed and adjusted periodically to ensure practical and effective operations as well as accurate documentation and review.

A study was conducted on the movement patterns of released farmed cod in Trinity Bay (Wroblewski *et al.* 1996). This study was carried out to determine whether inshore cod, when captured and farmed for the summer, would remain in the area and undermine spawning once released back into the wild in the fall. Cod were captured off East Random Head between June 8 and July 9, 1992 and farmed in Gooseberry Cove until November. Fourteen sonically tagged fish were tracked after release from Gooseberry Cove to determine movements. Results indicate that the cod over-wintered in Trinity Bay and were found maturing for spawning with wild cod in an area known as Heart's Ease Ledge in early July (Wroblewski *et al.* 1996). It was concluded that farming of inshore cod did not disrupt their normal movement patterns upon release.

5.5 DIRECT CHANGE OF HABITAT FOR NATURAL SPECIES

Habitat change for local species can be direct, such as displacement of individuals from actual farm locations, or more indirect such as alteration of an aspect of their habitat, life cycle, or food source. Habitat change can also include the attraction of many aquatic species to aquaculture operations due to feeding opportunities and cover offered by structures such as cages and anchors.

No literature was collected regarding this aspect of aquaculture from any jurisdiction. However, interviews with Newfoundland and Labrador growers indicate that many opportunistic species such as lobster, urchin, cod, and starfish typically increase in number near cage/long line sites (J. Moir pers comm., C. Loveless pers comm., W. Williams pers comm., O. Bailey pers comm., C. Collier pers comm.). Mr. O. Bailey indicated that he harvests the urchins that are attracted to his cod grow-out facility.

6.0 SUMMARY

A summary of available literature has revealed that limited research has been conducted in Newfoundland and Labrador. Most literature from this province is based on research conducted in Bay d'Espoir for salmonid aquaculture operations. It is not surprising that there is limited literature available on mussel and cod grow-out operations as mussel farm impacts appear to be minor and cod grow-out is relatively new in Newfoundland and Labrador.

Although numerous monitoring and mitigation techniques were recorded and described from other jurisdictions, their purpose and applicability in Newfoundland and Labrador are not yet known.

It is important to note the typical operating practices that are employed in the various operations throughout the province. Aquaculture practices in Newfoundland and Labrador are the end result of considerable discussion and debate with the industry and both levels of government. Many of these practices vary from other locations in Canada, either due to logistic or biophysical differences, but they incorporate procedures that assist in mitigating many of the anticipated effects on fish and fish habitat. Seasonal site use by salmonid growers for summer growing and over-wintering is a prime example.

6.1 THE CEAA PROCESS IN RELATION TO MARINE AQUACULTURE IN NEWFOUNDLAND AND LABRADOR

The marine aquaculture industry in Newfoundland and Labrador has an opportunity for growth that is supported by the experience of present operators, knowledge gained from decades of local research and development, large areas of suitable coastline, and a skilled workforce. The industry also has an opportunity to work with federal and provincial regulators to ensure that industry growth is planned and implemented in an environmentally sustainable manner. The CEAA process can play a central role in this growth, as a supporter or as a spoiler. DFO, as the likely Responsible Authority (RA) for the application of CEAA to marine aquaculture in Canada, has a prominent role to ensure that the environmental-review process is applied objectively. The industry also has a role to work cooperatively with the RA to recognize issues, provide information necessary to address these issues, and to act responsibly. Finally, the provincial government and development agencies have a role to play in providing the necessary physical information and information infrastructure for the benefit of the industry as a whole.

The following is a summary of how the CEAA process and related activities could be applied to support marine aquaculture growth in Newfoundland and Labrador. This summary is based on experience with similar developments in other parts of Canada. Many of the comments expressed below have been acknowledged by DFO, and are being implemented in other provinces.

The objective should be to provide the information infrastructure on which a proponent could confidently base a successful aquaculture business venture.

6.1.1 A Class-type Approach

A matrix of potential marine aquaculture developments exists for Newfoundland and Labrador, with various combinations of species and culture methods. This matrix facilitates the application of a class-type approach to environmental assessment. At this point in time it is unlikely there is sufficient refinement within this matrix, or within the range of potential environments, to identify projects to which the CEAA Class Assessment process applies holistically. Further, the immediate pressure for industry expansion and the paucity of previous environmental assessments of marine aquaculture projects in Newfoundland and Labrador and Canada does not support the knowledge base that is necessary for a CEAA Class Assessment to be declared.

There is, however, enough consistency to facilitate a process whereby many of the potential effects of various species/method combinations can be pre-determined. Information requirements to address these concerns can be identified. This is consistent with the recent Aquaculture Policy Framework (Fisheries and Oceans Canada 2002) and the CEAA guides to information requirements for environmental assessments of aquaculture projects.

However, the information requirements to meet all aspects of CEAA will remain onerous, even with a class-type approach. It will take the combination of a supportive provincial government and a positively minded RA to streamline the process. It also will require compilation of a great deal of information, the cost of which should be accounted for in a manner consistent with infrastructure support to other industries.

6.1.2 Industry-Wide Pre-Development Activities

CEAA requires four basic elements that are combined to make a final environmental assessment of a project:

- a scoping exercise to determine potential Valued Ecosystem/Socioeconomic Components (VEC/VSCs);
- a collection of information to describe the VEC/VSCs;
- a project description that includes best practices to mitigate, monitor, and if necessary compensate for potential adverse effects; and,
- a public consultation process.

Scoping

The DFO Aquaculture Policy Framework and the present study have laid a significant foundation from which to undertake the first element, the scoping exercise. Ongoing work in Newfoundland and Labrador should continue and be coordinated with other provinces and Ottawa. It is imperative, both from a technical and public perspective, that the scoping exercise consider all ecosystem and socioeconomic components of concern, and through a pathway analysis, determine whether or not there are potential VEC/VSCs. Knowledge and data gaps should be identified and research plans developed to address these gaps in a prioritized manner. The scoping exercise should be led by the RA and supporting agencies within DFO and the federal government, and conducted in collaboration with the province, industry, and other stakeholders.

Integrated Coastal Management Database

Collection of information to describe VEC/VSCs should follow the results of the provincial planning and scoping exercises. The planning process will result in collection of socioeconomic and ecosystem information that is necessary to establish potential for areas to be developed. The scoping exercise will determine which ecosystem and socioeconomic components have the potential to be VEC/VSCs for effects of the project on the environment, and vice versa, as well as identify additional information required to conduct the environmental assessment.

It is recommended that detailed information be collected and collated for areas of highest potential development in Newfoundland and Labrador. This exercise should follow the model and experience of the project currently underway in Guysborough County, NS. This project is aimed at aquaculture, but in many ways is a standard integrated coastal management database exercise. DFO and the provinces have considerable recent experience in this process. This exercise should be consistent with the goal of providing an information infrastructure to support successful business ventures. Proponents should recognize, however, that additional site- or project-specific information might need to be collected.

