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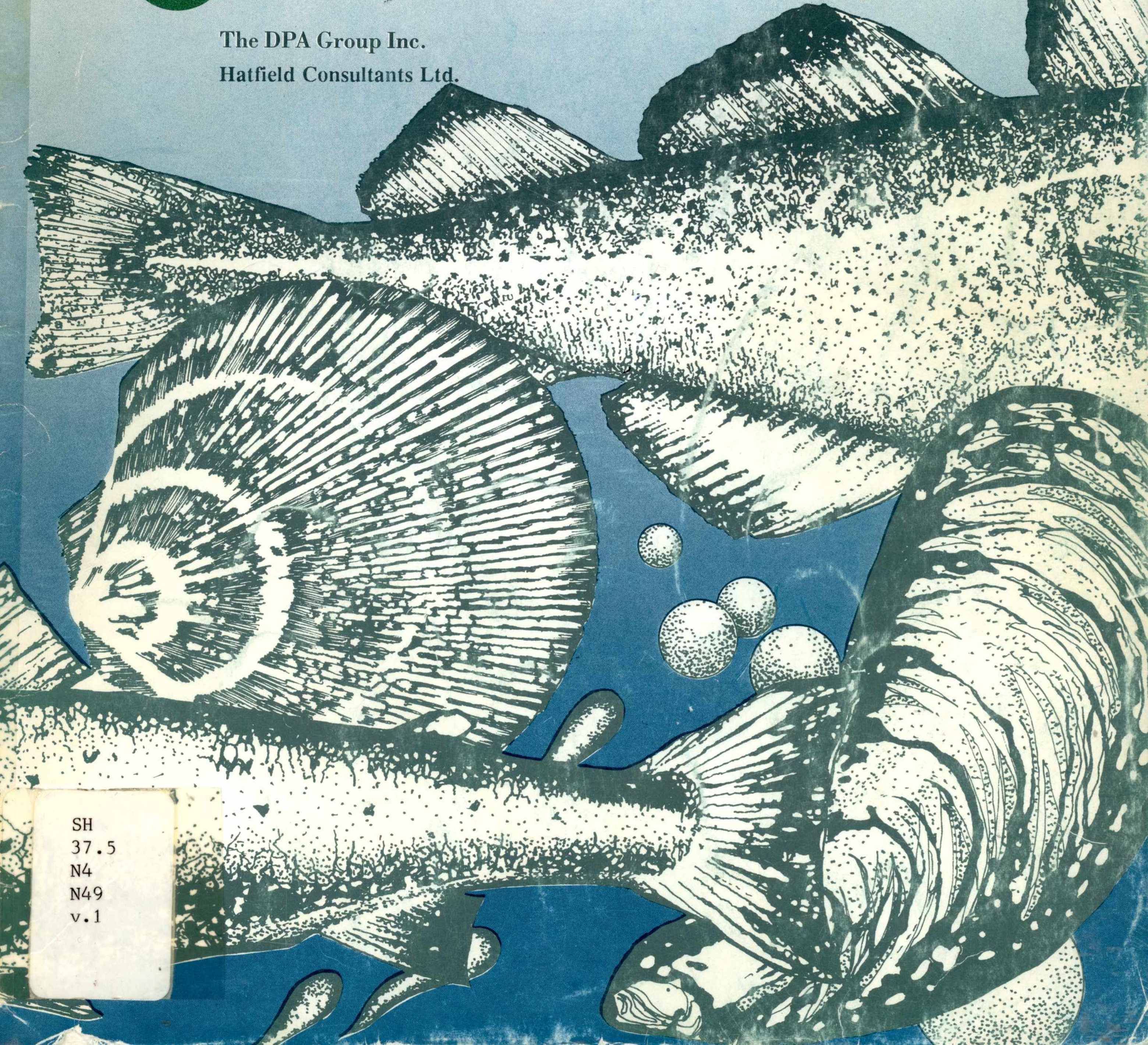
Aquaculture Development Strategy

The DPA Group Inc.
Hatfield Consultants Ltd.



Newfoundland & Labrador Aquaculture Development Strategy

Volume 1

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Cautionary Note

This report has been prepared under a contract awarded to The DPA Group Inc. and its associates by the Department of Fisheries, Government of Newfoundland and Labrador. The information contained herein is believed to be accurate. Any errors or ommissions are the responsibility of the authors. The conclusions reached and recommendations made constitute advice to the government by individual members of The DPA Group Inc. and associates' Study Team. Acceptance of this report by the Department of Fisheries is for contractual purposes only and should not be construed as acceptance of any of the opinions, conclusions and recommendations contained herein.

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1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE OF THE STUDY

This report is part of a study to develop a comprehensive aquaculture development plan for the Province of Newfoundland and Labrador. The terms of reference call for the study to determine the species, culturing techniques and site areas that present the most attractive commercial aquaculture opportunities for Newfoundland. The specific objectives of the study are to:

- identify and rank aquaculture zones for at least ten species, with particular emphasis on Atlantic salmon and blue mussels;
- assess the market, technical and financial viability of culturing species whose required conditions for rearing match those found in Newfoundland; and
- prepare a broad development strategy for aquaculture in Newfoundland.

Our methods during the study included a comprehensive literature review; interviews with the Steering Committee, representatives of provincial and federal government departments in Newfoundland, representatives of producer groups, individual producers and suppliers, representatives of development associations, and government officials in Ottawa, other provinces and in several states in the U.S.; visits to aquaculture sites; and use of computerized growth forecasting models and existing cost of production models.

1.2 ORGANIZATION OF THE STUDY

The study findings are summarized in three volumes. In Volume I the site criteria for culturing each species and information on the siting conditions within the province are presented. Volume II deals with technical, market and economic aspects of culturing salmon and mussels (the two species with which the most commercial development has occurred), and eight other species under consideration. Volume III contains a comprehensive strategy for all species.

This document is Volume I and is comprised of two major sections:

- Section 2.0 presents a review of the siting requirements for ten potential culture species; and
- Section 3.0 presents a review of logistic and biophysical conditions related to potential aquaculture development within the province.

The text of Section 2.0 presents summaries of the siting requirements; detailed descriptions of culture methods and related siting requirements for each species are presented as appendices.

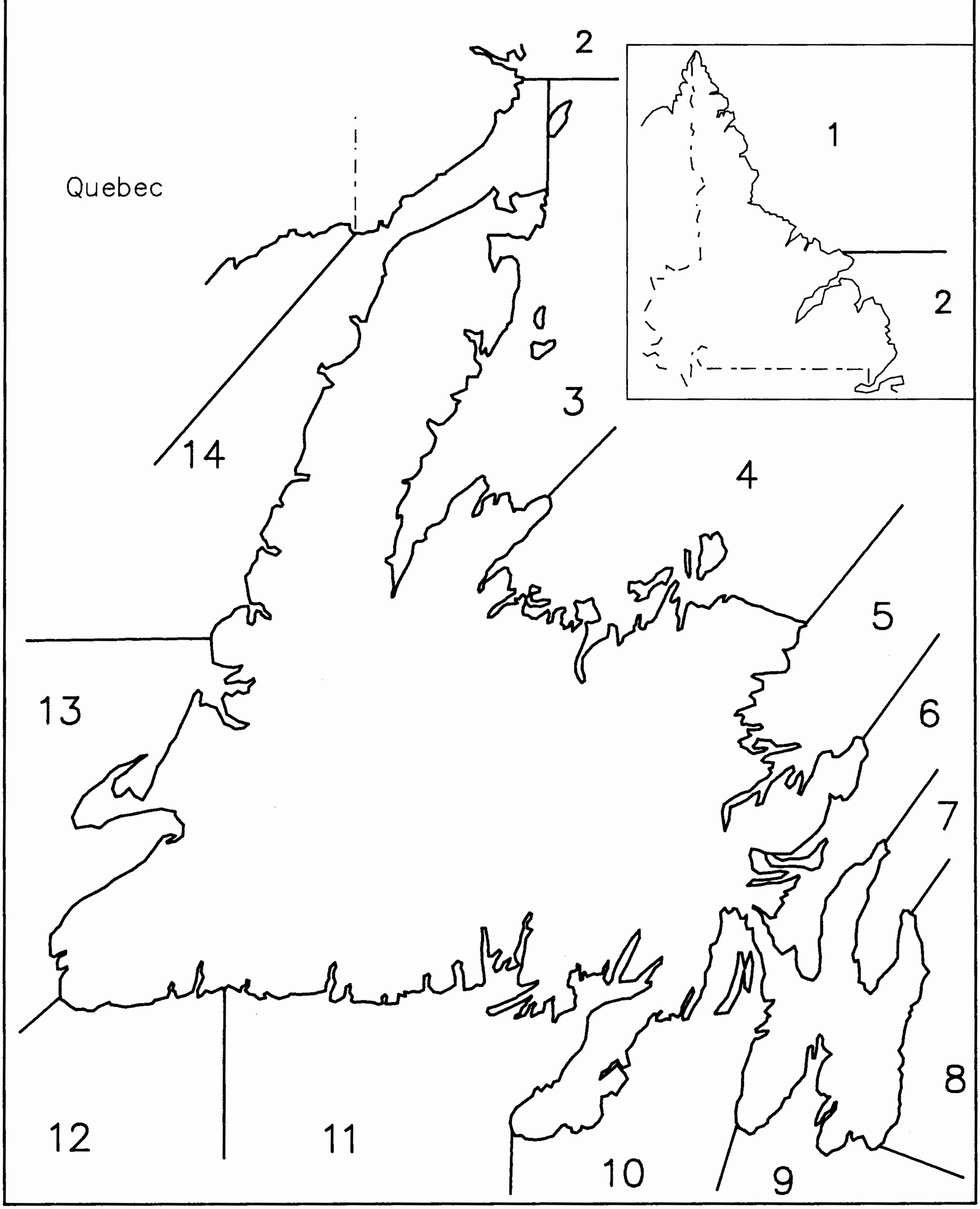
Information in Section 3.0 is presented in three major sub-sections:

- Regional Infrastructure;
- Marine Biophysical Conditions; and
- Freshwater Biophysical Conditions.

Fisheries Management Zones used by the Newfoundland Department of Fisheries have been used to define Aquaculture Development Zones (Figure 1.1). These zones were used as the basis for undertaking the regional assessments of aquaculture potential in Volume II. Background information in Section 3.0 of Volume I is presented for each zone. The geographical area covered by each zone is as follows:

- Zone 1: Northern Labrador, Cape Chidley to Cape Harrison.
- Zone 2: Cape Harrison to Cape Charles, including Hamilton Inlet/Lake Melville.
- Zone 3: Cape Bauld to Cape St. John (Hare Bay, White Bay).
- Zone 4: Cape St. John to Cape Freels (Notre Dame Bay, Bay of Exploits, Fogo Island).
- Zone 5: Bonavista Bay, Cape Freels to Cape Bonavista.

FIGURE 1-1: Aquaculture Development Zones



- Zone 6: Trinity Bay, Cape Bonavista to Grates Point.
- Zone 7: Conception Bay, Grates Point to Cape St. Francis.
- Zone 8: East Avalon, Cape St. Francis to Cape Race.
- Zone 9: South Avalon, Cape Race to Cape St. Mary's.
- Zone 10: Placentia Bay, Cape St. Mary's to Point Crewe.
- Zone 11: South Coast East (Bay d'Espoir and Fortune Bay), Cape Crewe to Burgeo.
- Zone 12: South Coast West, Burgeo to Cape Ray.
- Zone 13: Cape Ray to Cape St. Gregory (St. George's Bay, Port aux Port, Bay of Islands).
- Zone 14: Cape St. Gregory to Cape Bauld (Island of Newfoundland) and L'Anse-au-Clair to Cape Charles (Labrador).

The reader should note that the logistic and biophysical descriptions in Section 3.0 are provided as background for the interpretation of the general development potential within the aquaculture zones (Volume II). Most data are not site-specific and are not intended for use in selecting specific culture sites. This is especially true for water quality and pollution data which can change over time and can vary greatly over a small geographical area. Prospective culturists must evaluate each potential site on its own merits and should contact appropriate government agencies to gather site-specific data early in the project planning process.

2.0 CULTURE SITING REQUIREMENTS FOR SELECTED SPECIES

The culture requirements for identifying suitable culture facility sites have been reviewed for ten potential aquaculture species. These species are:

Salmonid Species

- Atlantic Salmon (*Salmo salar*);
- Rainbow Trout (*Oncorhynchus mykiss*); and
- Arctic Char (*Salvelinus alpinus*).

Shellfish Species

- Blue Mussels (*Mytilus edulis*); and
- Giant Scallops (*Placopecten magellanicus*).

American Eel (*Anguilla rostrata*)

Marine Finfish

- Atlantic Halibut (*Hippoglossus hippoglossus*);
- Atlantic Cod (*Gadus morhua*);
- Lumpfish (*Cyclopterus lumpus*); and
- Wolffish (*Anarhichas lupus*).

The technology for culturing these species is at different stages of development. Some species are now in commercial production, while others are at the research or pilot development stages. The industrial development status of each species is summarized in Table 2.1.

The siting requirements for each species are summarized in the text of this section and detailed information is presented in appendices:

- Appendix A: Salmonid Species;
- Appendix B: Shellfish Species;
- Appendix C: American Eel; and
- Appendix D: Marine Finfish Species.

TABLE 2.1: SUMMARY OF INDUSTRIAL DEVELOPMENT STATUS OF SELECTED AQUACULTURE SPECIES.

SPECIES	COMMERCIAL PRODUCTION	DEVELOPMENT/ PILOT PRODUCTION	RESEARCH
Salmonids			
Atlantic Salmon	X		
Rainbow Trout	X		
Arctic Char	X	X	
Shellfish Species			
Blue Mussels	X		
Giant Scallops	X	X	
American Eel		X	X
Marine Finfish			
Atlantic Cod	X	X	
Atlantic Halibut		X	X
Lumpfish		X	X
Wolffish			X

NOTE: Research is ongoing for all species and therefore is only noted where species are still undergoing substantial research before commercial production can begin.

The appendix for each species contains a brief review of the current state of culture technology (including the status of development within Newfoundland and general culture methods and production options), followed by identification of important biological and physical factors for siting culture facilities. Emphasis was placed on Atlantic salmon and blue mussels during the review because commercial production is relatively advanced for these species within Newfoundland.

The facility siting information contained in this section was used to guide the assessment of regional development potential within the province (Volume II).

2.1 SALMONIDS

Salmonid culture in Newfoundland began with the introduction of rainbow trout late in the last century (reviewed in Appendix A). At present, Atlantic salmon, rainbow trout and Arctic char are being cultured for commercial growout at private operations. Atlantic salmon are also being cultured for release as juveniles in several public participation facilities for Atlantic salmon resource enhancement. The potential for commercial Arctic char culture is being assessed at several proposed locations.

The basic culture facility designs and site selection criteria are similar for all salmonids. Important siting factors for each species are summarized below.

2.1.1 Atlantic Salmon

Table 2.2 summarizes the biophysical requirements for salmon netpen facilities; Tables 2.3 and 2.4 summarize, respectively, the general siting requirements and water quality requirements for salmon freshwater facilities. For assessment of the regional development potential for each species in Volume II, the siting requirements were grouped into general categories:

TABLE 2.2: SUMMARY OF BIOPHYSICAL SITING CRITERIA FOR SALMON FARMS. (Source: Caine et al. 1987; Beveridge 1987; Saunders 1986)

FACTOR	GOOD CONDITIONS	LIMITS
TEMPERATURE		
Summer	10 - 16°C.	Less than 20°C.
Winter	Greater than 4°C.	Greater than 2°C.
DISSOLVED OXYGEN		
Minimum Concentration	8.5 mg/L.	5.0 mg/L.
Minimum Saturation	100%.	60%.
SALINITY		
Long-Term	Greater than 24 ppt.	Greater than 15 ppt.
Fluctuations	3% change.	Less than 5%.
HYDROLOGY	Freshwater lens depth of less than 1 m.	Freshwater lens depth of less than 4 m.
PLANKTON	No record of harmful blooms.	Infrequent harmful blooms.
POLLUTION	No nearby sources.	Nearby low level sources.
CURRENTS		
At Slack Water	10 - 15 cm/s.	Greater than 2 cm/s.
At Peak Flows	10 - 50 cm/s.	Less than 100 cm/s.
DEPTH		
At Low Tide	20 - 30 m.	Greater than 10 m below cages.
SITE PHYSIOGRAPHY	Greater than 30° slope allowing anchoring to shore; rock, sand or gravel bottom; no sills.	Greater than 15° slope (anchoring distant from shore); sand and mud bottom (no organic ooze); some sills.
PREDATORS	No nearby concentrations of avian and mammalian predators and few known to use area.	Avian and mammalian predators known to use area, but large concentrations absent.
MARINE PLANTS AND FOULING	Low levels of fouling organisms; no kelp.	Moderate levels of fouling organisms; kelp nearby.
WIND AND WAVES	Sheltered site; wave height less than 0.6 m.	Partially exposed; wave height less than 1.2 m.
ICE CONDITIONS	No drift ice; no fast ice.	No drift ice; fast ice.