This is not a trivial exercise. There are many potential VEC/VSCs associated with marine aquaculture that must be addressed for each project undergoing any type of a CEAA assessment. It is this magnitude, coupled with a general lack of knowledge by proponents on the required level of detail, and the applicability of the data to multiple projects (not just aquaculture), that make this exercise best suited to be undertaken by a development agency in association with the RA and the province.

Best Practices

The application of a class-type approach requires that projects are similar enough that standard best practices could be applied, with some adjustment for site or project specific conditions. Application of best practices, with good supporting information on VEC/VSCs, would facilitate the role of the RA to screen a project quickly and confidently.

Best practices should be developed for defined groups of projects. For example: long-line culture of mussels, summering and over-wintering of salmonids, growout of gadoid juveniles to market size. Groups should be defined by industry, but be based primarily on similarities in potential effects to VEC/VSCs, that in turn are based on an analysis of pathways from the group of projects to the environmental components of concern. This will encourage development of appropriate mitigation and monitoring procedures to accompany standard practices for construction, operation, and decommissioning of a project. Best practices would be recognized as minimum standards.

As with the coastal database compilation, preparation of best practices is not a trivial task. Best practices must be based on the business constraints of industry, as well as satisfy the RA that they will render potential effects insignificant or unlikely. These two objectives may well be at odds, if it is even possible to define them. In this matter it must be recognized that much will be learned through experience. The principles of adaptive management must be applied, with aspects of risk considered in monitoring and research activities. For the near term, not all the answers will be known with absolute certainty for every project.

Public Consultations

The need for effective public consultation is a requirement of CEAA. It begins with the development of a province-wide strategic plan and continues through issues scoping, coastal ecosystem and socioeconomic information compilation, and environmental assessment of specific projects. Each of these consultations should be aimed at the task at hand. They should be completed with the goal of fostering long-term communication and integrated coastal management.

7.0 RECOMMENDATIONS

Further to this literature review, recommendations can be made to address gaps in a number of areas. These include: additional data/literature from other jurisdictions in Canada and worldwide in similar geographic/biophysical zones; basic biophysical information requirements of potential local aquaculture sites; and, potential mitigation techniques suitable to Newfoundland and Labrador. Listed below are recommendations that would fall into these categories.

1. **Fill gaps in large-scale, local biophysical information**
   Several growers indicated the need for local biophysical data to be available for assistance in environmental aspects of their operations. Information would include such variables as general current profiles, species in the area (especially any identified as special concern, threatened, or endangered as per the *Species at Risk Act*), bathymetry, flushing times, turnover rates, and bottom substrate types. It is recommended that such available information be compiled into a single-source contact (possibly a CD or website) so that any existing or proposed operations could assess the feasibility of a site (summer or over-wintering), potential problems with predators, oil spill contingencies, or any other factor requiring biophysical data. Large-scale information (e.g., pertaining to an entire bay) could be locally available for all operators and likely would be cost-effective (since all operators would not have to duplicate effort), and would assist in all federal, industry, and provincial assessments. One source of information that could be compiled on a regional or bay-wide basis is the Coastal Classification of the Placentia Bay Shore (Catto *et al.* 1997).

2. **Fill gaps in National/International Literature and Experience**
   It would seem necessary to update the database continually by using literature and research results regarding same/similar species from national and international sources. This should include both published and unpublished literature, personal communications and directed expert opinion. It should include effects as well as mitigations where appropriate. It is recommended also that the database be the responsibility of a designated individual or group to ensure appropriate revisions are tracked and implemented.

3. **Develop Province-specific Mitigation Techniques**
   While many of the mitigation techniques outlined in this report appear to be applicable to the areas where they were developed (i.e., most are from outside Newfoundland and Labrador), it is unclear if they would be applicable in Newfoundland and Labrador. It is recommended that further testing of potential mitigation techniques be conducted to determine their applicability. This may be in terms of an "adaptive management" context whereby potential mitigation techniques are implemented and adapted as necessary through results of ongoing monitoring.

4. **Environmental Effects Monitoring Programs**
   It is recommended that there should be ongoing testing protocols at selected sites to determine any accumulating effects. This collection of data would serve also to refine acceptable operating parameters for existing and new aquaculture sites.

5. **Regulatory Challenge Template**
   It is recommended that DFO, in consultation with Industry, develop a template for regulatory challenges by the user/applicant. It should ensure also that collected data are available for support in the challenges/requests for exemption.

6. **On-line Data Support**
   It is recommended that DFO and NAIA place this report and any future literature data on-line to make the supporting information more accessible.

7. **Workshop Support**
   It is recommended that DFO sponsor workshop(s) detailing findings and proposed strategy and protocol for challenges/changes. This could be conducted through NAIA for its members. Information sessions for industry on how to interpret DFO's environmental guidelines also should be included.

8. **Further Research**
   There appears to be insufficient information regarding parameters for many of the bio-physical factors that influence potential negative effects on aquaculture. For example; how does flow rate relate to any feed waste dispersal or sediment accumulation? More specifically, how does flow rate relate to the dispersal of feed waste or sediment accumulation in relation to feed type, size and buoyancy? The effects of other scavenging species in the area should be considered. How does water temperature relate to the rate of bio-degradation? Do aquaculture cages serve to attract or repel feral aquatic species? Does the placement of aquaculture cages have any relevance to wild-fish migration patterns? If so, what is the mechanism of this effect? Related field testing and further national and international literature reviews is advised.

9. **Standard Operating Procedures**
   It is recommended that Standard Operating Procedures (SOPs) be developed on a species basis. These would represent "Best Management Practices" whereby compliance with the SOPs would represent compliance with appropriate national and/or provincial aquaculture site application guidelines <u>or</u> compliance with an accepted/acceptable challenge to the national or provincial guidelines. Hazard Analysis and Critical Control Point considerations should be applied by aquaculture industry producers with the assistance of experts made available by the RAs.

Acknowledgements

The AMEC study team would like to take the opportunity to thank those who provided comments, input and advice. The Department of Fisheries and Oceans, the Newfoundland Aquaculture Industry Association, the provincial Department of Fisheries and Aquaculture (St. John's and Grand Falls offices), and the Newfoundland Salmon Growers Association all have provided valuable information. Apart from the members of the project review committee (scientists and managers from both the Department of Fisheries and Oceans and the Newfoundland Aquaculture Industry Association), many growers directly involved in the aquaculture industry took valuable time from their schedules and operations to provide useful, practical, applied experience to this project.

In particular: Mr. J. Moir, Mr. B. Carter, Mr. C. Loveless, Mr. W. Williams, Mr. O. Bailey, Mr. S. Butt, Mr. R. Hedderson, Mr. G. Herritt, Mr. J. Kealey, Mr. M. Anstey, and Mr. C. Collier. Many thanks also go to Ms. J. Rideout who provided valuable information and literature regarding the potential effects of the aquaculture industry in Newfoundland and Labrador.

This study was supported by Aquaculture Collaborative Research and Development Program (ACRDP) funding. This research project was managed by the Marine Environment and Habitat Management Division of the Department of Fisheries and Oceans. Carole Bradbury, Terry Fleet and Vern Pepper (DFO, St. John's) served as editors for this technical report.

For more information regarding this report or the literature database, please contact the Department of Fisheries and Oceans, Habitat Management, Newfoundland Region or the Newfoundland Aquaculture Industry Association at the addresses below.

Government of Canada
Department of Fisheries and Oceans
Marine Environment & Habitat Management Division
Newfoundland Region
P.O. Box 5667
St. John's, NL A1C 5X1

Newfoundland Aquaculture Industry Association
176 Nagle's Hill
P.O. Box 23176
St. John's, NL A1B 4J9

8.0 REFERENCES

ADB. 1998. Roti Bay aquaculture management plan. Aquaculture Development Branch, Department of Fisheries and Aquaculture, Government of Newfoundland and Labrador, St. John's, NF. 18p.

Aure, J., A. Ervik, P. Johannessen and T. Ordemann. 1988. The environmental effects of sea water fish farms. Fisken og Havet 1. Institute of Marine Research, Bergen, Norway, 94p. (in Norwegian, abstract and legends to figures in English).

Axler R., C. Larsen, C. Tikkanen, M. McDonald, S. Yokom and P. Aas. 1996. Water quality issues associated with aquaculture: a case study in mine pit lakes. *Water Env. Res*. 68(6): 995-1011.

Bergheim, A. and O.I. Forsberg. 1993. Attempts to reduce effluent loadings from salmon farms by varying feeding frequencies and mechanical effluent treatment. European Aquaculture Society Special Publication, No. 18.

Beveridge, M. 1987. Cage aquaculture. Fishing News Books. Surrey, England. 352p.

Beveridge, M. and J.M. Muir. 1982. An evaluation on proposed cage fish culture on Loch Lomond, an important reservoir in central Scotland. *Can. Wat. Resources. J.* 7:181-196.

Boghen, A. D. 1995. Cold Water Aquaculture in Atlantic Canada. 2nd Edition. New Brunswick: Canadian Institute for Research on Regional Development. xiii + 672p.

Bridger, C.J., R.K. Booth, R.S. McKinley and D.A. Scruton. 2001. Site fidelity and dispersal patterns of domestic triploid steelhead trout (*Oncorhynchus mykiss* Walbaum) released to the wild. *ICES Journal of Marine Science* 58:510-516.

Brown, C., C. Coututier, T. Zokvic and J. Parsons. 1998. "Towards Best Practices": a practical guide for mussel aquaculture in Newfoundland (draft). Marine Institute of Memorial University of Newfoundland, Centre for Aquaculture and Seafood Development, St. John's, NF. 60p.

Brown, J.R., R.J. Gowan and D.S. McLusky. 1987. The effect of salmon farming on the benthos of a Scottish sea loch. *J. Exp. Mar. Biol. Ecol.* 109:39-51.

Burke Consulting Inc. 2000. Strategic Plan – Newfoundland and Labrador Aquaculture. Prepared by Burke Consulting Inc, Manuals, NF. In collaboration with Resource Development Associates, St. John's, NF.

Caine, G., J. Truscott, S. Reid and K. Ricker. 1987. Biophysical criteria for siting salmon farms in British Columbia. B.C. Aquaculture Commercial Fisheries Branch. 50p.

Catto, N.R., M.R. Anderson, D.A. Scruton and U.P. Williams. 1997. Coastal classification of the Placentia Bay shore. Can. Tech. Rept. Fish. Aquat, Sci. No. 2186:v+48p.

CCFAM. 2002. National code of introductions and transfers of aquatic organisms. Canadian Council of Fisheries and Aquaculture Ministers. www.ncr.dfo.ca/science/OAS/aquaculture/nationalcode/codedefault_e.htm. (accessed 13 September, 2002).

Clarke, J.F. 2000. Bioremediation of salmonid wastewater using seaweeds species native to Newfoundland, Canada. Report as part of Advanced Diploma in Aquaculture, Marine Institute of Memorial University of Newfoundland, St. John's, NF. 44p.

Clemens, T., C. Couturier, G.J. Parsons and P. Dabinett. 2000. Environmental characterization of Newfoundland shellfish farms for 1995-1999. ACERA Mussel Project #1. Marine Institute and Ocean Sciences Centre, Memorial University of Newfoundland, St. John's, NF. 159p.

Crawford, C. M., I.M. Mitchell and C. K. A. Macleod. 2001. Video assessment of environmental impacts of salmon farms. ICES Journal of Marine Science, 58(2): 445-452.

Dempson, J.B., G. Furey and M. Bloom. 1999. Status of Atlantic salmon in Conne River, SFA 11, Newfoundland, 1998. DFO Canadian Stock Assessment Secretariat Research Document 99/92. 45p.

Dempson, J.B., G. Furey and M. Bloom. 2000. Status of Atlantic salmon in Conne River, SFA 11, Newfoundland, 1999. DFO Canadian Stock Assessment Secretariat Research Document 2000/032. 45p.

Dempson, J.B., G. Furey and M. Bloom. 2001. Status of Atlantic salmon in Conne River, SFA 11, Newfoundland, 2000. DFO Canadian Stock Assessment Secretariat Research Document 2001/030. 45p.

Department of Fisheries and Oceans. 2002. Aquaculture Site Application: Review Process and Guidelines. Office of Sustainable Aquaculture, DFO, Ottawa.

Deveau, G. 1997. Preliminary assessment of salmonid aquaculture in Bay d'Espoir (Draft). Prepared for Aquaculture Section, Department of Fisheries and Aquaculture, Gander, NF. 43p.

Faris, T.L. 1987. Environmental effects of finfish cage culture. Fourth Alaska Aquaculture Conference, November, 1987, Sitka, Alaska.

Findley, R.H., L. Watling and L.M. Mayer. 1995. Environmental impact of salmon net-pen culture on marine benthic communities in Maine: A Case Study. *Estuaries* 18:145-179.

Fisher, R. 1988. Assessments and observations of a cod farming operation in Newfoundland. Can. Ind. Rep. Fish. Aquat. Sci. 194:vi+81p.

Fisheries and Oceans Canada. 2002. DFO's Aquaculture Policy Framework. Communications Branch, Fisheries and Oceans Canada, Ottawa, ON. K1A 0E6. DFO/6228. Cat. No. Fs23-411/2002. ISBN 0-662-66346-2. 32p.

Frid, C.L.J. and T.S. Mercer. 1989. Environmental monitoring of caged fish farming in macrotidal environments. *Marine Pollution Bulletin* 20(8):379-383.