TABLE 2.3: SUMMARY OF GENERAL SITING REQUIREMENTS FOR AN ATLANTIC SALMON FRESHWATER CULTURE FACILITY. (Sources: Piper et al. 1982; Sedgewick 1988)

	OPTIMUM	MINIMUM
1. PROXIMITY TO:		
a) Support Community	- Adjacent to a community capable of supplying labour and/or staff housing, material supply needs, and feed.	- Community within several hours travel time (staff live at the site).
b) Market or Release Sites	- Adjacent to the smolt sales area or growout sites, or release sites (ranching).	- Most growout sites located within cost-effective transport distance.
2. SITE ACCESS	- Paved road to site.	- New road must be constructed, 2-3km.
3. POWER	- Connected to outside hydroelectric power lines.	- Power produced on site.
4. COMMUNICATIONS	- Connection to telephone lines.	- Radio phone.
5. LAND	- Sufficient gradient to allow water to move by gravity. - Minimal earth moving or site preparation.	- Above watertable and flood risk area. - Less than 30° gradient; no solid rock requiring extensive blasting.
6. WATER SUPPLY		
a) Type	- Springs (ideally one cool water (6-8°C); and one warmwater (14-18°C)).	- Lake; stream with low seasonal turbidity or extreme flows.
b) Quantity	- Sufficient to meet production targets without recirculation.	- 10% maximum required flow, assuming water re-use is viable.
c) Temperature	- One supply at 14-18°C (for smolt rearing). - One supply at 8°C (for egg incubation).	- Greater than 2°C; less than 20°C.
d) Oxygen	- Saturated (100%).	- Aeration is incorporated in the facility design so that saturation is maintained above 80%.
e) Water Quality	- As per Table 2.4.	- As per Table 2.4.
7. EFFLUENT	- Discharge is possible without effluent treatment (e.g., to swamp or marsh not having direct input to stream or lake).	- Removal of suspended solids to permissible level. - Removal of nitrogen compounds permissible level, if required.

The minimum acceptable conditions are difficult to specify since they will vary from site to site according to whether one or more other factors are close to optimum. The descriptions generally assume the other factors to be close to optimum.

TABLE 2.4: WATER QUALITY SCREENING PARAMETERS FOR SALMON HATCHERIES. (Source: Shepherd 1984)

CAUTION:
The levels in this table are not criteria; they are intended only to indicate which of the parameters in a water analysis require closer examination and comparison with detailed criteria. Notes outlining the rationale for establishment of the screening levels are given following the table.

Fish Culture Parameters	Recommended Screening Levels[1]	Metals	Maximum Acceptable Levels(ug/l)
Alkalinity[2]	G 15 mg/l as $CaCO_3$	Aluminum (total)[12]	100
Ammonia (total)[3]	L 0.05 mg/l as N	Cadmium (dissolved)	0.3
Carbon Dioxide[4]	L 10 mg/l CO_2	Chromium (total)	40
Dissolved Oxygen[5]	G 11.2 mg/l O_2 and G 95% saturation	Copper (dissolved)	2
		Iron (total)[12]	300
Hardness[6]	G 20 mg/l as $CaCO_3$	Mercury (total)	0.2
Hydrogen Sulphide (total sulphide)[7]	L 0.002 mg/l as H_2S	Manganese (total)[12]	100
Nitrite[8]	L 0.015 mg/l as N	Nickel (total)	45
pH[9]	7.2 to 8.5	Lead (total)	4
Temperature[10]	5 to 10°C	Selenium (total)	50
Total Gas Pressure	L 103%	Silver (dissolved)	0.1
Suspended Solids[11]	L 3 mg/l	Zinc (dissolved)	15

NOTES TO ACCOMPANY TABLE 4

1 G = Greater than; L = Less than

2 This is a suggested minimum level of alkalinity to buffer pH changes in rearing ponds.

3 The total ammonia concentration of 0.05 mg/l as N, at pH 8.5 and T = 18°C, gives an unionized ammonia concentration of 5 ug/l NH_3-N. This value is 50% of the maximum recommended level and therefore allows for an ammonia increase within the hatchery.

4 The recommended screening level allows for an increase in carbon dioxide within the hatchery.

5 A screening level of 11.2 mg/l O_2 corresponds to the most stringent dissolved oxygen criteria for hatchery operation. This is the minimum acceptable concentration for incubation of eggs just prior to hatch at a temperature of 10°C. The dissolved oxygen levels in any water source should also be examined closely if saturation is depressed below 95%. The causes of the DO drop from equilibrium and the potential for further DO depression should be investigated.

6 This is a suggested minimum level of hardness to reduce risks of toxic effects of metals, low pH and poor fish health. Although insufficient data are available to establish specific criteria for hardness, the importance of hardness (the divalent metallic cations Ca^{2+}, Mg^{2+} and others) in reducing the toxic effects of metals, low pH, total gas pressure, and nitrite has been documented.

7 Hydrogen sulphide is detectable by sense of smell at much lower concentrations than the recommended level.

8 The recommended level assumes that the chloride concentration is very low, thereby maximizing the toxicity of nitrite.

9 A minimum inflow pH of 7.2 makes some allowance for the pH reduction due to CO_2 respiration in a rearing pond. Inflow pH criteria should be evaluated on a site-specific basis with consideration of alkalinity, free CO_2 and fish loading density.

10 This is the safe temperature range for incubation of sensitive species to both high and low temperatures.

11 The characteristics of the suspended solids should be carefully considered. For example, some materials (ie iron hydroxide precipitates) are toxic at lower concentrations than 3 mg/l.

12 Analyses for total aluminum, iron and manganese frequently result in high metal concentrations (exceeding the screening levels) if the water sample contains a significant quantity of suspended silt or clay. These mineral forms of the metal are essentially non-toxic. However, aluminum, iron and manganese precipitates are toxic. Their presence should be investigated if the total metal levels are high and the inert mineral fraction of the suspended solids appears to be relatively low.

- Marine physical factors (i.e., depth, wind and wave action, ice conditions, water currents as they relate to placement of structures, and bottom and shoreline physiography).

- Marine biological factors (i.e., temperature, dissolved oxygen, salinity, phytoplankton conditions, currents as they relate to oxygen supply and waste removal, predation and fouling).

- Freshwater quality and quantity.

- Waste heat potential.

- General accessibility (of sites or groups of sites).

- Infrastructure (i.e., general size and proximity of possible support communities).

- Potential for siting conflicts or water quality problems.

The siting factors identified within the marine physical category and the marine biological category are listed in their approximate order of priority.

In Volume II, geographical areas within the province are assessed using a subjective ranking of the level of suitability or potential in each category. Although all categories are clearly important, in general, the first three categories (physical, biological, waste heat potential) have greater importance for the regional assessment than the following three categories (potential siting conflicts or water quality problems, accessibility and infrastructure). A numerical weighting system was not developed because such a system would likely be misleading if applied uniformly to the broad geographical areas contained within the Aquaculture Development Zones.

2.1.2 Siting Considerations

Siting decisions for salmonids are strongly influenced by the production objectives, the choice of facility design concepts, and the assumptions concerning biological performance.

2.1.2.1 Production Objectives

The production objectives and culture methods for Atlantic salmon vary from commercial growout production (in netpens or in landbased tanks) to ocean ranching. Commercial growout production involves maintaining the fish in captivity until they reach harvestable size. In contrast, salmon ranching involves producing juveniles for release into freshwater or estuarine areas, from which they will eventually migrate to ocean feeding areas and will be harvested upon their return to the coastal area. The siting requirements can differ considerably depending on the type of production intended for culture facilities.

Commercial Growout to Market Size

Commercial salmon production can generally be divided into smolt production and adult growout components. The smolt production objectives are to:

- sell to other operators for on-growing;
- produce smolts for an integrated smolt/adult growout operation; or
- produce smolts to both sell to other operators and to use in an integrated operation.

The size and location of a smolt facility is influenced in part by proximity to the intended growout area and by the biophysical criteria outlined in Tables 2.3 and 2.4. Table 2.5 summarizes technologies that can be utilized for reducing certain site constraints at freshwater salmonid facilities. The requirements for a smolt facility contrast with siting requirements for a ranching facility (discussed below) because smolt production for commercial on-growing in netpens places low importance on siting near a large river or a site allowing capture of returning adults.

TABLE 2.5: SUMMARY OF TECHNOLOGIES THAT CAN BE USED TO REDUCE SITE CONSTRAINTS FOR SALMONID FACILITIES.
(Sources: Allen and Kinney 1981; Piper et al. 1982)

	SITE CONSTRAINT				
TECHNOLOGY	WATER VOLUME	TEMPERATURE	WATER QUALITY	LAND REQUIREMENTS	EFFLUENT DISCHARGE RESTRICTION
WATER REUSE	X	X			
REARING IN LAKE NETPENS	X	X		X	
WATER HEATING		X			
WATER TREATMENT (e.g., solids settling or filtration; use of oyster shells to increase alkalinity; sterilization; oxygenation)			X		X

Adult growout normally takes place in saltwater cage facilities but can also take place in saltwater landbased facilities or in freshwater. Marine siting requirements for netpens are indicated in Table 2.2. As outlined in Appendix A.1, landbased systems can eliminate concern over some siting factors, such as wave action, currents, predators and conflict with other marine activities, but capital costs are generally much higher and other siting factors, such as power supplies and logistics, can be more important.

Salmon Ranching

Salmon ranching can occur as either a public activity or a commercial activity. In both cases, the intention is to reduce high natural mortalities during the early life history stages (i.e., the egg to smolt stages). Once released, the cost of maintaining the fish is eliminated and the fish are subject to normal losses under natural conditions. In concept, public ranching activities can range between large-scale government funded and operated smolt production facilities to small-scale community operated streamside egg incubation units. After release, the fish are considered a public resource to be harvested by the locally prevalent fisheries (e.g., commercial, recreational). A primary siting criterion for a public hatchery, therefore, is how to best supply a target fishery. Larger facilities are usually strategically located to provide direct fish releases to a main waterbody, but also provide outplanting to other release sites. In some cases, juvenile fish might be held in coastal netpens for a short period prior to release.

In contrast to public ranching activities, commercial ranching operations usually require greater control over the rights to harvest returning fish and can be of two types:

- one type involves owners and operators who are the normal or traditional harvestors of the salmon resource in a given area; and
- the second type involves a corporate entity which is not the traditional resource harvestor.

In these situations, a critical factor is that the project investors require some form of exclusivity to the returning fish or must choose a location that avoids interception of the fish they have produced. Similarly, the biological objectives and strategies (e.g., size and timing of juvenile release and genetic selection programs) can vary between public and commercial ranching facilities. Also, commercial ranching operations usually attempt to select sites allowing easy capture and maintenance of fish in landbased facilities upon their return.

2.1.2.2 Facility Design Concepts That Can Affect Siting Decisions

Smolt Production Sites

As indicated in Table 2.3 important siting considerations include water supply volume, temperature and quality, topographic conditions and effluent discharge considerations. If these factors are limiting at particular sites, they can be resolved in some cases by applying special design features such as those summarized in Table 2.5. Consequently, criteria outlined in Table 2.3 must be interpreted in relation to the possible application of an appropriate technology to improve apparent marginal site conditions (such as water temperature or volume) if other site features (such as site accessibility and proximity to a market and logistic centre) are good.

Growout Sites

Facility design options for growout vary greatly, ranging from floating netpen structures suitable for relatively calm, nearshore waters to landbased growout tanks supplied by pumped seawater. Other options include offshore netpen designs, marine production scenarios involving a first stage growout in landbased tanks followed by growout in netpens during the final summer, or growout in freshwater.

The landbased tank growout facilities are similar in concept to the freshwater smolt production facilities. However, major differences are the much larger scale of the marine growout facility and requirement for pumped seawater. In general, the types of special design features that can be used to help resolve siting constraints at freshwater facilities (Table 2.5) can be used to resolve siting constraints at saltwater landbased facilities.

2.1.2.3 Assumptions Concerning Biological Performance

Biological considerations for choosing and developing a site are largely addressed by the biophysical criteria for site selection. However, the biological performance and viability of an operation can be greatly affected by the stocks chosen and types of biological manipulation used. These are outlined in Appendix A and are discussed further in relation to the technical viability of salmon culture in Newfoundland (Volume II).

Normally commercial aquaculture operations try to obtain the best stocks (e.g., in terms of growth and survival) for the conditions under which they will be grown. In Newfoundland, the available stocks in general have high proportions of early maturating fish (grilse) and would not be chosen as good culture stocks.

2.1.3 Rainbow Trout

The freshwater and marine siting requirements of rainbow trout are basically similar to those for Atlantic salmon, though some biophysical factors such as temperature vary. Table 2.6 summarizes the temperature requirements at different life history stages for Atlantic salmon, rainbow trout and Arctic char. A larger variety of production systems have been used for rainbow trout culture, compared to other salmonid species, and siting requirements can vary greatly amongst these systems. Rainbow trout production in Canada has been comprised of:

- small-scale "backyard" growout in ponds, mainly for household use and limited off-sales;
- large-scale growout to market size in freshwater facilities (that range from intensive operations utilizing concrete or fibreglass tanks, to operations using large natural ponds);

TABLE 2.6: SUMMARY OF OPTIMUM AND ACCEPTABLE EXTREME TEMPERATURES (°C) FOR ATLANTIC SALMON, ARCTIC CHAR AND RAINBOW TROUT CULTURE.
(Sources: Klontz *et al.* 1979, Saunders 1986; Piper *et al.* 1982; Reisnes and Wallace 1988; Scott and Crossman 1973; Baker 1981)

SPECIES	INCUBATION		FIRST FEEDING		FRESHWATER GROWOUT		SALTWATER GROWOUT		SPAWN	
	Optimum	Extreme	Optimum	Extreme	Optimum	Extreme	Optimum	Extreme	Optimum	Extreme
Atlantic Salmon	6-8	(2-10)	10-14	(8-18)	14-18	(2-20)	10-16	(2-20)	6-10	(2-12)
Rainbow Trout	10-12	(4-18)	12-15	(8-18)	15-16	(2-20)	15-16	(2-18)	10-13	(2-13)
Arctic Char	4-5	(0-8)	8-9	(3-10)	10-14	(2-18)	12	(2-16)	6-8	(2-10)

- juvenile production for lake or stream stocking;
- juvenile production for further growout in fee fishing ponds; and
- growout to market size in saltwater facilities.

Water quality conditions are important in all cases and are similar to those for Atlantic salmon as outlined in Table 2.4 (freshwater) and Table 2.2 (marine). However,. the relative importance of water quality and other siting considerations (e.g., site logistics) can vary amongst the different production systems. Small-scale "backyard" production has perhaps the least stringent requirements. The larger commercial freshwater production facilities and juvenile production facilities for stocking purposes or growout in fee fishing ponds have siting requirements similar to those for freshwater salmon facilities (Table 2.3). However, as discussed in Appendix A, some pond culture requirements (such as the acceptable nutrient and plant life levels) are different. Site selection for lake or stream stocking programs must consider proximity to the target waterbodies and fee fishing sites must consider the possible use of existing small ponds (on owned or leasable land) or the land area requirements to construct such ponds.

Marine siting requirements are to a large degree the same as for Atlantic salmon. Rainbow trout appear more tolerant of lower salinity conditions, but more susceptible to harmful phytoplankton problems, at least at high temperatures. Greater care must be taken in choosing growout sites that do not have blooms of harmful plankton.