Frogh, M. and M. Schaanning. 1991. Benthic degradation in bottom sediments from salmon cage farming at 66°N in Norway. *In*: Aquaculture and the Environment. N. DePauw and J Joyce (eds.), European Aquaculture Society Spec. Pub. No. 14, Bredene, Belgium.

Goudey, C.A., G. Loverich, H. Kite-Powell and B.A. Costa-Pierce. 2001. Mitigating the environmental effects of mariculture through single-point moorings (SPMs) and drifting cages. ICES *Journal of Marine Science* 58:497-503.

Gowen, R.J. and N.B. Bradbury. 1987. The ecological impact of salmonid farming in coastal waters: a review. *Oceanogr. Mar. Biol. Annu. Rev.* 25:563-575.

Hansen, P.K., A. Ervik, M. Schaanning, P. Johannessen, J. Aure, T. Jahnsen and A. Stigebrandt. 2001. Regulating the local environmental impact of intensive, marine fish farming II. The monitoring programme of the MOM system (Modelling – Ongrowing fish farms – Monitoring). *Aquaculture.* 194:75-92.

Hatcher, A., J. Grant and B. Schofield. 1994. Effects of suspended mussel culture (*Mytilus* spp.) on sediementation, benthic respiration and sediment nutrient dynamics in a coastal bay. *Marine Ecology Progress Series* 115:219-235.

Hatfield Consultants Ltd. 1990. Newfoundland and Labrador Development Strategy. Department of Fisheries, Government of Newfoundland and Labrador, St. John's, NF. 118p.

Hargrave, B.T., D.E. Duplisea, E. Pfeiffer and D.J. Wildish. 1993. Seasonal changes in benthic fluxes of dissolved oxygen and ammonium associated with marine cultured Atlantic salmon. *Marine Ecology Progress Series* 96:249-257.

Henderson, A.R. and D.J. Ross. 1995. Use of macrobenthic infaunal communities in the monitoring and control of the impact of marine cage fish farming. *Aquacult. Res.* 26:659-678.

Holmer, M. and E. Christensen. 1992. Impact of marine fish cage farming on metabolism and sulphate reduction of underlying sediments. *Mar. Ecol.: Prog. Ser.* 80:191-201.

Johannessen, P.J., H.B. Botnen and O.F. Tvedten. 1994. Macrobenthos: before, during and after a fish farm. *Aquacult. Fish. Manage.* 25:55-66.

Lee, E.M., M.G. Foy and R.A. Buchanan. 1995. Canada-Newfoundland Agreement Respecting Water Resource Management: Sustainability of Lakes and Ponds for Finfish Aquaculture in Newfoundland. Water Resources Division, Department of Environment, Government of Newfoundland and Labrador. 124p.

Levings, C.D. 1994. Some ecological concerns for net-pen culture of salmon on the Northwest Pacific and Atlantic Oceans, with special reference to British Columbia. *Journal of Applied Aquaculture* 4(1):65-141.

Levings, C.D., A. Ervik, P. Johannessen and J. Aure. 1995. Ecological criteria used to help site fish farms. *Estuaries* 18(1a):81-90.

Lumb, C.M. 1989. Self-pollution by Scottish salmon farms? *Marine Pollution Bulletin* 20(8):375-379.

Lim, S. 1991. Environmental impact of salmon farming on the benthic community in the Bay of Fundy. *Bull. Aquacul. Assoc. Canada* 91(3):126-128.

Mattson, J. and O. Linden. 1983. Benthic macrofauna succession under mussels, *Mytilus edulis* L. (Bivalvia), cultured on hanging long lines. *Sarsia* 68:97-102.

Misdorp, R., L.H.M. Kohsiek, F.H.M. Steyaert and R. Dijkema. 1984. Environmental consequences of a large scale coastal engineering project on aspects of mussel cultivation in the eastern Scheldt. *Nat. Sci. Tech.* 16:95-105.

Newcombe, C. 1995. Assessment of potential aquaculture site within the Bonavista Peninsula and surrounding area. Bonavista Peninsula and Surrounding Area Community Futures Development Corporation. Bonavista. 108p.

North Atlantic Salmon Conservation Organization (NASCO). 1994. Amendments to the protocols for the introduction and transfer of salmonids. North American Commission. NAC(94)14. NASCO, Scotland.

Novotny, A.J. and W. Pennell. 1996. Rearing fish to market size in marine waters. p. 477-605. *In*: W. Pennell and B.A. Barton (eds.). Principles of Salmonid Aquaculture. Developments in Aquaculture Fisheries Science, 29: xxix + 1039p.

Oberdorff, T. and J.P. Porcher. 1994. An index of biotic integrity to assess biological impacts of salmonid farm effluents on receiving waters. *Aquaculture* 119:219-235.

Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. Mar. Biol. Ann. Rev.* 16:229-311.

Pei-Yuan, Q., W.C.S. Madeline and N. I-Hsun. 2001. Comparison of nutrients release among some maricultured animals. *Aquaculture*, 200:305-316.

Pennell, W. 1992. British Columbia Salmon Farming Manual: Site Selection Handbook. Province of British Columbia, Ministry of Agriculture, Fisheries and Food, Aquaculture and Commercial Fisheries Branch. 15p.

Phillips, M., M. Beveridge. 1986. Cages and the effect on water condition. *Fish Farmer* 9:17-19.

Pitts, J. 1990. Washington State's environmental impact statement (EIS) on fish culture in floating net-pens. Aquaculture International Congress (1990 Vancouver, B.C.) Proceedings. 285-289.

Ritz, D.A., M.E. Lewis and M. Shen. 1989. Response to organic enrichment of infaunal macrobenthic communities under salmonid seacages. *Marine Biology* 103:211-214.

Rosenthal, H., D. Weston, R. Gowen and E. Black. 1988. Report of the ad hoc study group on environmental impact of mariculture. ICES, Cooperative Research Report 154. Copenhagen, Denmark. 83p.

Rosenthal, H. and R.W. Rangeley. 1989. The effect of a salmon cage culture on the benthic community in a largely inclosed bay (Dark Harbour, Grand Manan Island, New Brunswick, Canada. *ICES Journal of Marine Science* 23:1-17.

Rosenthal, H., D.J. Scarrat and M. McInerney-Northcott. 1995. Aquaculture and the environment. p. 451 – 500. *In*: A.D. Boghen. Cold Water Aquaculture in Atlantic Canada. 2nd Edition. New Brunswick: Canadian Institute for Research on Regional Development. xiii + 672p.

SCB Fisheries. 1992. Marine grow-out assessment of Atlantic salmon in the outer Bay d'Espoir system. Canada/Newfoundland Inshore Fisheries Development Agreement, Aquaculture Report 30, Department of Fisheries, Aquaculture Section. File #271.109.

Silvert, W. 1994. Modelling benthic deposition and impacts of organic matter loading. Chapter 1. *In*: B.T. Hargrave (ed.). Modelling benthic impacts of organic enrichment from marine aquaculture. *Can. Tech. Rep. Fish. Aquat. Sci.* No. 1949: 1-18.

Silvert, S. and J.W. Sowles. 1996. Modelling environmental impacts of marine finfish aquaculture. *Journal of Applied Ichthyology* 12(2):75-81.

Smith, J.A. 2001. Environmental management guide for marine aquaculture cage sites located in areas of concern for juvenile lobster habitat, with specific reference to sites at Seeleys Cove (Site MF-400) and Red Head (Site MF-412). Prepared for Department of Fisheries and Oceans, Dartmouth, NS. 30p.

South Coast Community Development Corporation (SCCDC). 1998. Assessment of potential aquaculture sites in economic zone 13 (Coast of Bays region). Final Report. HRDC contract #A56364-2; ACOA Contract #620-4032260-1. 170p., South coast Community Development Corporation.

Tlusty, M., M.R. Anderson and V.A. Pepper. 1998. Assuring sustainable salmonid aquaculture in Bay d'Espoir, Newfoundland. *Bull. Aquacul. Assoc. Canada* 98-2:35-37.

Tlusty, M.F., V.A. Pepper and M.R. Anderson. 1999. Environmental monitoring of finfish aquaculture sites in Bay d'Espoir, Newfoundland during the winter of 1997. *Can. Tech. Rep. Fish. Aquat. Sci.* No. 2273.

Tlusty, M.F., V.A. Pepper and M.R. Anderson. 2000a. Realizing the potential of frontier regions in aquaculture – the Newfoundland salmonid experience. *World Aquaculture* 31(1):50-54.

Tlusty, M., K. Snook, V.A. Pepper and M.R. Anderson. 2000b. The potential for soluble and transport loss of particulate aquaculture wastes. *Aquaculture Research* 31:745-755.

UMA Engineering Ltd. 1989. Adequacy of effluent treatment facilities – Sugarloaf Farms, Williamsdale, Nova Scotia. EDRA Report #21. Nova Scotia Department of Fisheries, Halifax, NS. 8p.

Warwick, R.M. 1989. A new method for detecting pollution effects on marine macrobenthic communities. *Marine Biology* 92:527-562.

Wells, D.M. 1999. Canada-Newfoundland Agreement on Economic Renewal: A Growers Guide To Small Scale Cod Grow-Out Operations. Prepared for Department of Fisheries and Oceans, St. John's, NF. 40p.

Wells, P.G., L. Harding, J. Karau and G. Packman. 1987. Marine environmental quality in Canada. *In*: Oceans 87 Proceedings: The Ocean – An International Workplace. Marine Technology Society, Washington, D.C. 1633-1636.

Weston. D.P. 1990. Quantitative examination of macrobenthic community changes along an organic enrichment gradient. *Mar. Ecol. Prog. Ser.* 61: 233-244.

Wildish, D.P., P.D. Keiser, A.J. Wilson and J.L. Martin. 1993. Seasonal changes of dissolved oxygen and plant nutrients in seawater near net pens in the macrotidal Bay of Fundy. *Can. J. Aquat. Sci.* 50:303-311.

Wildlish, D.J., H.M. Akagi, N. Hamilton and B.T. Hargrave. 1999. A recommended method for monitoring sediments to detect organic enrichment from mariculture in the Bay of Fundy. *Can. Tech. Rep. Fish. Aquat. Sci.* No. 2286:iii+31p.

Wildish, D.J., B.T. Hargrave and G. Pohle. 2001. Cost-effective monitoring of organic enrichment resulting from salmon culture. ICES *Journal of Marine Science* 58:469-476.

Wroblewski, J.S., R.K. Smedbol, C.T. Taggart and S.V. Goddard. 1996. Movements of farmed and wild Atlantic cod (*Gadus morhua*) released in Trinity Bay, Newfoundland. *Marine Biology* 124:619-627.

Wu, R.S.S. 1995. The environmental impact of marine fish culture: towards a sustainable future. *Marine Pollution Bulletin*, 31:159-166.