2.1.4 Arctic Char

Compared to Atlantic salmon and rainbow trout, the culture experience with Arctic char is very limited particularly at commercial production levels. Culture to market size has been undertaken in freshwater and recent research indicates that production to market size will also be likely in saltwater. In general, the physical facility siting requirements for culture in freshwater are the same for Arctic char as for other species (i.e., Table 2.3). However, the temperature requirements for Arctic char differ (Table 2.6) and acceptable stocking densities (which can affect water volume and land area requirements) are substantially higher. Important differences amongst Arctic char strains are becoming evident in culture research in which strains are compared.

As with the other salmonid species, the production objectives might either be for commercial growout or for producing juveniles for stocking natural waterbodies.

2.2 SHELLFISH

The siting requirements for blue mussels and giant scallops are reviewed in Appendix B and summarized in Table 2.7.

2.2.1 Blue Mussels

Blue mussel culture has expanded rapidly in insular Newfoundland and now takes place at many locations concentrated mainly along the northeast coast.

Blue mussel culture, and mollusc culture generally, must consider:

- physical factors affecting equipment (e.g., ice movement, water depth, bottom type, exposure to wind and sea conditions and current strength);
- factors affecting biological performance (e.g., temperature, salinity, oxygen, food availability, including water exchange, and predation);
- the abundance of initial seed supply (spatfall);
- presence of pollutants (e.g., fecal coliforms) and harmful natural chemicals (e.g., PSP and Domoic acid) which might make the product unmarketable;
- site logistics, including site access, proximity to a labour and supply base, etc.; and
- conflicts with other resource users including marine traffic.

Operators often have little direct control over most factors. In some situations, the operator can modify equipment to adapt to the local physical conditions; for example:

TABLE 2.7: SITING REQUIREMENTS FOR MUSSELS AND SCALLOPS.
(Sources: Sutterlin *et al.* 1981; Somers 1988; Caine *et al.* 1987; Young-Lai and Aiken 1986)

	BLUE MUSSELS		SCALLOPS	
PARAMETER	OPTIMUM CONDITIONS	MINIMUM CONDITIONS	OPTIMUM CONDITIONS	MINIMUM CONDITIONS
WIND AND WAVES	- Sheltered site; wave height less than 0.6m	- Partially exposed; wave height less than 1.2m.	- As per blue mussels.	- As per blue mussels.
ICE CONDITIONS	- No drifting pack ice; no fast ice.	- No drifting pack ice; fast ice, not subject to excessive movement.	- As per blue mussels.	- As per blue mussels.
CURRENTS AND WATER EXCHANGE				
Slack Water	- 10-15 cm/s.	- Greater than 2 cm/s.	- As per blue mussels.	- As per blue mussels.
Peak Flows	- 10-50 cm/s.	- Less than 100 cm/s.	- As per blue mussels.	- As per blue mussels.
WATER DEPTH AND BOTTOM TYPE	- 10-20 m.	- Greater than 4 m; - Less than 40 m.	- 15-20 m (bottom culture). - 20-30 m (suspended culture).	- Greater than 10 m and less than 30 m (bottom culture); greater than 10 m and less than 40 m (suspended culture).
Summer	- 12-18°C.	- Less than 20°C.	- 10-15°C.	- Less than 20°C.
Winter	- Greater than 10°C.	- Greater than 0°C.	- Greater than 8°C.	- Greater than 0°C.
OXYGEN	- Well oxygenated at all times.	- Periodic reductions.	- As per blue mussels.	- As per blue mussels.
SALINITY; NEARBY HYDROLOGY	- 26 ppt., no freshwater minor fluctuations.	- Greater than 22 ppt.; periodic freshwater lens less than 1.0m; fluctuations less that 3-5 ppt.	- Greater than 30 ppt.; no freshwater lens; minor fluctuations.	- Greater than 25 ppt.; periodic freshwater lens (3-5m); minor fluctuations.
PLANKTON				
Beneficial	- 90 mg/L total particulate matter.	- Greater than 5 mg/L; less than 400 mg/L; Chor a greater than 2 ug/L.	- As per blue mussels.	- As per blue mussels.
Harmful	- No presence of PSP organisms.	- Presence of organisms; but bloom conditions not expected.	- As per blue mussels.	- As per blue mussels.
PREDATORS	- No known concentrations of predators.	- Minor occurrence of predators.	- As per blue mussels.	- As per blue mussels.
MARINE FOULING ORGANISMS	- Low levels of fouling organisms.	- Moderate levels of fouling organisms.	- As per blue mussels.	- As per blue mussels.
POLLUTION	- No sources nearby.	- Nearby low level sources.	- As per blue mussels.	- As per blue mussels.
SPATFALL	- Good natural spatfall source nearby.	- Good conditions for spatfall production from farm stock.	- As per blue mussels.	- As per blue mussels.

- sinking gear to avoid unfavourable ice conditions;
- using shore anchors to avoid bottom anchoring (and possibly depth and/or bottom-type problems);
- if drift ice is a problem but small in scale, placing ice-diverting booms; and
- using large or small float types to adapt to local ice conditions.

Site production methods for mussel culture within Newfoundland have been tested and modified to suit site constraints in the province, and these activities are continuing (outlined in Appendix B and discussed in Volume II).

As outlined above for Atlantic salmon, the siting requirements were grouped into categories for undertaking the regional assessments of development potential in Volume II:

- Marine physical factors (i.e., depth, wind and wave action, ice conditions, water currents as they relate to placement of structures, and bottom and shoreline physiography).

- Marine biological factors (i.e., temperature, dissolved oxygen, salinity, phytoplankton conditions, currents as they relate to oxygen supply and waste removal, predation and fouling).

- General accessibility (of sites or groups of sites).

- Infrastructure (i.e., general size and proximity of possible support communities).

- Potential for siting conflicts or water quality problems.

The siting factors identified within the marine physical category and the marine biological category are listed in their approximate order of priority. In Volume II, geographical areas within the province are assessed using a subjective ranking of the level of suitability or potential in each category.

Although all categories are clearly important, in general, the first two categories (physical and biological) have greater importance for the regional assessment than the following three categories (potential siting conflicts or water quality problems, accessibility and infrastructure). A numerical weighting system was not developed because such a system would likely be misleading if applied uniformly to the broad geographical areas contained within the Aquaculture Development Zones.

2.2.2 Giant Scallops

Giant scallop culture in Newfoundland has been investigated for close to two decades and commercial production is now taking place. As discussed in Appendix B, scallop production methods have been adapted from Japanese technology and are comprised of three production phases:

- an initial spat collection phase;
- an interim growout phase using small bags (blue bags, pearl bags); and
- a final growout phase using either bottom culture or suspended culture methods (e.g., ear-hanging or lantern nets).

The physical site requirements for suspended scallop culture are similar to those for mussel culture (Table 2.7). However, production methods differ and, for bottom culture, the siting requirements also differ. Some physical siting factors (winds and wave conditions, ice conditions and currents) do not apply to bottom culture because the preferred bottom culture depths are normally greater (approximately 20 to 30 m compared to 10 m).

2.3 AMERICAN EEL

Commercial eel culture is not currently being undertaken in Newfoundland (or elsewhere Canada) though the potential was briefly assessed at Bay D'Espoir. Commercial culture of the American eel has been attempted in the United States and New Brunswick and a small amount of research has been undertaken in Ontario. Other species of eel have been cultured in Europe and Japan for approximately 150 years. The expected siting requirements for American eel are reviewed in Appendix C.

Opportunities for culture in Newfoundland are severely constrained by high temperature requirements (20-30°C) for optimum growth. Also, eel appear to grow best in waters that are slightly alkaline or, as a minimum, of neutral pH. Under natural conditions, most growth occurs during periods of high temperature in the summer and ceases during the winter.

Culture production options in Newfoundland include:

- capture and initial growout of elvers prior to sale for culture elsewhere (Japan and Europe);
- growout to commercial size (100-300 gm) under intensive or extensive conditions, in water that warms to more than 20°C in summer; and
- growout to large commercial size in waters warmed to at least 15°C over winter.

A geothermal or industrial waste heat source would likely be required for growout to a commercial size.

2.4 MARINE FINFISH

Four species of marine finfish have been examined:

- Atlantic cod;
- Atlantic halibut;
- Lumpfish; and
- Wolffish.

The state of culture development, culture biology and siting requirements of each species are reviewed in Appendix D. The temperature and salinity requirements of each species are summarized in Table 2.8. Production options influencing siting requirements for each species are outlined in the following subsections.

TABLE 2.8: SUMMARY OF TEMPERATURE AND SALINITY REQUIREMENTS FOR MARINE FINFISH.

SPECIES	SPAWN TIMING	EGGS / LARVAE		GROWOUT		SOURCES
		Temp. (°C)	Sal. (ppt.)	Temp. (°C)	Sal. (ppt.)	
ATLANTIC COD	Late winter-spring	5-6 (-1.5 - 10)	32-35 G25	10-13 (-0.5 - 17)	32-35 G25	Scott and Scott 1988; Howell 1984; Bratten 1984.
ATLANTIC HALIBUT	Winter-Spring	3-4 (2 - 9)	37 G33	8-10 (3 - 12)	G30 G25	Lonning *et al.* 1982; Rabben and Huse 1986.
LUMPFISH	Spring-early	6-8 (4 - 5)	G30 G20	7-10 (-1 - 20)		Davenport 1985; Collins 1976.
WOLFFISH	Late summer	4-8 (0 - 9)	G25 G20	8-12 (0 - 14)	G25 G20	Gjosaetor and Moksness 1987; Pavlov and Navikov 1986.

G = greater than.

Note: Comparative studies at different temperatures and salinities appear to be lacking for most species, especially for wolffish and lumpfish and especially for salinity (for all species). The data in this table are best approximations based on the literature reviewed. Some studies were for fish stocks located elsewhere (Europe) and variability amongst stocks suggest temperature and salinity tolerances might differ.

2.4.1 Atlantic Cod

Hatchery production of cod began late in the last century in Europe and Newfoundland to produce fry for ranching. Recently, undersized cod from the commercial fishery have been raised successfully to harvest size in marine netpens in Newfoundland. Cod production activities have involved using fry from hatchery/larvae growout facilities and using juveniles caught in inshore trap fisheries. Therefore, production options include:

- hatchery production of fry for wild release (ranching);
- hatchery production of fry for placement in growout facilities; and
- capture of wild juveniles for placement in growout facilities.

The financial viability of cod culture has been questionable even for netpen culture given the generally low and uncertain market price. Consequently, landbased growout, though technically feasible, is highly unlikely (unless the cod are grown in a facility producing a different primary species). Use of netpens normally requires siting in areas of high salinity or, at least, areas having low fluctuations in salinity to reduce energy loss due to osmotic stress.

2.4.2 Atlantic Halibut

As indicated in Table 2.1, Atlantic halibut culture is still at the developmental stage in Canada. Advancement of Atlantic halibut culture will basically involve development of self-sustaining broodstock methods, hatchery production of fry and methods for growout to market size. Growout to market size does not appear possible in normal netpen units since halibut culture units require a solid, non-abrasive bottom. Apart from landbased rearing units, netpens with rigid bottoms or intertidal enclosures are possible. Use of intertidal enclosures are being investigated in New Brunswick and Nova Scotia.

2.4.3 Lumpfish

Lumpfish culture is being pioneered in Newfoundland and is essentially in the transition between research and pilot testing (Table 2.1). Production options at this stage include hatchery production of fry for growout and/or ranching. The potential for growout in netpens, landbased tanks and ranching is being investigated.

2.4.4 Wolffish

Wolffish appear to offer potential, but culture technology is largely at the research level (Table 2.1). Production options might include hatchery fry production for contained growout and/or ranching. However, early juvenile wolffish and larger, adult wolffish have been observed to display aggressive behaviour and their tolerance to high, commercially-viable densities must be assessed.

2.5 LITERATURE CITED IN SECTION 2.0

Allen, J.L. and E.C. Kinney. 1981.
Proceedings of the bio-engineering symposium for fish culture. Fish Culture Section of the American Fisheries Society and Northeast Society of Conservation Engineers. 307 pp.

Baker, R. 1981.
Survival and development of Arctic char eggs and fry at four different temperatures. From: Waste Heat Aquaculture Interim Report - 1981, prepared by M.H. Papst for Noval Technologies Ltd.

Beveridge, M.C. 1987.
Cage aquaculture. Fishing News Books Ltd. Surrey, England. 352 pp.

Braaten, B. 1984.
Growth of cod in relation to fish size and ration level. Flodevigen rapportser 1(1984):677-710 pp.

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

Collins, M.A. 1976.
The lumpfish (Cyclopterus lumpus L.) in Newfoundland waters. The Canadian Field - Naturalist (90):64-67 pp.

Davenport, J. 1985.
Synopsis of biological data on the lumpsucker Cyclopterus lumpus (Linnaeus, 1758). Food and Agriculture Organization of the United Nations, Rome. FAO Fisheries Synopsis No. 147. 31 pp.

Gjosaeter, J. and E. Moksness. 1987.
Some preliminary observations on catfish (Anarhichas lupus and A. minor Olafsen) in captivity. ICES. C.M. 1987/F-32. 12 pp.

Howell, B.R. 1984.
The intensive rearing of juvenile cod, Gadus morhua L. Flodevigen rapportser 1(1984):657-675 pp.

Klontz, G.W., P.C. Downey and R.L. Focht. 1979.
A manual for trout and salmon production. Prepared for Sterling H. Nelson & Sons Inc., Murray Elevators Division, Murray, Utah. 22 pp.

Lonning, S., E. Kjorsvik, T. Haug and B. Gulliksen., 1982.
The early development of the halibut Hippoglossus hippoglossus (L.), compared with other marine teteosts. Sarsia 67:85-91 pp.

Pavlov, D.A. and G.G. Novikiv. 1986.
On the development of biotechnology for rearing of White Sea wolffish, Anarhichas lupus marisalbi. I Experience on obtaining mature sex products, incubation of eggs and rearing of the young fish. J. Ichthyology. 26(4):95-106.

Piper, R.G., I.B. McElwain, L.E. Orme, J.P. McCraren, L.G. Fowler and J.R. Leonard. 1982.
Fish hatchery management. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 517 pp.

Rabben, H. and I. Huse. 1986.
Growth of juvenile halibut (Hippoglossus hippoglossus L.) in captivity. International Council for the Exploration of the Sea. C.M. 1986/F-20. 7p plus figures.

Reisnes, T.G. and J.C. Wallace. 1988.
The Arctic char as a farmed fish. Feskeriteknologisk Forskningsinstitutt Rapport U.41. 34 pp. (Can. Transl. Fish. Aquat. Sci. No. 5404).

Saunders, R.L. 1986.
The thermal biology of Atlantic salmon: influence of temperature on salmon culture with particular reference to constraints imposed by low temperature. [IN]: L. Nyman and B. Ericsson. Aquaculture in subarctic areas. Institute of Freshwater Research, Drottringholm, Sweden. Report No. 63.

Scott, W.B. and E.J. Crossman. 1973.
Freshwater fishes of Canada. Canada Department of the Environment. Fisheries Research Board. Bulletin 184, 966p.

Scott, W.B. and M.G. Scott. 1988.
Atlantic fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219. 731p.

Sedgewick, S.D. 1988.
Salmon farming handbook. Fishing News Books Ltd. Surrey, England. 207p.

Shepherd, B.G. 1984.
The biological design process used in the development of federal government facilities during Phase I of the Salmonid Enhancement Program. Canada Department of Fisheries and Oceans. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1275. 188p.

Somers, W. 1988.
Technical details on culture methods in P.E.I. [IN]: Emmett, B. (ed). B.C. mussel culture workshop. Prov. B.C. Min. Agr. Fish. 63-72p.

Sutterlin, A., D. Aggett, C. Couturier, R. Scalpen, and D. Idler. 1981.
Mussel culture in Newfoundland waters. Mar. Sci. Res. Lab. Tech. Rep. Technical Report Number 23. Memorial University of Newfoundland. St. John's, Newfoundland. 82p.

Young-Lai, W.W., and D.E. Aiken. 1986.
Biology and culture of the giant scallop, Placopecten magellanicus: A review. Can. Tech. Rep. Fish Aqua. Sci. 1478:21p.

3.0 COMPILATION OF LOGISTICAL AND BIOPHYSICAL INFORMATION

This section presents a summary of logistical and biophysical information that was reviewed to assess the regional development potential for individual species in Volume II.