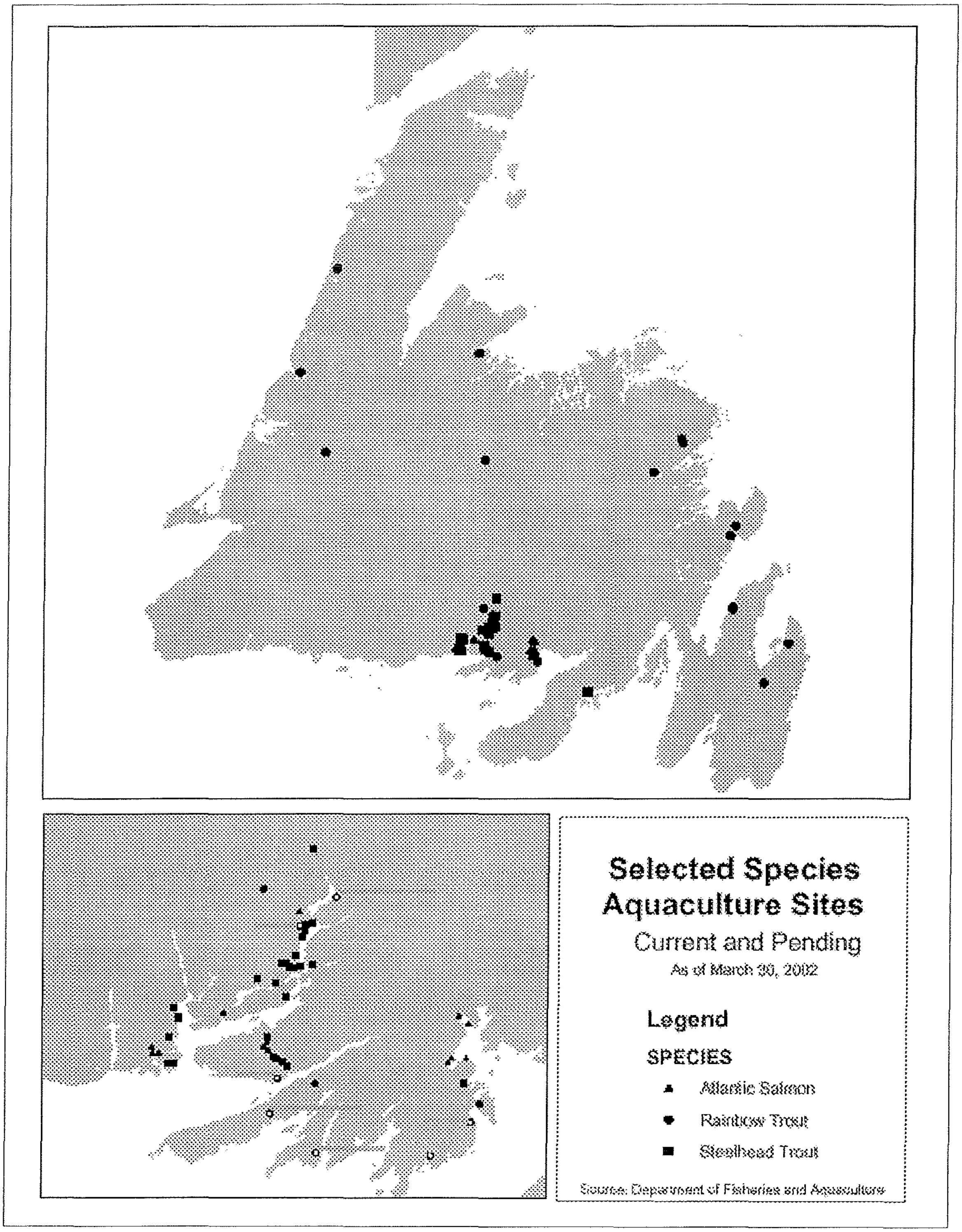

Figure 1. Salmonid Aquaculture Sites

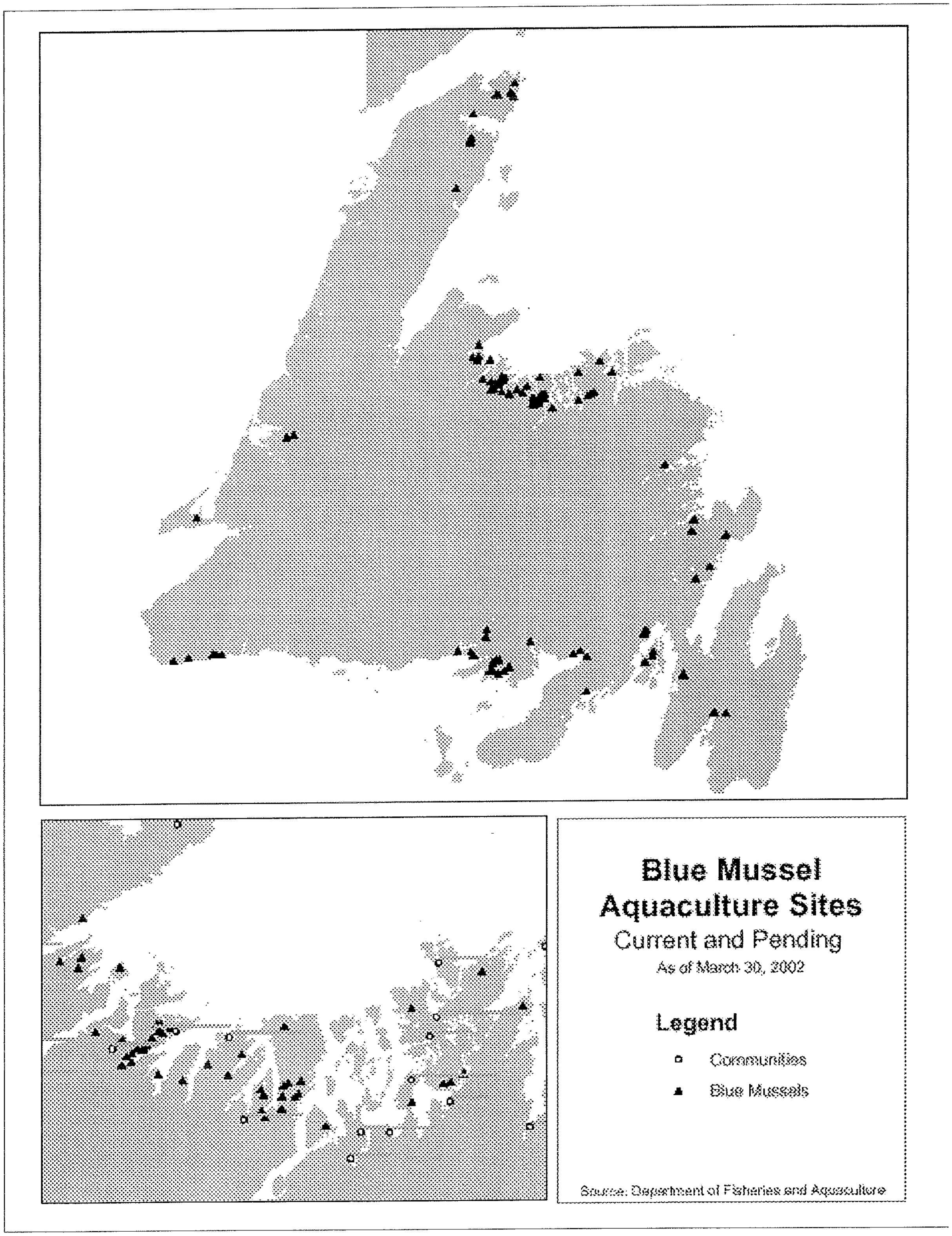

Figure 2. Mussel Aquaculture Sites.

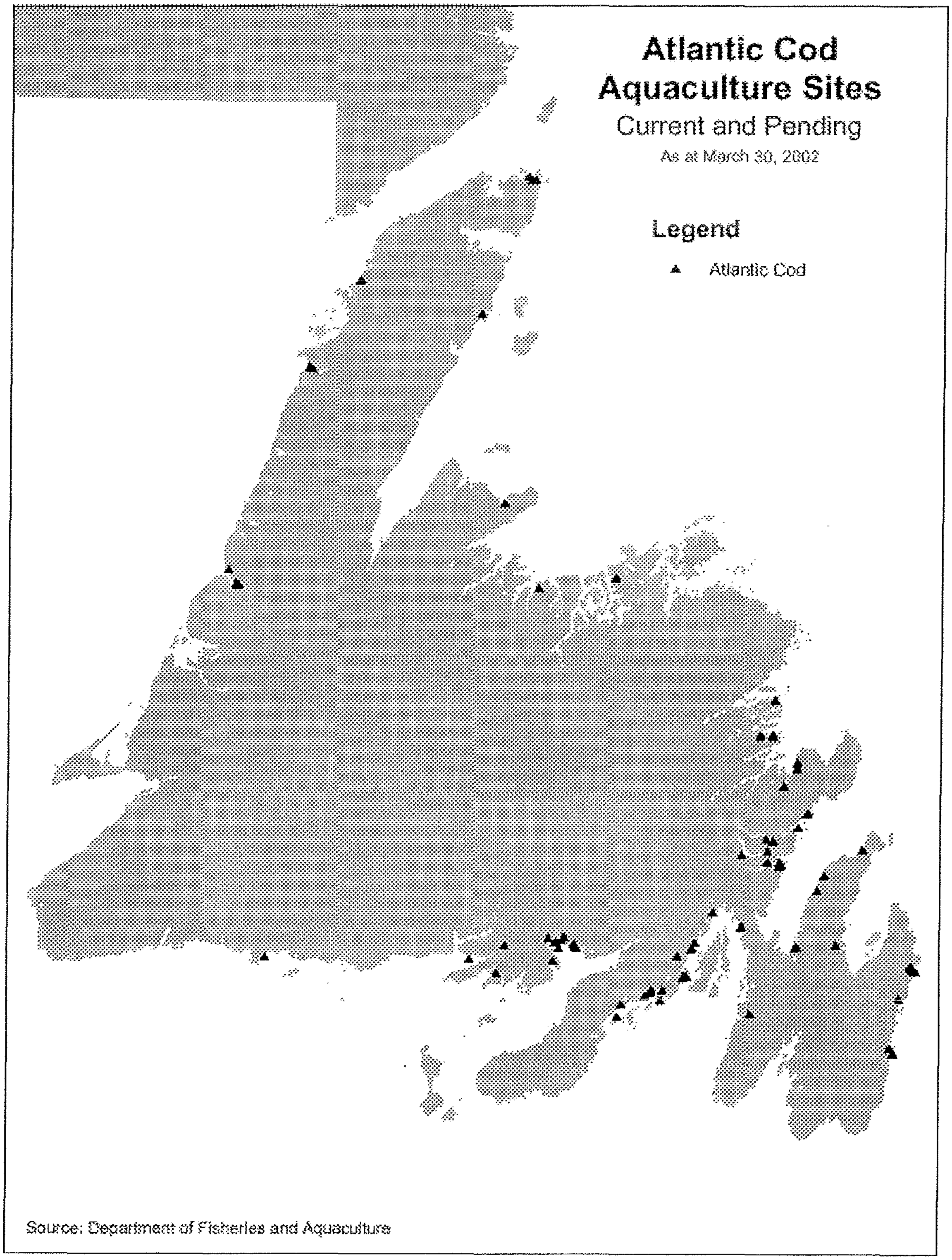

Figure 3. Atlantic Cod Grow-out Sites.

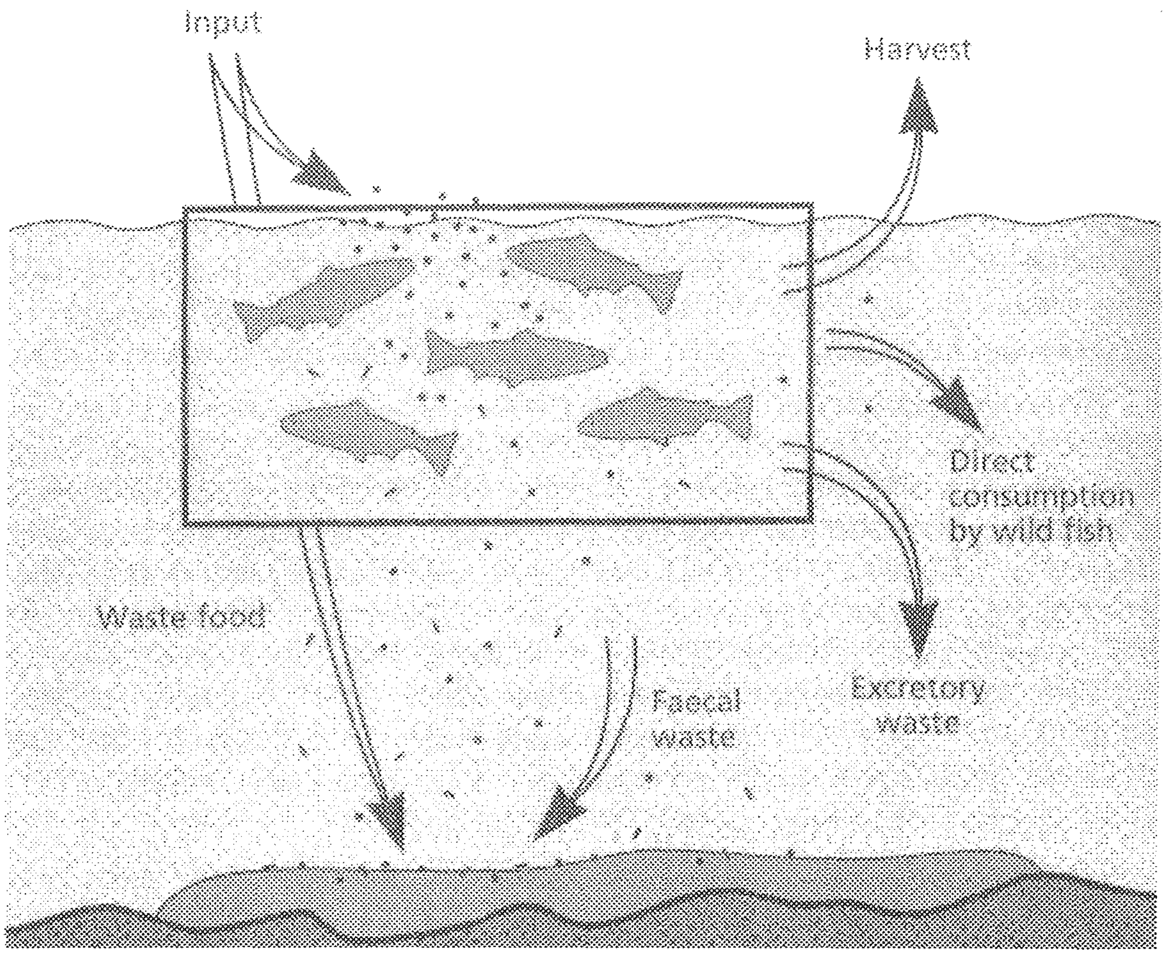

Figure 4. Simplified pathway showing fate of nutrients on a typical fish farm (Rosenthal *et al.* 1995).

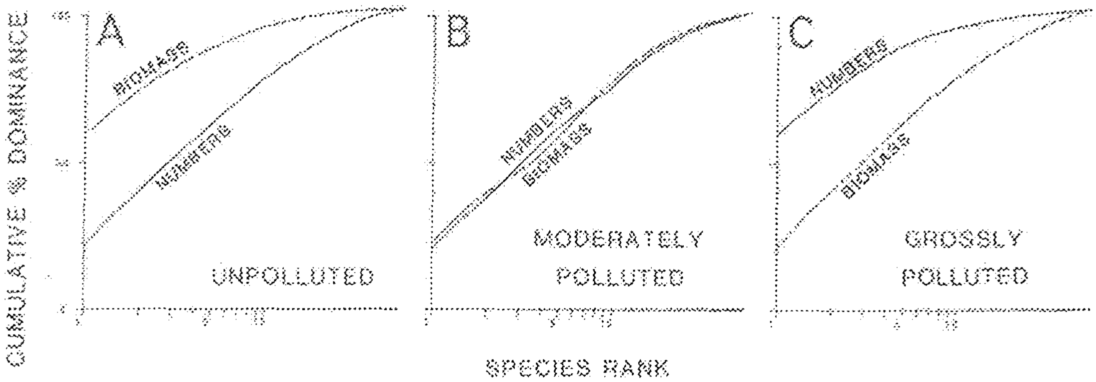

Figure 5. Hypothetical *k*-dominance curves for species biomass and numbers, showing unpolluted, moderately polluted and grossly polluted conditions (Warwick 1989).