Information in this section is presented under the following general headings:

- Regional Infrastructure (Section 3.1);
- Marine Biophysical Conditions (Section 3.2); and
- Freshwater Biophysical Conditions (Section 3.3).

The review of regional infrastructure includes the locations of logistic centres, industrial activity, fish processing plants and possible waste heat sources. The review of marine biophysical conditions includes: weather, sea and ice conditions, sheltered areas, currents and water exchange, temperatures and salinities, phytoplankton conditions, potential predators, possible water quality and pollution problems, and potential siting conflicts. The review of freshwater biophysical conditions includes the quantity and quality of surface water and groundwater.

As described in the Introduction (Section 1.0), the 14 Fisheries Management Zones used by the Newfoundland Department of Fisheries have been used to undertake the regional assessments of aquaculture potential described in Volume II. Some information presented in this section is summarized for each of these zones (the zones shown in Figure 1.1 are repeated in Figure 3.1).

3.1 REGIONAL INFRASTRUCTURE

3.1.1 Labrador

Except for relatively large settlements within the interior of Labrador (Happy Valley/Goose Bay, Labrador City and Wabush), the communities are small (less than 1,500 people) and distributed along the coast. Figure 3.2 indicates the locations and relative sizes of these communities as of 1981. The coast north of Hamilton Inlet is very sparsely

FIGURE 3.1: Aquaculture Development Zones

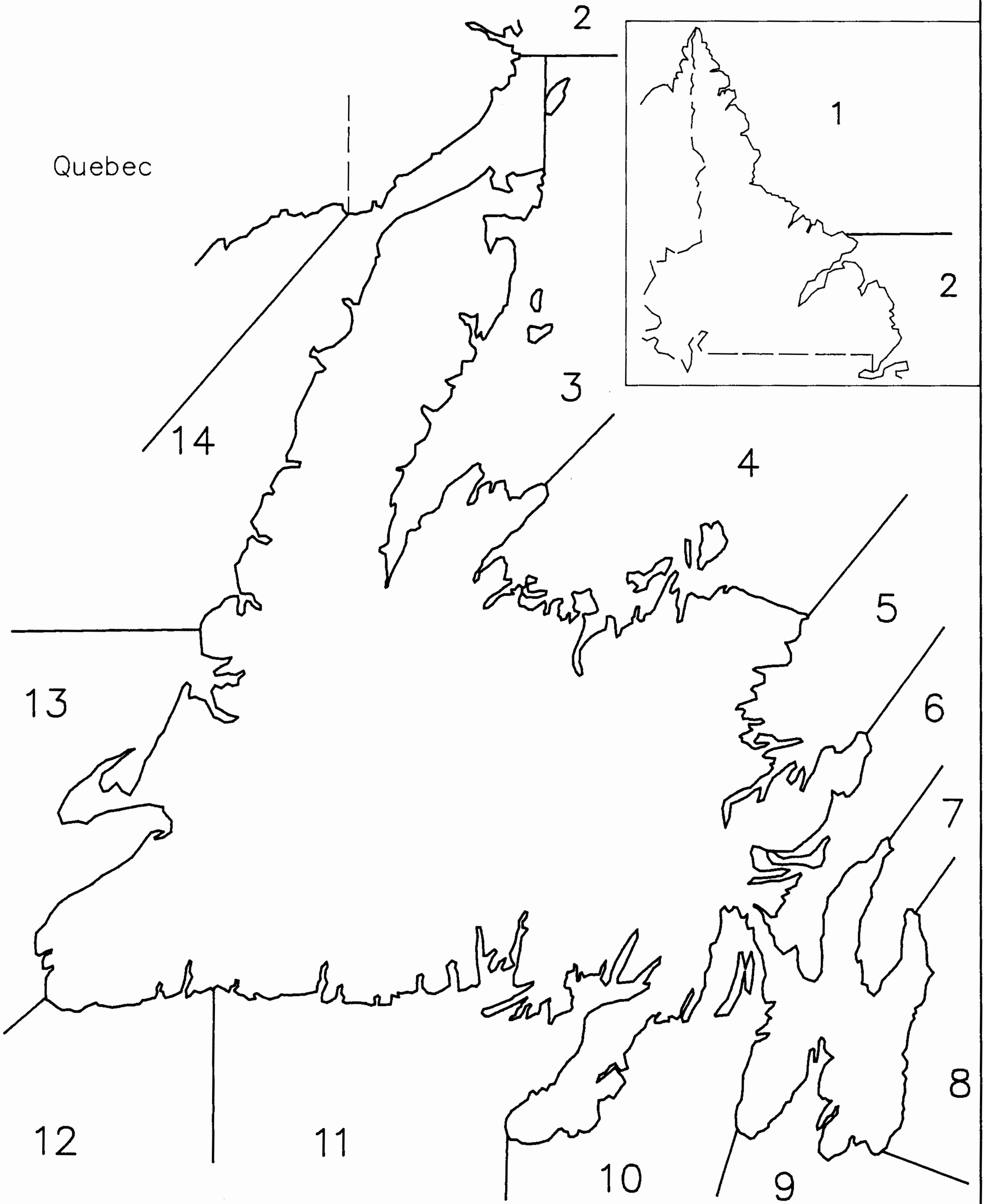
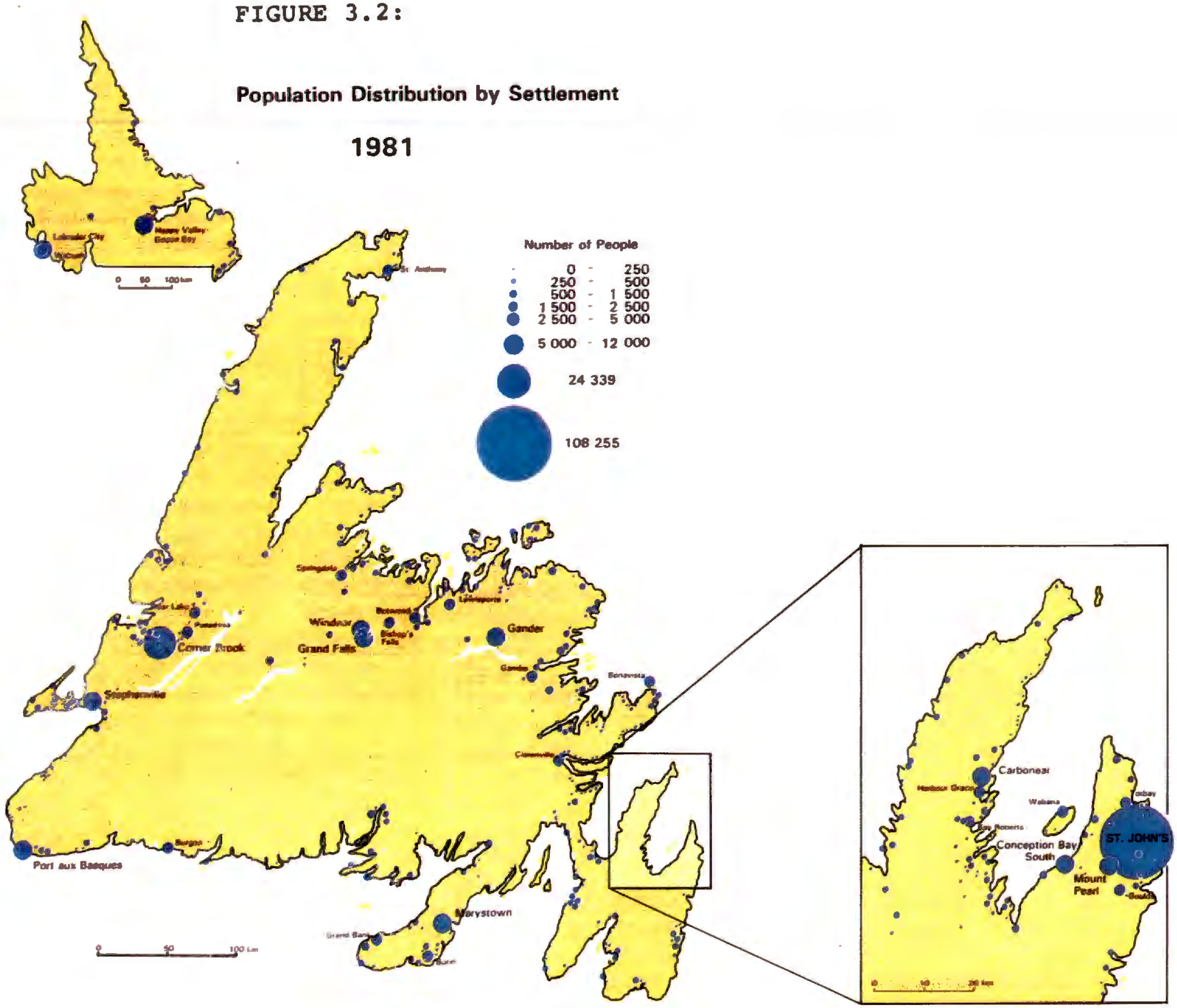


FIGURE 3.2:

Population Distribution by Settlement

1981



David J. Mercer, 1985.
Department of Geography, Memorial University of Newfoundland,
St. John's, Newfoundland, Canada. A1B 3X9

settled. Industrial activity, fish processing facilities, transportation systems, and potential waste heat sources in Labrador are briefly described below.

3.1.1.1 Industrial Activity and Fish Processing Facilities

As in the past, the fishing industry is the main source of income for people living in the coastal areas. In 1988, there were 2,000 registered fishermen in Labrador (Economic Research and Analysis Division of the Executive Council 1988). However, as indicated by Figure 3.3, fish processing plants are concentrated in the area south of Indian Harbour.

Since the 1970's, industrial development has taken place largely in the central and western part of Labrador (Figure 3.4). The hydro development in Churchill Falls, the iron ore mines in Labrador City and Wabush, and the Canadian Armed Forces Base in Happy Valley-Goose Bay, have become major sources of revenue for this part of the province.

The number, location and operating season of fish plants in Labrador are summarized in Table 3.1 (Zones 1 and 2). These plants are described in Appendix E. As outlined in the Appendix, all three plants in Zone 1 (Cape Charles to Nain) are provincially owned facilities operated by the Torngat Fish Producers Co-op Society, based in Happy Valley, and are seasonal, operating mainly from June/July to September. One plant operates until November. Fourteen fish plants are located in Zone 2, also operating on a seasonal basis from late May or June to October/November. Salmon, char, cod and turbot are important species processed in the plants in Zone 1 and cod, salmon, trout, crab, lumpfish roe, mussels, scallops and whelks are processed at plants in Zone 2.

3.1.1.2 Transportation Systems

Due to the sparse nature and relatively small sizes of the coastal communities, those that are north of Red Bay are not connected by roads. However, roads extend inland from Happy Valley-Goose Bay to Churchill Falls, Labrador City and Wabush (Figure 3.5).

FIGURE 3.3:

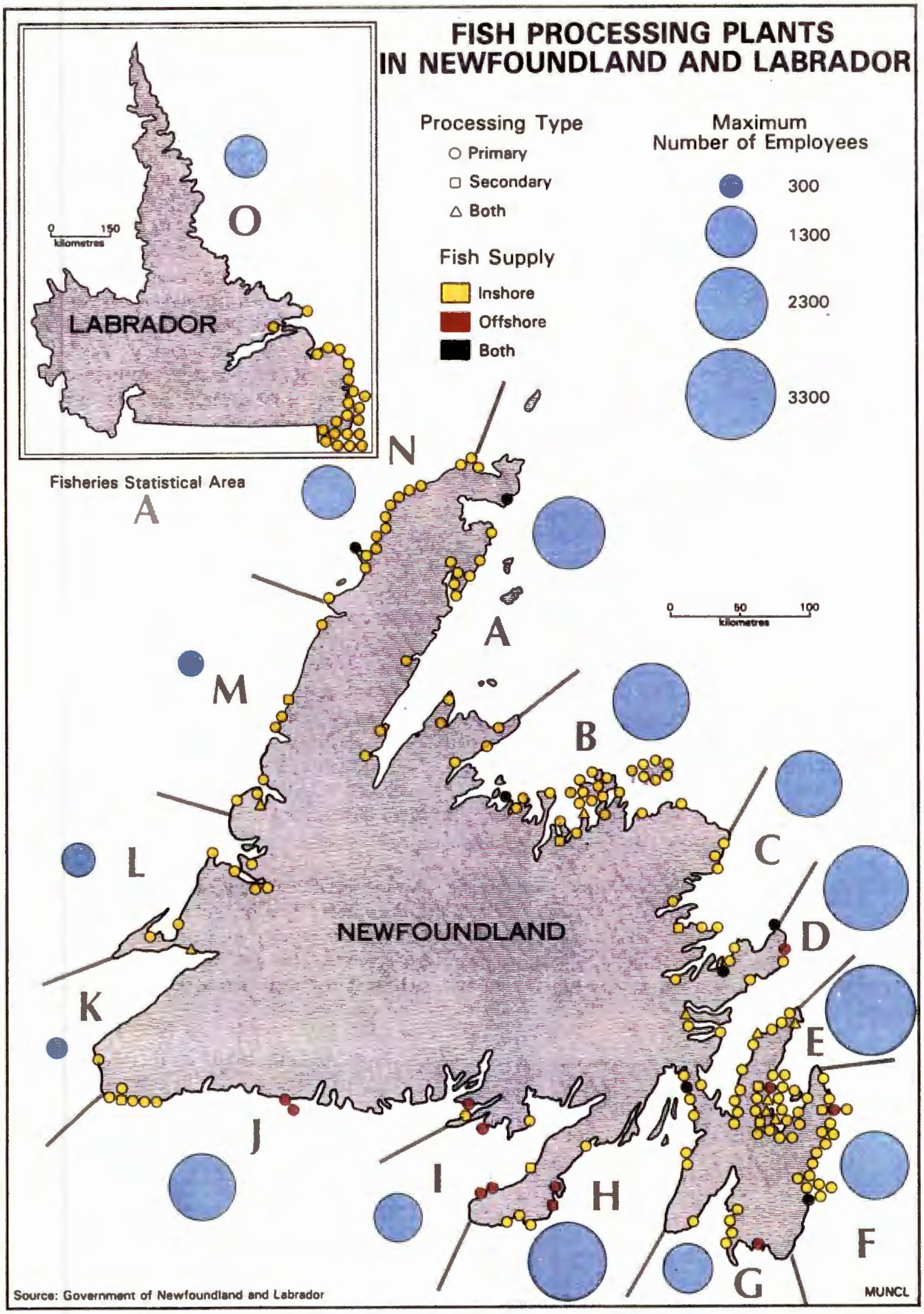
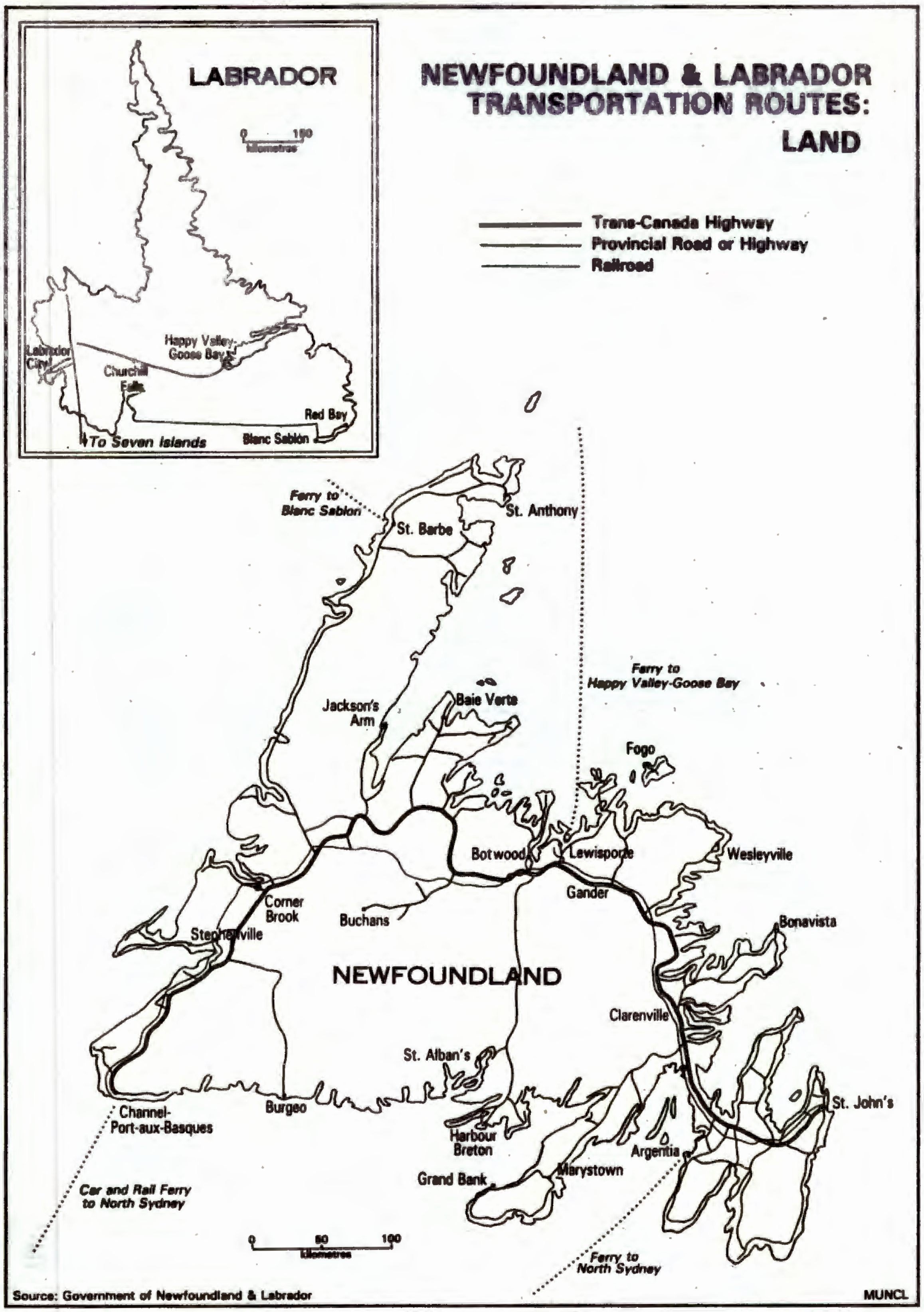

FISH PROCESSING PLANTS
IN NEWFOUNDLAND AND LABRADOR
Processing Type
Primary
Secondary
Both
Fish Supply
Inshore
Offshore
Both
Maximum
Number of Employees
300
1300
2300
3300
LABRADOR
0 150
kilometres
O
Fisheries Statistical Area
A
N
M
L
K
J
I
H
G
F
E
D
C
B
NEWFOUNDLAND
0 50 100
kilometres
Source: Government of Newfoundland and Labrador
MUNCL

FIGURE 3.4:


SELECTED MANUFACTURING LOCATIONS IN NEWFOUNDLAND AND LABRADOR
LABRADOR
kilometres
Labrador City
Happy Valley-Goose Bay
Wabush
Pinware
Food Industry
Beverage Industries
Plastic Products Industry
Leather and Allied Products Industries
Textile Products Industries
Clothing Industries
Wood Industries
Furniture and Fixture Industries
Paper and Allied Products Industries
Printing, Publishing and Allied Industries
Fabricated Metal Products Industries
Transportation Equipment Industries
Electrical and Electronic Products Industries
Non-Metallic Mineral Products
Refined Petroleum Products
Chemical and Chemical Products Industries
Other Manufacturing Industries
NEWFOUNDLAND
Nipper's Harbour
Springdale
Pasadena
Corner Brook
Grand Falls
Glenwood
Eastport
Glovertown
Trinity
Stephenville
English Harbour
Port Blandford
Nut Cove
Milton
Harbour Grace
Clarenville
Carbonear
Conne River
Come-by-Chance
Bay Roberts
Coley's Point
St. John's
Long Harbour
Brigus
Marystown
Burin
Paradise
Mount Pearl
0 50 100
kilometres
Source: Government of Newfoundland and Labrador
MUNCL

FIGURE 3.5:



LABRADOR
0 150
Kilometres
Happy Valley-Goose Bay
Labrador City
Churchill Falls
Red Bay
Blanc Sablón
To Seven Islands
NEWFOUNDLAND & LABRADOR
TRANSPORTATION ROUTES:
LAND
Trans-Canada Highway
Provincial Road or Highway
Railroad
Ferry to Blanc Sablon
St. Barbe
St. Anthony
Ferry to Happy Valley-Goose Bay
Jackson's Arm
Baie Verte
Fogo
Botwood
Lewisporte
Wesleyville
Gander
Corner Brook
Buchans
Stephenville
Bonavista
NEWFOUNDLAND
Clarenville
St. Alban's
Channel-Port-aux-Basques
Burgeo
St. John's
Harbour Breton
Argentia
Marystown
Grand Bank
Car and Rail Ferry to North Sydney
0 50 100
Kilometres
Ferry to North Sydney
Source: Government of Newfoundland & Labrador
MUNCL

TABLE 3.1: NUMBERS AND OPERATING SEASONS OF FISH PROCESSING PLANTS IN EACH AQUACULTURE ZONE.

Zone	Plant Location	Plant Code	Operating Season
Zone 1 (3 plants)			
	Makkovik	88007	June - November
	Postville	88009	July - September
	Hopedale	88008	July - September
Zone 2 (14 plants)			
	Battle Harbour	82014	June - October
	Black Tickle (p)	78022	June - October
	Cartwright (p)	80008	June - October
	Domino	81004	June - October
	Frenchman's Island	82013	June - October
	Georges Cove	87004	June - October
	Mary's Harbour (p)	81008	June - November
	Pinsent's Arm (p)	86008	May - October
	Punch Bowl	87008	June - November
	Rigolet (p)	82018	June - October
	Smokey	76019	June - October
	St. Lewis (p)	80010	June - October
	Triangle	86003	June - October
	Williams Harbour (p)	80019	June - October
	(P = Permanent communities)		
Zone 3 (17 plants)			
	Bide Arm	79004	January - March/ May - October
	Conche	84002	May - October
	Croque	76021	May - October
	Englee	74007	January - March/ May - November
	Englee	74021	May - December
	Fleur de Lys	78015	June - November
	Fleur de Lys	86014	April - June
	Great Harbour Deep	78014	May - October
	Jackson's Arm	77013	April - December
	La Scie	76013	June - October
	Pacquet	84005	June - September
	Roddickton	83002	May - November
	Sop's Arm	76026	May - October
	St. Anthony	75009	January - February/ April - November
	St. Juliens	81010	May - October
	Wild Cove	79012	June - September
	Baie Verte	85001	April - September
Zone 4 (34 plants)			
	Botwood	88005	Year-round
	Boyd's Cove	76023	June - November
	Bridgeport	81002	June - August (est.)
	Campbellton	80001	Year-round
	Carmanville	82012	August - December
	Carter's Cove	79018	N/A
	Change Islands	79009	June - October
	Comfort Cove	75018	Year-round
	Cottlesville	78013	March - December
	Deep Bay	82010	May - October
	Durrells	81016	N/A
	Fogo	75013	May - December
	Fortune Harbour	81001	Year-round
	Herring Neck	80006	May - November
	Hillgrade	81012	N/A
	Hillgrade	80012	N/A
	Joe Batts Arm	77010	May - December
	Leading Tickles	78005	April - November
	Lewisporte	83004	Year-round
	Middle Arm	80007	January-November 15
	Moreton's Harbour	86002	N/A
	Musgrave Harbour	76002	May - August
	Nippers Harbour	77016	N/A
	Port Albert	86009	May - December
	Seldom	74013	May - December
	Summerford	80004	N/A
	Summerford	87006	N/A
	Triton	81006	January - October
	Triton	76022	April - July
	Twillingate	86001	May - October

TABLE 3.1 (CONT'D.)

Zone	Plant Location	Plant Code	Operating Season
	Virgin Arm	82008	N/A
	Whales Gulch	82009	June - September
	Little Bay Island	74016	May - November
	Tilting	79010	May - November
Zone 5 (15 plants)			
	Bonavista	74010	May - October
	Bonavista	88004	May - November
	Charleston	76009	May - October
	Dover	86013	April - December
	Glovertown	82003	Year-round
	Glovertown	88014	April - November
	Greenspond	77002	June - August
	Happy Adventure	81011	May - November
	Newtown	78001	June - August
	Newtown	86010	April - November
	Plate Cove	81015	N/A
	Plate Cove	79011	May - October
	Salvage	78012	April - December
	Summerville	76025	April - December
	Valleyfield	74005	April - November
Zone 6 (21 plants)			
	Bunyan's Cove	79019	N/A
	Catalina	75010	January - July
	Catalina	76014	January - February/ August - December
	Chance Cove	79020	April - November
	Clarenville	78004	Year-round
	Clarenville	82019	Year-round
	Hants Harbour	74015	February - December
	Hearts Desire	74023	May - July
	Hickman's Harbour	88001	Year-round
	Long Cove	86003	April - November
	New Harbour	75016	Year-round
	New Harbour	74025	Year-round
	Old Perlican	80015	June - November
	Old Perlican	78016	Year-round
	Sibley's Cove	77015	June - September
	South Dildo	78002	April - August
	South Dildo	79008	January - November
	South Dildo	75021	January - February/ June - December
	Southport	75004	May - September
	Trouty	81014	May - November
	Winterton	74020	Year-round
Zone 7 (25 plants)			
	Bay de Verde	75017	January - November
	Bay Roberts	80017	Year-round
	Bell Island	83001	May - October
	Brigus	76016	Year-round
	Brigus	79015	May - September
	Carbonear	76018	Year-round
	Carbonear	77014	Year-round
	Coley's Point	77006	Year-round
	Coley's Point	78017	June only
	Colliers	81013	May - December
	Cupids	75007	Year-round
	Foxtrap	76012	May - October
	Foxtrap	83005	June - October
	Harbour Grace	86006	January - July/ October - December
	Harbour Grace	86007	April - August
	Harbour Main	81009	May - December
	Holyrood	75001	April - November
	Holyrood	79016	June and September
	Marysvale	86005	May - November
	Port de Grave	74009	June - October
	Port de Grave	86004	April - October
	Port de Grave	88015	Year-round
	Portugal Cove	78018	May - December
	Spaniards Bay	88002	N/A
	Bareneed	74002	April - December

TABLE 3.1 (CONT'D.)

Zone	Plant Location	Plant Code	Operating Season
Zone 8 (19 plants)			
	Aquaforte	74003	January - February/ April - November
	Bay Bulls	82001	June - October
	Calvert	75005	March - December
	Calvert	87001	N/A
	Cape Broyle	79002	May - November
	Fermeuse	76024	January - April/ June - December
	Ferryland	80005	June - October
	Ferryland	75015	May - December
	Petty Harbour	74004	June - November
	Petty Harbour	78003	May - September
	Petty Harbour	84003	June - November
	Pouch Cove	80014	May - July/ September-November
	Red Cliffe	78008	June - August
	St. John's	82004	Year-round
	St. John's	77003	January and April - December
	St. John's	74018	Year-round
	Tors Cove	74024	January - May/ June - October
	Witless Bay	74006	Year-round
	Quidi Vidi	75020	N/A
Zone 9 (7 plants)			
	Admirals Beach	79001	April - December
	Branch	78006	May - December
	O'Donnels	87005	Year-round
	Riverhead	74022	May - August
	St. Joseph's	79006	Year-round
	St. Mary's	80011	January - October
	Trepassey	74011	Year-round ex. Ma.

Zone	Plant Location	Plant Code	Operating Season
Zone 10 (13 plants)			
	Argentia	80002	Year-round
	Arnold's Cove	74014	Year-round
	Baine Harbour	79007	June - October
	Burin	77008	June - December
	Fairhaven	80013	May - August/ October - December
	Jerseyside	76005	April - December
	Lawn	82016	June - Setember
	Lord's Cove	81005	April - October
	Mooring Cove	76007	Year-round ex. July
	Southern Harbour	78021	Year-round
	St. Brides	75003	N/A
	St. Brides	88010	June - September
	St. Lawrence	80016	April - October
Zone 11 (10 plants)			
	Belleoram	77001	Year-round
	Burgeo	74017	Year-round
	Fortune	76010	January - July/ October - December
	Frenchman's Cove	84001	Year-round (?)
	Gaultois	77009	April - September
	Grand Bank	75011	Year-round ex. June
	Harbour Breton	75012	January - October
	Hermitage	76004	Year-round
	Ramea	75008	January - September
	St. Alban's	88013	N/A
Zone 12 (6 plants)			
	Margaree	75002	Year-round
	Margaree	80009	Year-round
	Port aux Basques	75006	January - October
	Rose Blanche	74012	January - July
	Isle aux Morts	74008	Year-round
	Burnt Islands	76017	Year-round ex. August

TABLE 3.1 (CONT'D.)

Zone	Plant Location	Plant Code	Operating Season
Zone 13 (12 plants)			
	Benoits Cove	76001	April - December
	Codroy	80018	January - June
	Corner Brook	74001	February - July/ September-December
	Corner Brook	74019	April - July/ September-December
	Corner Brook	75022	May - December
	Cox's Cove	78019	Year-round ex. March
	Fox Island River	82007	April - November
	Lark Harbour	75014	January - June/ October - December
	Pasadena	88016	Year-round
	Piccadily	85002	January - November
	Stephenville	86011	June - September/ February - August
	Stephenville	77017	Year-round
Zone 14 (39 plants)			
	Sandy Cove	75019	January - March/ May - October
	Anchor Point	79003	January - March/ May - September
	Bartletts Harbour	81007	May - October
	Bear Cove	83003	May - September
	Black Duck Cove	79005	May - September
	Blue Cove	77005	May - October
	Brig Bay	77004	January - March/ May - November
	Cook's Harbour	87002	May - November
	Cook's Harbour	76011	May - July
	Cook's Harbour	78007	June - October
	Cow Head	76006	January - March/ May - November
	Cow Head	78009	April - October
	Flowers Cove	80003	January - February/ May - September
	Green Island Brook	82002	June - October
	Green Island Cove	86012	May - November
	Hawkes Bay	84004	April - December
Zone 14	Main Brook	81003	June - October
	New Ferrole	79013	January - March/ May - December
	North Boat Harbour	78020	May - September
	Parsons Pond	82017	January - March
	Plum Point	87003	N/A
	Port aux Choix	76008	Year-round ex. March
	River of Ponds	79014	May - December
	Rocky Harbour	79017	Year-round
	Savage Cove	76003	February - May/ June - September
	Trout River	76020	April - November
	Winterhouse Brook	88006	April/May - December
	Woody Point	88011	April - October
	Cape Charles	82006	June - October
	Cape Charles	88012	June - October
	English Point	82015	June - October
	Forteau	82011	June - August
	Forteau	77012	June - September
	Lanse au Clair	76015	June - September
	Lanse au Loup	78011	June - October
	Lanse au Loup	77011	July only
	Pinware	87007	June - October
	Red Bay	77007	June - October
	West St. Modeste	82005	June - October

The following communities have provincial airstrips: Nain, Hopedale, Davis Inlet, Postville, Makkovik, Rigolet, Cartwright, Port Hope Simpson, Paradise River, Charlottetown, St. Lewis, Mary's Harbour, Black Tickle, Red Bay and English Point (A. Arklie, personal communication). Federal airports are at Saglek, Happy Valley-Goose Bay, Churchill Falls and Wabush. Figure 3.6 indicates the scheduled air services to Labrador, the major airports, airport/airstrips, and water aerodromes.

Several coastal communities are ports of call for the coastal passenger/freight service as indicated by Figure 3.7. The ferries that make this trip are not designed to carry vehicles. The only ferries that are equipped for vehicular traffic make scheduled stops in Happy Valley-Goose Bay and Cartwright. Cargo service is offered to only Nain, Happy Valley-Goose Bay, Cartwright and Black Tickle.

3.1.1.3 Potential Waste Heat Sources

Electrical power is supplied to many of the communities within Labrador by diesel generating stations that are owned by Newfoundland and Labrador Hydro Limited. The locations, numbers of plants and the individual sizes are indicated in Table 3.2. A diesel plant is also located in Happy Valley-Goose Bay; however, this plant is connected to the main electrical grid from Churchill Falls and is used for back-up. As potential sources of waste heat, most generating units are small; the L'Anse au Loup and, possibly, Nain generating units, however, are relatively large.