Appendix 1. Contact was made with the following people during the project (exclusive of the direct contact with the Steering Committee):

Contact	Affiliation
David Coffin	DFO
Abdel Rasek	Dep. of Environment – Water Resources Division
Shawn Robinson	Department of Fisheries and Aquaculture (DFA)
Paul James	DFA
Brent Tompkins	DFA
Gordon Deveau	AquaNet Administrative Centre – MUN
Ray Thompson	OSC - MUN
Don Deibel	OSC - MUN
Pat Dabinett	MUN
Chris Hendry	DFA
Cyr Couturier	NAIA
Chris Brown	NRC
Ron Scaplen	DFA
Brian Meaney	DFA
Joe Brown	OSC
Danny Boyce	OSC
Robin Anderson	DFO
Larry Yetman	DFO
Daryl Whelan	DFA
Randy Penney	DFO
Jay Parsons	MUN / DFO
Jonathan Moir	Industry - Finfish
Cynthia McKenzie	DFO
Travis Mahoney	Zone Board / DFA
Garry Hartle	Industry
Louis McDonald	Industry
Marc Kielley	CCFI
Bob Fisher	Zone Board (former)
Bill Driedzic	OSC - MUN
Vern Pepper	DFO
Bob O'Neill	NAIA
Mike Rose	NAIA
Harold Murphy	NAIA
Bill Carter	Industry - Mussels
John Kealey	Industry - Salmonid
Guy Herritt	Industry - Salmonid
Calvin Loveless	Industry - Mussels
Stan Butt	Industry - Cod Grow-out
Alonzo Bailey	Industry - Cod Grow-out
Wes Williams	Industry - Cod Grow-out
Marvin Anstey	Industry - Mussel (former), Prov.
Roland Hedderson	Industry - Cod Grow-out / FFAW
Clyde Collier	Industry - Salmonid
Andy Walsh	Industry - Cod
Colin Taylor	DFA
David Wells	Industry

Appendix 2. Ranges of water quality parameters suitable for cod grow-out facilities (abstracted from Wells (1999)).

Parameter	Description
pH	- seawater normally ranges from 7.5 - 8.5 - for cod, a range of 6 - 8.5 is preferred
Salinity	- salinity affects water movement in and out of fish - cod prefer a salinity range of 32 - 35 ppt but can tolerate salinities outside this range
Dissolved Oxygen	- affected by temperature, salinity and atmospheric pressure - ie. higher water temperatures/less oxygen dissolved higher salinity/lower dissolved oxygen higher atmospheric pressure/higher dissolved oxygen - 5-6 mg/l range
Ammonia	- a nitrogenous waste product of protein breakdown in fish - sources - fish excretions, uneaten food, decomposing organic matter - less than 0.05 mg/l is recommended level
Turbidity	- suspended solids, both organic and inorganic, present in water. - too much suspended material can damage fish gills as well as destroy protective mucus covering the eyes and scales; impair feeding of visual feeders; displace or disturb aquatic organisms that may provide food for cod.
Temperature	- water temperature is a key element for fish growth - low temperatures and higher extreme temperatures slow down fish metabolism - high temperatures, fish are susceptible to disease - lower temperatures, fish cease feeding - preference zone is from 5-12^{O}C and this also corresponds with the temperature where stomach emptying rate, feed intake, oxygen consumption after feed intake are maximized.
Stress	- as stress increases, susceptibility to infections and disease increases - Things that cause stress: 1) over crowding – i.e., good stocking density 35 kg/m^3; 2) handling; and, 3) water quality

Appendix 3. Summary of seabed categories under salmonid aquaculture operations (abstracted from Lumb 1989).

Type	**Site # (n)**	**Sediment redox potential**	**Sediment Type**	**Benthic Species Presence**	**Description**
A	3	Anoxic (water anoxic)	Mud (flocculent)	Depauperate	o Located in extremely sheltered conditions o Experienced very low water exchange o Evidence of low oxygen concentrations occurring naturally in the water column o Acute organic enrichment recorded at all three sites o Substantial out-gassing at 2/3 sites
B	15	Oxic / Anoxic	Mud (semi-consolidated)	Species consisted of *Terebellidae* and *Sagartiogeton spp.* with drift algae present and localized bacterial mat	Mean current speed for deepest site 1.7cm/s, maximum speed 11cm/s **Established Sites*:** o 8/8 sites had acute organic enrichment o 7/8 sites had substantial out-gassing **New Sites*:** o 4/7 had acute organic enrichment
C	23	Oxic	Mud (extensive cohesive and deep)	Species consisted of diatom dominated mud with increasing species diversity	Mean current speed for deepest site 1.5cm/s, maximum speed 13cm/s **Established Sites:** o 11/15 sites had acute organic enrichment (9/11 had outgassing) **New Sites:** o 3/8 sites had organic enrichment
D	12	Oxic	Sandy mud (often overlying stones/rock)	Sediment overlain by algal mat and *Leptosynapta sp.* In shallow water and many small bivalves; *Mya truncata*, *Cerianthus lloydi* in deeper water	Mean current speed for deepest site 7.04cm/s, maximum speed 42.4cm/s, minimum speed 0.1cm/s **Established Sites:** o 3/7 sites had acute organic enrichment (2/3 had outgassing) o 3/7 little or no evidence of organic enrichment **New Sites:** o 4/5 little or no evidence of organic enrichment

Appendix 3. (Cont'd.)

E	3	Oxic	Sand (often overlying stones/rock)	Rich infaunal communities including *Ensis sp.*, *Dosinia exoleta*, *Venerupis spp.* and other burrowing bivalves	Mean current speed for deepest site 6.35cm/s, maximum speed 31.3cm/s **Established Site:** o 1/1 had no evidence of accumulation of faecal waste (some waste food pellets) **New Sites:** o 2/2 had no evidence of accumulation of organic wastes (one site had *Ensis sp.* in sediment suggesting some environmental deterioration)
F	2	Oxic	Gravel (often overlying stones/rock)	Algal meadows often with maerl present with diverse epifalunal and infaunal populations including *Pecten maximus*	**Established Sites:** o 2/2 showed little sign of accumulation of any organic waste, except in localized sheltered pockets. No current speed information provided

* Established sites were defined as those in operation for more than one year; new sites were in operation for 2-3 months.