3.1.2 Island of Newfoundland

The size and distribution of communities on the Island of Newfoundland are shown in Figure 3.2. The main logistic center is the capital, St. John's, and a large proportion of the population is concentrated there and elsewhere on the Avalon Peninsula. Small communities are distributed throughout most coastal areas, but few are located in the central portion of the south coast or along the eastern side of the northern peninsula. The major community on the northern peninsula (St. Anthony) is relatively

FIGURE 3.6:

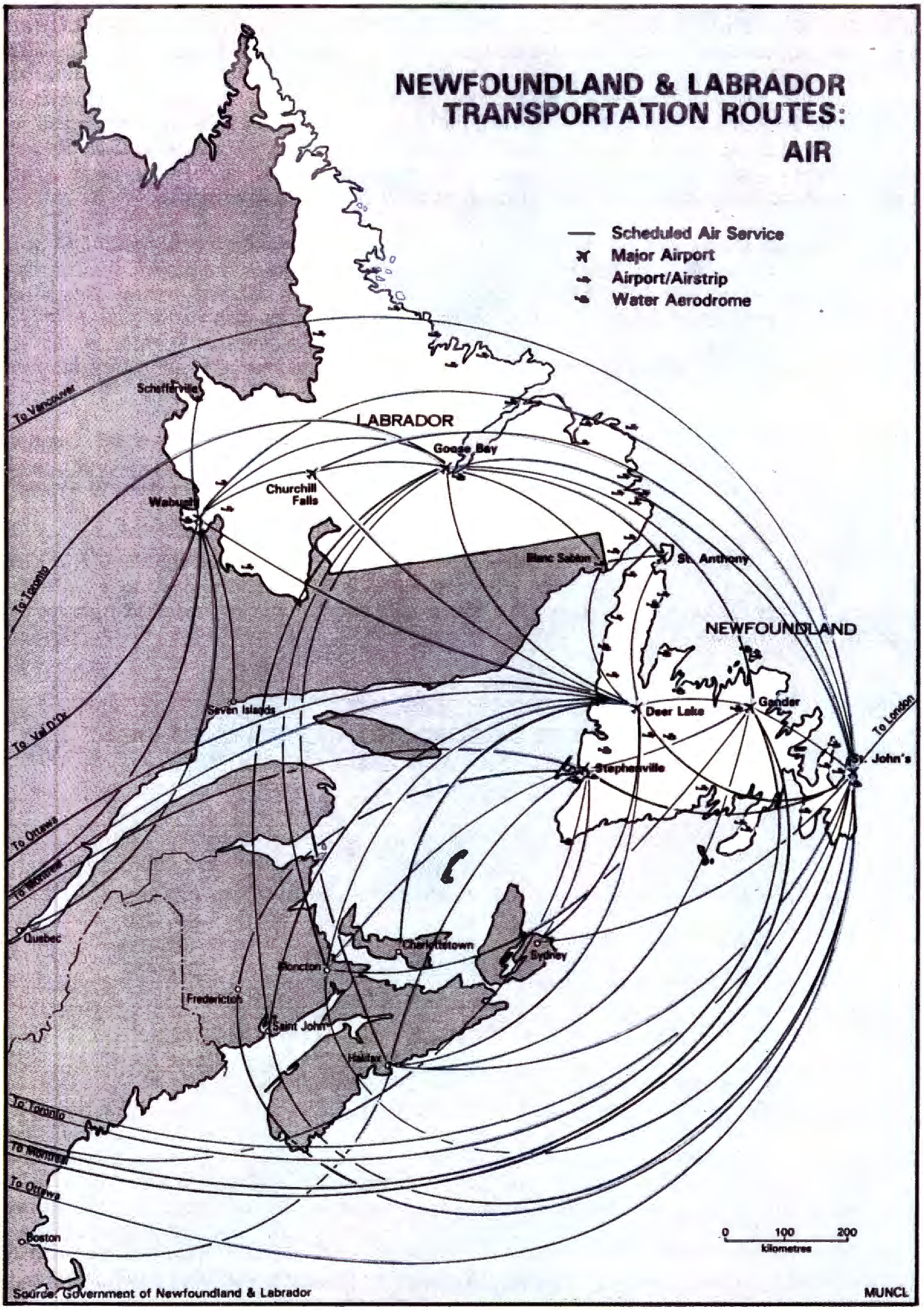

NEWFOUNDLAND & LABRADOR
TRANSPORTATION ROUTES:
AIR
Scheduled Air Service
Major Airport
Airport/Airstrip
Water Aerodrome
LABRADOR
NEWFOUNDLAND
Schefferville
Goose Bay
Churchill Falls
Wabush
Blanc Sablon
St. Anthony
Seven Islands
Deer Lake
Gander
St. John's
Stephenville
Charlottetown
Sydney
Moncton
Fredericton
Saint John
Halifax
Quebec
Boston
To Vancouver
To Toronto
To Val D'Or
To Ottawa
To Montreal
To London
0 100 200
kilometres
Source: Government of Newfoundland & Labrador
MUNCL

TABLE 3.2: POWER GENERATING PLANTS IN NEWFOUNDLAND

A. DIESEL GENERATING PLANTS - NEWFOUNDLAND AND LABRADOR HYDRO LIMITED.

Plant Location	Installed Capacity (kw)
Central Newfoundland:	
1. Burgeo	4,770
2. Change Islands	700
3. Fogo	3,320
4. Francois	475
5. Grand Bruit	140
6. Grey River	332
7. La Poile	200
8. Little Bay Island	800
9. McCallum	332
10. Monkstown	160
11. Petit Forte	256
12. Petites	260
13. Ramea	3,036
14. Rencontre East	332
15. St. Brendan's	600
16. S. East Bight	180
17. Westport	810
Sub-total	16,703
Northern Newfoundland:	
1. Croque	160
2. Grandois	140
3. Harbour Deep	658
4. Main Brook	772
5. Roddickton Syst.	3,860
6. St. Anthony	8,000
Sub-total	13,590
Labrador:	
1. Charlottetown	332
2. Lanse au Loup	3,100
3. Mary's Harbour	800
4. Port Hope Simpson	636
5. St. Lewis	567
6. Williams Harbour	160
7. Black Tickle	850
8. Cartwright	850
9. Davis Inlet	347
10. Hopedale	518
11. Makkovik	950
12. Nain	1,350
13. Paradise River	140
14. Postville	275
15. Rigolet	694
16. Mud Lake	160
Sub-total	11,729

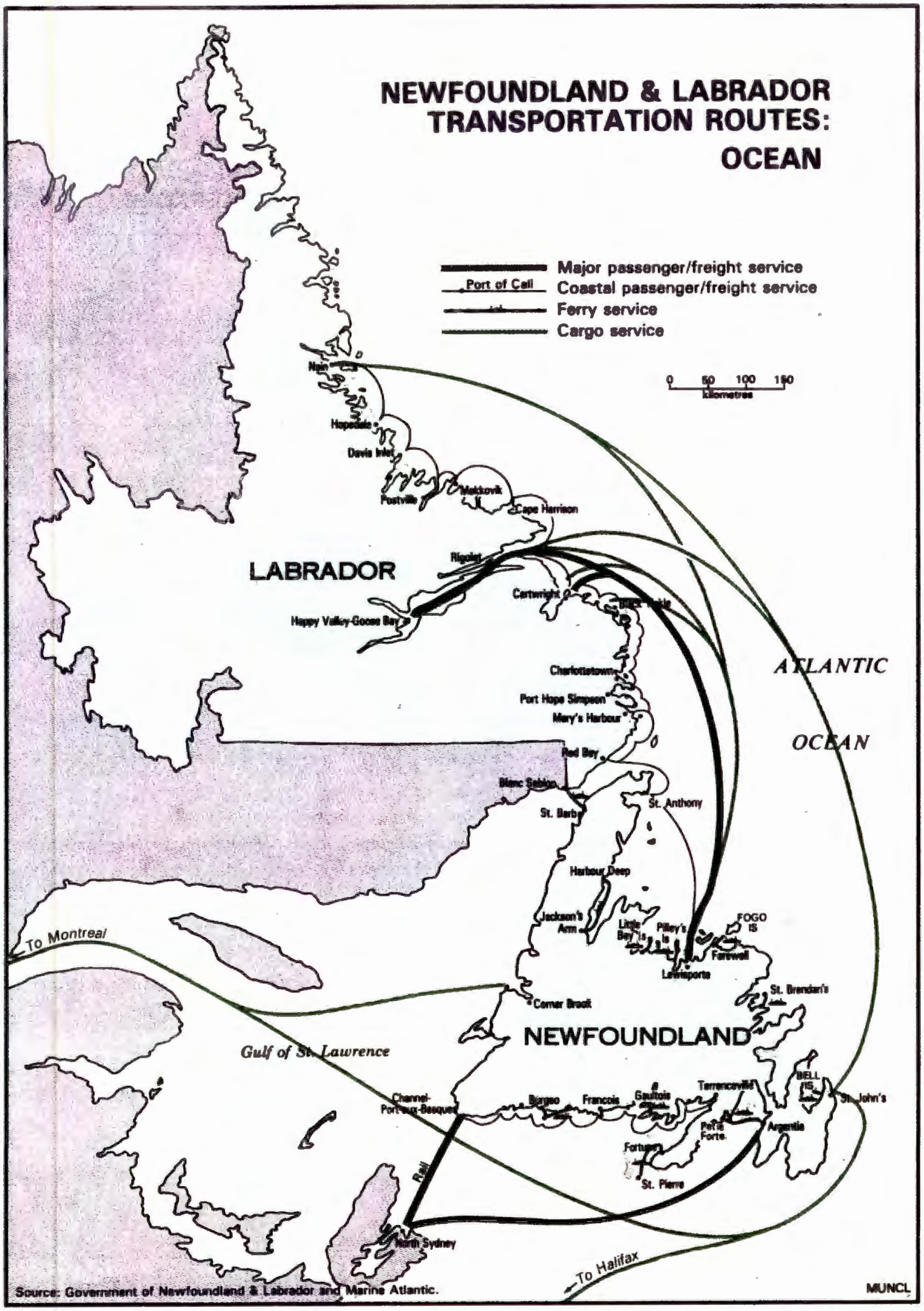
B. DIESEL OR GAS TURBINE GENERATING PLANTS - NEWFOUNDLAND LIGHT AND POWER.

Location	Installed Capacity in KW
St. John's	2,500
Gander	3,000
Port Union	590
Greenspond	250
Salt Pond	1,500
Aguathuna	1,200
Port-Aux-Basques	4,159
Mobile Unit 1	700
Mobile Unit I1	670
Total	14,569

C. HYDROELECTRIC GENERATING PLANTS - NEWFOUNDLAND LIGHT AND POWER CO. LTD.

Hydro Plants	Capacity in KW	Approx. Discharge in f^3/sec
Lookout Brook	5550	94
Rattling Brook	11000	534
Sandy Brook	5550	757
Lockston	3000	90
Port Union	630	118
Heart's Content	2650	230
Victoria	450	30
New Chelsea	3725	197
Pitman's Pond	610	177
Seal Cove	3180	260
Topsail	2250	110
Petty Harbour	4750	429
Pierres Brook	3850	184
Tors Cove	6700	574
Rocky Pond	3100	422
Mobile	9900	360
Morris	1150	150
Horse Chops	7600	354
Cape Broyle	6400	417
Lawn	660	145
Fall Pond	350	121
West Brook	500	70

FIGURE 3.7:


NEWFOUNDLAND & LABRADOR
TRANSPORTATION ROUTES:
OCEAN
Major passenger/freight service
Port of Call
Coastal passenger/freight service
Ferry service
Cargo service
0 50 100 150
kilometres
Nain
Hopedale
Davis Inlet
Postville
Makkovik
Cape Harrison
Rigolet
LABRADOR
Happy Valley-Goose Bay
Cartwright
Charlottetown
Port Hope Simpson
Mary's Harbour
Red Bay
Blanc Sablon
St. Anthony
Harbour Deep
Jackson's Arm
Little Bay Is
Pilley's Is
FOGO IS
Farewell
Lewisporte
St. Brendan's
Corner Brook
NEWFOUNDLAND
ATLANTIC
OCEAN
To Montreal
Gulf of St. Lawrence
Channel-Port-aux-Basques
Burgeo
Francois
Gaultois
Terrenceville
BELL IS.
St. John's
Argentia
Petite Forte
Fortune
St. Pierre
Rail
North Sydney
To Halifax
Source: Government of Newfoundland & Labrador and Marine Atlantic.
MUNCL

small (2,500-5,000 people). Corner Brook (population 25,000) would serve as the main logistic center for the Northern Peninsula, west coast and part of the south coast, though labour could be drawn from many smaller local communities. The population density along the coast between White Bay and the Avalon Peninsula is relatively high (compared to the south coast, northern peninsula and west coast). Transportation systems, industrial activity, fish processing facilities, and potential waste heat sources are outlined below.

3.1.2.1 Industrial Activity and Fish Processing Facilities

The distribution of major industrial activities is shown in Figure 3.4. As discussed in Subsection 3.1.2.3, some of these (e.g., paper and allied products industries) might possess sources of waste heat for use in aquaculture facilities. A large number of fish processing plants are broadly distributed along the coastline (Figure 3.3).

The processing facilities within each aquaculture development zone are listed in Table 3.1 and are summarized in Appendix E.

3.1.2.2 Transportation Systems

Major roads exist throughout many coastal areas except large portions of the south coast, the eastern edge of the northern peninsula and parts of the west coast (Figure 3.5). A coastal ferry services the small communities on the south coast and Harbour Deep on the eastern side of the northern peninsula (Figure 3.7).

3.1.2.3 Potential Waste Heat Sources

A list of generating facilities on the island is presented in Table 3.2. Besides providing power, these facilities could provide sources of waste heat for use in culture facilities. Relatively large (1 megawatt) electrical generating plants are located in St. Anthony and Roddickton, St. John's, Gander, Aguathuna, Port Aux Basques, Salt Pond, Grand Bank, Fogo, Burgeo and Ramea.

Plant capacities shown in Table 3.2 are not necessarily suitable indications of the waste heat produced. Operating practices and waste heat production can vary greatly amongst the plants. Power production at the hydroelectric units operated by Newfoundland and Labrador Light and Power Co. Ltd. are influenced by their rating capacities, power consumption and the amounts of water available in their reservoirs. Generally, minimum reservoir volumes occur during summer and maximum volumes occur during winter. Rattling Brook (in Zone 9) has the greatest capacity and monthly power production is relatively consistent, though typically higher in winter and lower over summer. The diesel plants and gas turbines operated by Newfoundland and Labrador Light and Power Co. Ltd. are used during periods of peak power usage and during emergencies. The St. John's steam plant is being phased out. The Newfoundland and Labrador Hydro Ltd. diesel generating plants are generally used more continuously but might not have adequate or dependable quantities of waste heat. The diesel generating plants at Roddickton and Main Brook were taken out of regular operating during mid-1989, but a new wood chip fired generating plant at Roddickton is scheduled for start-up during the latter part of 1989.

A large oil-fired generating plant is in operation at Holyrood. The potential for aquaculture development has been assessed at Holyrood and Roddickton (Sutterlin 1988). Heated wastewater at the large Newfoundland and Labrador Hydro Ltd. hydroelectric project at Bay D'Espoir is already being used for a salmonid rearing facility.

Other potential sources of waste heat include larger industrial activities such as the pulp mills at Corner Brook, Grand Falls and Stephenville. The mill at Grand Falls, however, is now using a large amount of waste heat for heating of its own facilities. Smaller waste heat sources include hospitals (Gander, St. John's, Grand Falls, Corner Brook and Clarenville); other manufacturing industries in St. John's (concrete products); Come-by-Chance (oil refinery); Corner Brook (Lundrigans-Comstock Ltd.); food and fish processing in St. John's and Corner Brook; beverage producers and breweries (St. John's, Corner Brook, Bishop Falls); dairies (St. John's and Corner Brook); larger bakeries; and possibly mines (O'Driscoll, personal communication). The size and location of many of these sources, such as the beverage and brewery locations, dairies and bakeries are likely not suitable for aquaculture.

3.2 MARINE BIOPHYSICAL CONDITIONS

3.2.1 General Conditions Along the Labrador Coast

There are numerous inlets and islands that could provide protected waters for saltwater aquaculture operations along the upper Labrador coast. However, the usable areas are greatly reduced if they are to be within a reasonable distance of the few settlements in the area. The areas north of Hamilton Inlet are likely not usable for marine culture activities given constraints related to ice, temperature, primary productivity and predator populations.

General biophysical conditions (weather, sea, ice, tides, temperature, salinity, and phytoplankton) along the Labrador coast are summarized below. Potential predator populations, water quality/pollution problems and siting conflicts are also described.

3.2.1.1 Weather Conditions

The Labrador Coast experiences a variety of climatic conditions because of its geographic range in latitude. Labrador is situated within the Icelandic low pressure system and is subjected to a pressure gradient that rises slowly from the northeast to the southwest (Department of Fisheries and Oceans 1986). This low pressure front attains its greatest extent during the winter. Many of the storms that characterize the area arise from low pressure systems that originate in lower latitudes at this time.

Winter cyclones that are directed toward the Labrador Sea from the Great Lakes Basin and from the coast between Cape Hatteras and Cape Cod, often intensify in the Newfoundland area. Many of these disturbances continue eastward, but some travel northwards towards the Davis Strait. Many of the more severe storms may persist in the Labrador Sea region for up to two weeks. Weather systems move northward as spring and summer advance, becoming weaker and less frequent as they move in that direction.

The prevailing winds are from the northwest and the southwest quadrants. In the northern part of Labrador, southwesterlies are the strongest winter winds, whereas north and northeast winds predominate in the summer. On the coast of central Labrador, southwest winds dominate while northerlies are secondary. In southwestern Labrador winds are generally west during the wintertime and southeast during the summertime (Thompson and Aggett 1981). Table 3.3 indicates the mean wind conditions at the Goose Bay airport between 1951 and 1980.

The paucity of meteorological data for coastal Labrador is because much of it is obtained from ships, and shipping is curtailed during periods of inclement weather. As may be seen on Table 3.3, wind speeds may exceed 100 km/h in this area.

3.2.1.2 Sea Conditions

Seas and swells on the east coast of Newfoundland are most intense in autumn and winter. At this time, the sea waves are greater than 3 m and swell waves are greater than 4 m for 30% of the time. This is the direct result of the intensification of storms in the area, under the influence of the Icelandic Low. In the North Atlantic, the wave energy is six to ten times greater during the wintertime than during the summertime (Thompson and Aggett 1981). During the winter, the full effect of waves and swells is considerably dampened in coastal Labrador due to the presence of ice. For this reason, the effects of waves and swells are of little consequence near the shore except during the spring and summer months.

During the spring and summer, the atmospheric gradient decreases and the Labrador Sea becomes more calm with seas that are generally less than 1 m. Although the calmest seas are recorded during the summer, this is also the time of greatest variation in wave height.

3.2.1.3 Ice Conditions

Thompson and Aggett (1981) recognize the following three types of ice along the coast of Labrador:

TABLE 3.3: MEAN PREVAILING WIND DIRECTION AND WIND SPEEDS AT GOOSE BAY AIRPORT BETWEEN 1951 AND 1980.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Prevailing wind direction	WSW	W	W	NE	NE	NE	W	W	W	W	W	WSW
Peak wind (km/h)	119	113	106	98	103	116	101	101	122	93	115	11
Mean wind (km/h)	17.0	16.1	16.7	16.3	14.8	14.3	13.8	14.1	16.0	16.1	16.7	176

(Source: Environment Canada, unpublished data)

a) first year sea ice, formed locally along the coast each winter;

b) first year and multi-year polar sea ice, which is carried south from the Foxe Channel and Davis Strait by the Labrador Current and by prevailing winds; and

c) icebergs that are calved from glaciers along the western coast of Greenland and Ellesmere Island and carried south by winds and currents.

Knowledge about local ice conditions is poorly documented. In general, the Labrador coast is free of ice from late summer until late November. During late November, ice begins to form in bays and inlets around Cape Chidley. At this time, polar ice reaches this latitude. Roughly once every five years the inshore areas north of Nain are ice-bound in November. By early December, sea ice moves as far south as Cape Harrison, and by late December the entire coast of Labrador is usually ice-bound.

Sheltered inlets such as Hamilton Inlet are totally covered by ice that is 12 to 25 cm thick in January. At this time, the coast north of Cartwright generally has ice with thicknesses of between 6 and 25 cm. In Hamilton Inlet, new ice begins to form at the western end of Lake Melville in early November extending to the approaches of Hamilton Inlet by mid-December (Department of Fisheries and Oceans 1988a).

Wind may cause the formation of ridges along the coast that are up to 5 m thick, however, ice thicknesses of between 1 to 2 m are more common (Thompson and Aggett 1981). The ice usually begins to retreat in April and normally by early June the waterway to Happy Valley-Goose Bay is navigable. The entire coast of Labrador is normally open to navigation by July. Due to its great mass, the ice not only moves with enormous force but may also act as a moving platform for marine fauna. Off the coast of Labrador, pack ice is used most notably as a whelping ground for harp seals (Phoca groenlandica) (Bowen 1985).

3.2.1.4 Tidal Conditions

The tidal range increases from south to north along the Labrador coast (Department of Fisheries and Oceans 1988b):

	TIDAL RANGE (m)	
	Mean	Large Tides
Bottom Harbour	0.9	1.4
Rigolet	1.0	1.5
Nain	1.8	2.6

Water exchange and currents in bay and island areas can be expected to be generally lower in the south coast areas compared to areas further north. Tidal action also occurs in Lake Melville. The mean tidal range at Northwest River is 0.4 m and during large tides the range is 0.6 m.

3.2.1.5 Temperature Conditions

The coastal portion of the Labrador Current primarily consists of water from the Canadian Current which originates near Baffin Island. Due to its arctic origin, the cool water tends to persist along the Labrador coast. During July, the Labrador Current near Hudson Strait consists of a very cold (-1.5°C) water core.

Detailed temperature information is available for the Hebron Fjord (latitude 50° 10'N). As with many of the fjords along the Labrador coast, the Hebron fjord possesses a shallow sill at its mouth which restricts water circulation and flushing. During the spring, much of the available heat is used in melting ice; therefore the surface waters do not begin to warm until the early summer. Below 100 m, water temperatures remain cold (-1.75°C). During October, surface waters begin to cool and later in the year the winter water temperature of -1.75°C is reached and extends throughout the water column (Nutt and Coachman as cited [IN]: Thompson and Aggett 1981).

Many of the fjords along the coast provide similar situations as those found in the Hebron fjord. Lake Melville is the exception due to considerable freshwater input from the Churchill River. Surface water temperatures in Lake Melville may reach 18°C (Thompson and Aggett 1981). However, sub-zero temperatures are described in the lake for deeper water (below 100 meters; Department of Fisheries and Oceans 1988a).

Summer (August 1 - September 5) water temperatures profiles taken in Makkovik Bay and off Cartwright range from 0°C at depths of 25 to 50 m, to greater than 10°C at the surface (Barrie et al. 1980).

3.2.1.6 Salinity

During winter, there is always a surface layer of low salinity water immediately below the ice which persists after the ice melts. Surface water runoff from the land influences the low salinities in the upper portion of the water column.

Barrie et al. (1980) noted surface salinities of less than 20 ppt. during falling tide and less than 28 ppt. during rising tides at Makkovik Bay. Similar salinities were found at sampling sites near Cartwright. In Hamilton Inlet, Lake Melville is tidal with reduced surface salinity resulting from river input (though under certain weather conditions, saltwater could be forced into the river mouths; Department of Fisheries and Oceans 1988a).

3.2.1.7 Phytoplankton

Buchanan and Foy (1980) studied the abundance and distribution of phytoplankton within the Labrador Sea, during the summer of 1979. Thirty-eight genera and 58 species were found, of which, only 18 species were dominant. The dominant taxa included nine species of centric diatoms, five species of pennate diatoms, one chrysophyte species, one dinoflagellate species, unidentified microflagellates and organisms that were tentatively identified as algal spores.

Water samples from various near-shore and offshore sites, and various depths, along the Labrador coast were analyzed for nitrates, reactive silicates and orthophosphates (Buchanan and Foy 1980). The respective near-shore mean results for these nutrients were 60 mg/m^2, 321.2 mg/m^2, and 29.0 mg/m^2. No significant inshore to offshore trends were noted. However, nutrient levels generally increased with increasing depth. Maximum increases were noted at between 25 and 50 m depths. Nutrient level increases were positively related to increasing depth as a result of photosynthetic processes (Buchanan and Foy 1980).

As a component of the Norwestlant survey chlorophyll a values were determined. The results indicated values of between 1 and 3 ug/L for near-shore surface waters off Nain during May and June (MacLaren Atlantic Ltd. 1977).

Steeman-Nielsen (cited [IN]: Thompson and Aggett 1981) conducted a study of primary production in the near-shore environment. He estimated primary production as being between 100 and 200 mg C/m^2/day for the inshore area between Hamilton Inlet and Nain during July and August. Thompson and Aggett (1981) suggested that these values are extremely low because the productivity of higher trophic levels is considerable. If such low productivity is confirmed, it may be attributed to intense vertical stratification due to melting ice, which results in reduced nutrient renewal throughout the euphotic zone.

3.2.1.8 Potential Predator Populations

Marine Mammals

Ringed seals (*Phoca hispida*) are year-round residents along the Labrador coast. They are generally associated with shorefast ice where they maintain breathing holes and lairs. Ringed seals are common on Lake Melville, but are not usually found in the outer coastal waters.

Harbour seals (*P. vitulina*) are present throughout the year along the coast of Labrador. Harbour seals prefer open water areas and therefore are not usually observed during the ice season.

Harp seals (P. groenlandica), grey seals (Halichoerus grypus), hooded seals (Cystophora cristata) and bearded seals (Erignathus barbatus) are not thought to present threats to an aquaculture endeavor as they head out on to the ice to whelp or moult and then generally move away from the Labrador coast.

Avifauna

The following species of seabirds have been identified by surveys in Labrador (Brown 1979):

- Common Murre (Uria aalge)
- Thick-billed Murre (Uria lomia)
- Razorbills (Alca torda)
- Atlantic Puffins (Fratercula arctica)
- Dovkie (Alle alle)

3.2.1.9 Potential Pollution Sources

As described in Section 3.1.2, Labrador has small and mainly remote community centres and very limited industrial activity. Most industrial activity (wood and metal products industries and hydroelectric development) is concentrated along the Churchill River corridor (Figure 3.4). Three fish processing plants are located in small communities in Zone 1 (north of Hamilton Inlet) and others are concentrated along the southern coastline (Zone 2). Small amounts of local organic or fecal coliform pollution could occur near these communities. Larger harbour facilities are located in the Happy Valley/Goose Bay area and Cartwright and higher risks of water quality problems can be expected in these locations.

3.2.1.10 Potential Siting Conflicts

Siting conflicts could occur on a small scale with local navigation near the larger harbour facilities (e.g., Happy Valley/Goose Bay and Cartwright) and smaller coastal communities. Given the small and dispersed nature of the smaller communities, conflicts would likely be minor.

3.2.2 General Conditions Along the Island of Newfoundland

3.2.2.1 Overview

The coastline of Newfoundland contains many small embayments and island clusters providing protected waters for netpen or suspended culture. However, large areas of the west coast and Northern Peninsula are relatively exposed as are areas along the western and southern edges of the Burin and Avalon Peninsulas. The northeast coast, Avalon Peninsula and eastern edge of the south coast appear to have large areas of protected waters. However, the northeast coast and portions of the Avalon Peninsula are susceptible to drifting sea ice.

Small communities along the coastline have tended to concentrate in the sheltered areas (Figure 3.2). On one hand, this is a positive feature, since a source of labour is provided close to protected waters, but on the other, it could be negative, since the communities can be local sources of pollution. Contamination by human waste is particularly important for mollusc culture.

General weather, sea, ice, tidal, temperature, salinity and phytoplankton conditions are summarized below.

3.2.2.2 Weather Conditions

As may be noted in Table 3.4, the prevailing winds are west to southwest. The southwest winds are more frequent during the summer, whereas west and northwest winds prevail during the winter months; changes in pressure fronts cause the changes in prevailing winds.

In winter, there is a pressure gradient that generally decreases from the southwest to the northeast, which causes winds to blow generally from the west.

TABLE 3.4: WIND OBSERVATIONS FROM COASTAL WEATHER STATIONS.
(Source: Department of Fisheries and Oceans 1986)

PORT AUX BASQUES, NFLD., 47°34′N, 59°09′W.

	Wind Direction % of Observations From N	NE	E	SE	S	SW	W	NW	Calm	Mean Wind Speed (Knots)	Strongest Wind Speed (Knots)
January	8	9	10	4	7	7	33	21	2	16.7	79.9
February	7	10	13	4	6	5	27	15	5	15.9	86.9
March	7	11	21	4	6	5	27	15	5	14.0	79.9
April	7	8	31	4	4	4	27	12	4	12.6	58.8
May	5	6	40	3	3	3	26	9	5	11.2	56.7
June	3	5	49	3	3	3	23	7	6	10.5	52.3
July	2	4	49	4	5	4	22	5	6	9.3	59.9
August	3	6	31	5	7	5	26	9	7	9.4	48.0
September	6	7	23	5	7	6	28	13	7	10.3	52.3
October	6	7	19	5	7	7	29	16	5	12.4	82.6
November	8	8	19	5	7	6	27	17	3	14.4	81.5
December	9	10	14	5	7	7	28	18	2	16.0	78.8
Means	6	8	27	4	6	5	27	13	5	12.7	
Totals											
Extremes											86.9
No. of Years of Observations	15	15	15	15	15	15	15	15	15	3	3

GRAND BANK, NFLD., 47°06′N, 55°46′W.

	Wind Direction % of Observations From N	NE	E	SE	S	SW	W	NW	Calm	Mean Wind Speed (Knots)	Strongest Wind Speed (Knots)
January	11	6	7	5	7	14	34	13	2	18.2	70.1
February	11	8	9	6	6	13	33	13	1	18.3	59.9
March	11	12	11	6	7	17	26	9	2	17.4	85.3
April	11	11	15	6	6	17	20	12	2	15.3	50.2
May	8	9	18	6	7	25	18	7	3	13.2	56.7
June	5	7	14	5	9	34	16	5	5	10.9	61.0
July	3	4	12	7	10	38	17	3	6	9.9	50.2
August	5	5	10	7	12	30	20	6	5	11.3	44.8
September	8	7	9	6	12	22	25	8	4	13.1	55.0
October	10	4	7	8	9	19	29	11	3	14.9	65.3
November	11	8	11	8	9	14	27	11	2	16.5	62.6
December	14	6	9	8	7	13	30	12	2	18.0	65.3
Means	9	7	11	6	8	21	25	9	3	14.8	
Totals											
Extremes											85.3
No. of Years of Observations	15	15	15	15	15	15	15	15	15	15	15

CAPE RACE, NFLD., 46°39′N, 53°04′W.

	Wind Direction % of Observations From N	NE	E	SE	S	SW	W	NW	Calm	Mean Wind Speed (Knots)	Strongest Wind Speed (Knots)
January	12	19	3	10	5	10	24	17	*	18.3	56.7
February	5	24	1	15	1	18	16	20	*	18.1	57.2
March	4	25	1	7	2	18	16	27	*	17.3	65.8
April	3	22	1	8	2	32	16	16	*	15.2	52.3
May	4	31	3	2	3	26	23	7	1	13.3	38.9
June	2	24	1	4	2	45	16	6	*	12.6	31.3
July	*	20	1	4	2	47	15	10	*	12.1	31.3
August	*	16	1	11	2	38	20	12	*	11.7	39.9
September	3	18	3	4	2	31	22	16	1	13.7	48.0
October	6	16	1	8	2	27	22	18	*	13.7	65.3
November	4	13	1	11	2	20	15	33	1	15.2	52.9
December	7	14	1	7	2	27	19	22	1	17.0	55.6
Means	4	20	2	8	2	28	19	17	*	14.8	
Totals											
Extremes											65.8
No. of Years of Observations	4	4	4	4	4	4	4	4	4	4	4

TABLE 3.4 (CONT'D.)

BELLE ISLE, NFLD., 51°53'N, 55°23'W.

	Wind Direction										
	% of Observations From										
	N	NE	E	SE	S	SW	W	NW	Calm	Mean Wind Speed	Strongest Wind Speed
										Knots	Knots
January	12	4	3	5	10	13	30	22	1	16.4	74.5
February	12	4	4	5	11	15	25	24	1	16.4	86.9
March	22	6	3	5	14	9	15	24	2	16.2	85.3
April	24	7	6	8	16	7	9	21	3	14.6	70.1
May	21	7	5	10	26	6	7	14	4	12.5	61.0
June	18	8	5	12	31	8	5	10	4	12.5	65.3
July	13	6	4	13	37	9	6	7	4	11.5	50.2
August	14	6	5	14	29	9	10	10	4	11.8	56.1
September	13	5	4	10	24	14	16	13	3	13.4	74.5
October	11	4	4	9	18	17	20	16	2	14.5	65.3
November	11	4	4	9	18	16	23	16	1	15.9	64.8
December	9	3	4	5	13	14	31	20	1	16.9	82.6
Means	15	5	4	9	20	11	16	16	2	14.4	
Totals											
Extremes											86.9
No. of Years of Observations	23	23	23	23	23	23	23	23	23	23	13

ST. JOHN'S, NFLD., 47°37'N, 52°45'W.

	Wind Direction										
	% of Observations From										
	N	NE	E	SE	S	SW	W	NW	Calm	Mean Wind Speed	Strongest Wind Speed
										Knots	Knots
January	9	6	5	7	11	19	30	11	2	14.8	90.1
February	9	6	5	8	11	18	29	12	2	14.8	104.1
March	14	9	6	7	9	20	22	11	2	14.5	79.9
April	13	7	6	9	10	22	18	13	2	13.2	85.8
May	13	8	7	9	11	25	16	9	2	12.4	78.8
June	11	7	4	8	12	33	17	6	2	12.0	58.3
July	5	4	4	9	15	39	18	4	2	11.5	57.7
August	7	5	4	8	14	36	18	6	2	11.4	61.0
September	9	6	4	6	13	30	22	8	2	11.9	65.8
October	9	4	4	7	13	26	22	13	2	12.8	65.8
November	9	6	5	7	16	22	22	11	2	13.6	78.2
December	9	5	4	7	14	20	27	12	2	14.5	82.6
Means	9	6	5	8	12	26	22	10	2	13.1	
Totals											
Extremes											104.1
No. of Years of Observations	26	26	26	26	26	26	26	26	26	26	26

STEPHENVILLE, NFLD., 48°32'N, 58°33'W.

	Wind Direction										
	% of Observations From										
	N	NE	E	SE	S	SW	W	NW	Calm	Mean Wind Speed	Strongest Wind Speed
										Knots	Knots
January	6	18	10	3	6	10	30	11	6	10.4	64.2
February	7	18	10	2	5	13	25	10	9	9.9	73.9
March	8	21	11	3	5	14	18	10	10	9.1	75.5
April	8	20	13	3	5	17	14	10	11	8.4	59.9
May	6	18	12	4	6	21	13	9	11	7.5	56.1
June	4	17	11	4	7	23	14	6	15	6.4	43.2
July	3	15	9	4	9	26	14	4	17	6.0	43.2
August	5	14	9	4	9	25	16	7	13	6.9	50.2
September	6	16	7	3	9	20	19	8	12	7.5	51.8
October	7	15	8	4	8	16	21	10	11	8.0	66.9
November	6	16	12	4	8	12	25	9	8	9.1	59.9
December	7	16	11	4	6	10	29	10	7	10.0	73.9
Means	6	17	10	3	7	17	20	9	11	8.3	
Totals											
Extremes											75.5
No. of Years of Observations	26	26	26	26	26	26	26	26	26	26	26

Transient depressions that move over or near the Gulf of St. Lawrence and Newfoundland, cause frequent winter storms. The associated winds are often of gale force.

The southern part of Newfoundland is usually on the southern part of these fronts and therefore often experiences storms with winds that veer from the east or southeast to southwest and then west or northwest. The winds increase in strength as they change directions. Moderate to heavy storms occur with southeast winds in advance of high pressure fronts. Snow often falls along the west coast at these times. The northern parts of Newfoundland are often north of the high pressure fronts and experience heavy snowfall with winds from the northeast. Clear weather in the north is usually associated with northwest winds (Steele 1983; and Department of Fisheries and Oceans 1986).

During the spring, the pressure gradient is weaker and the winds become somewhat more variable. As summer advances, the anticyclonic system from the lower latitudes reaches the southern part of Newfoundland causing a second pressure gradient. During these months, winds are generally from the southwest. Local sea breezes develop and storms are generally not as numerous or intense as during the winter.

In the late summer and autumn, very intense storms may reach Newfoundland. These storms often originate in the south as tropical hurricanes.

Topography modifies the effects of winds, often causing offshore winds to develop into squalls that blow down from high ground. The Strait of Belle Isle creates a funneling effect that causes winds to blow along the length of the strait in a northeast or southwest direction at what may be twice the speeds of winds over the adjacent ocean or Gulf of St. Lawrence area (Department of Fisheries and Oceans 1986).

3.2.2.3 Sea Conditions

The movement of frontal systems past the island means that high winds are common and, therefore, that the seas are often rough. Figure 3.8 indicates that the

FIGURE 3.8: Mean annual wind speed (km/hr). (Steele 1983)

western prevailing winds often increase in strength as they move across the island. This results in increased wave heights as one moves from west to east across the island. Thus, the largest waves should be expected along the Avalon Peninsula (Steele 1983); this is depicted by Figure 3.9.

The prevailing winds are west to southwest and therefore blow against the oceanic swells, thereby lessening the force of the water. However, as indicated above, since the winds are from the west, wave heights increase as one moves east along the coast. When these waves break into or along the shore, they undermine the shore at the high water mark until overhanging rocks collapse causing the formation of cliffs. Waves also cause the formation of gently sloping platforms that extend to below the low water level along many parts of the coastline. Such platforms dissipate the energy of the waves (Steele 1983).

During the winter months, the north Atlantic storms are at their worst, however, the forces of the waves that are generated by these storms are greatly dampened by the presence of ice. Wave-energy data collected from Botwood and Logy Bay show that during February and March, the force of the waves may be reduced to zero (Owens and White 1982). It is only during ice break-up that ice scouring against the shore may cause erosion.

3.2.2.4 Ice Conditions

Both moving pack-ice and fast-ice may damage, destroy or displace gear. Records of pack-ice, between 1963 and 1973, indicate that under normal conditions, pack-ice occurs around the island except along the south coast and Placentia Bay, though under extreme conditions, such ice can occur even there (Markham 1980; Davidson 1985; and U.S. Navy 1986). Seasonal sea ice limits along the coast of Newfoundland are shown in Figure 3.10. Fast-ice frequently occurs within the bays and fiords on all coasts.

3.2.2.5 Tidal Conditions

In general, the tidal range around Newfoundland is small and in most areas strong currents would not be expected (Department of Fisheries and Oceans 1988b):

FIGURE 3.9: Maximum wave height in 1970.
(Neu 1970 cited in Steele 1983)

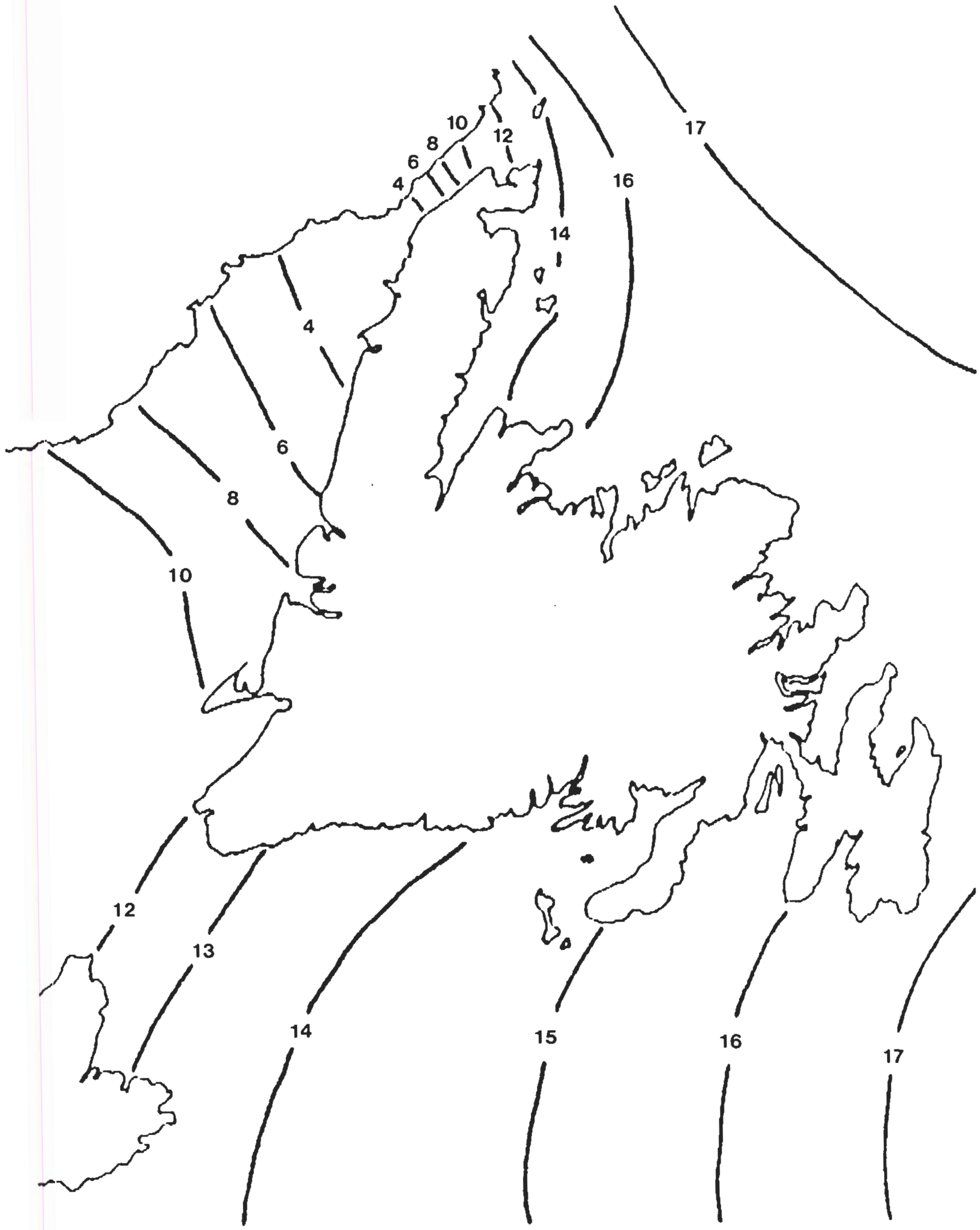
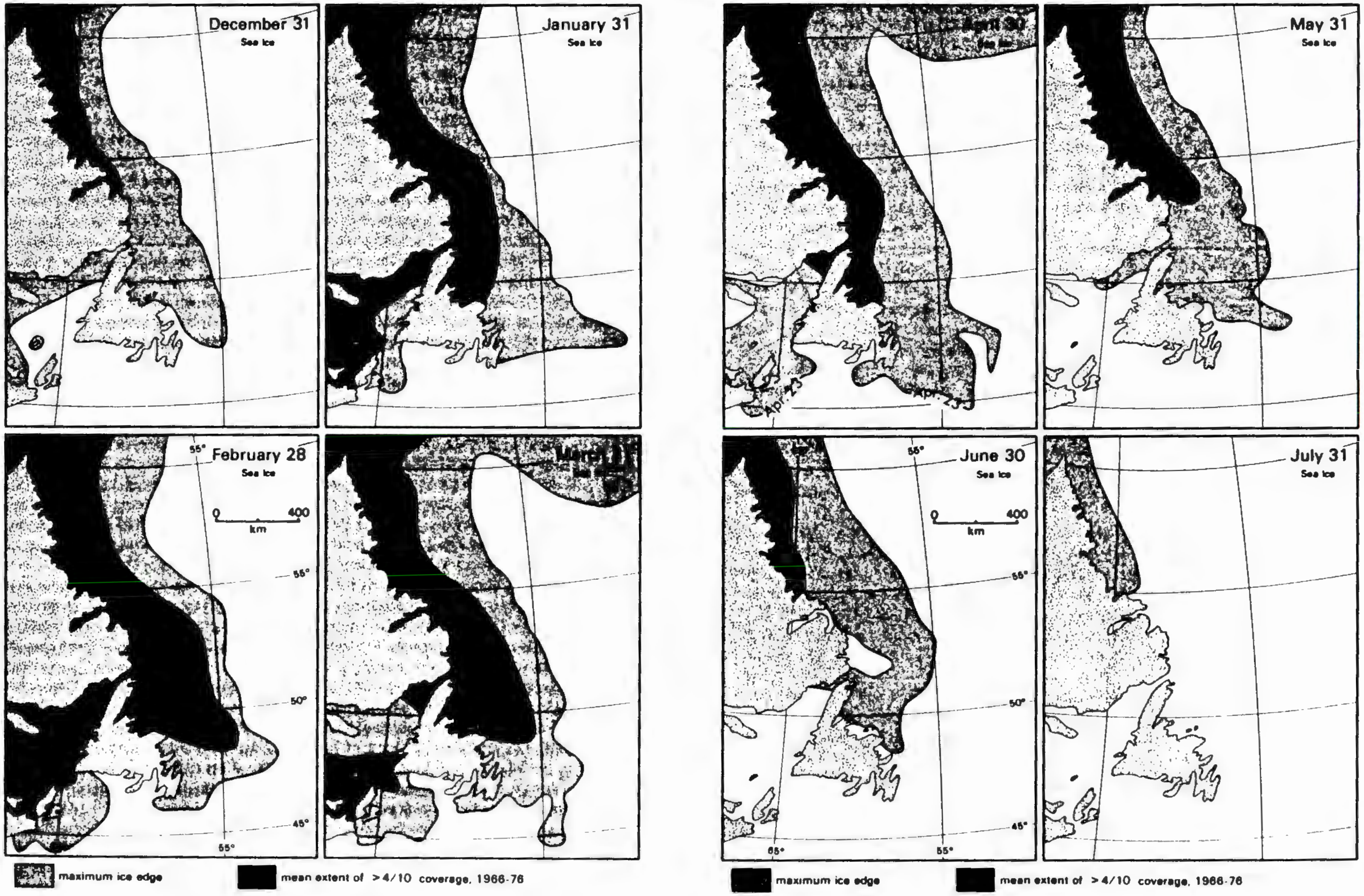


FIGURE 3.10:

Sea ice limits in Newfoundland waters. (MacPherson and MacPherson 1981)



Tide Reference Port	Range (m) Mean	Large	Extreme Highest High Water (m)
Port aux Basques	1.1	1.7	2.6
Argentia	1.6	2.5	3.1
St. John's	0.9	1.4	2.2
St. Anthony's	0.9	1.4	-

The tide types are described as semi-diurnal (Argentia) and mixed, mainly semi-diurnal (Port aux Basques and St. John's). Low tidal amplitudes likely would produce protracted periods of low water exchange at some locations, particularly for the mixed, mainly semi-diurnal tides. Tidal currents and water exchange will vary considerably over a small area in locations having complex island clusters (such as along the northeast coast).

3.2.2.6 Temperature Conditions

As indicated by Figure 3.11, the cold Labrador current flows around the island of Newfoundland in a clockwise direction. The main flow is toward the offshore, however, there is a nearshore component.

Daily maximum and minimum temperatures that occur in nearshore coastal areas are summarized in Table 3.5. A summary of extreme cold water temperatures is shown in Table 3.6. Figure 3.12 indicates the nearshore sites at which the Department of Fisheries and Oceans have set Ryan thermograph meters for at least a portion of the winter. Only one site (Garden Cove) recorded surface temperatures that were above freezing during March, which is the coldest month. However, this was the result of only one sampling session and therefore caution must be used in interpreting its significance.

During winter, the coast of Labrador and the northern part of Newfoundland are ice-bound, therefore, it is not possible to obtain winter surface sea temperatures in locations other than along the south coast. In general, the average surface temperature along this coast is approximately 0°C during January, and below -1.7°C during March (Department of Fisheries and Oceans 1986). By May, the temperature warms to an average of over 2°C. At this time, the temperature within the Strait of Belle Isle is at

FIGURE 3.11: The flow of the Labrador Current waters around Newfoundland. (Steele 1983)

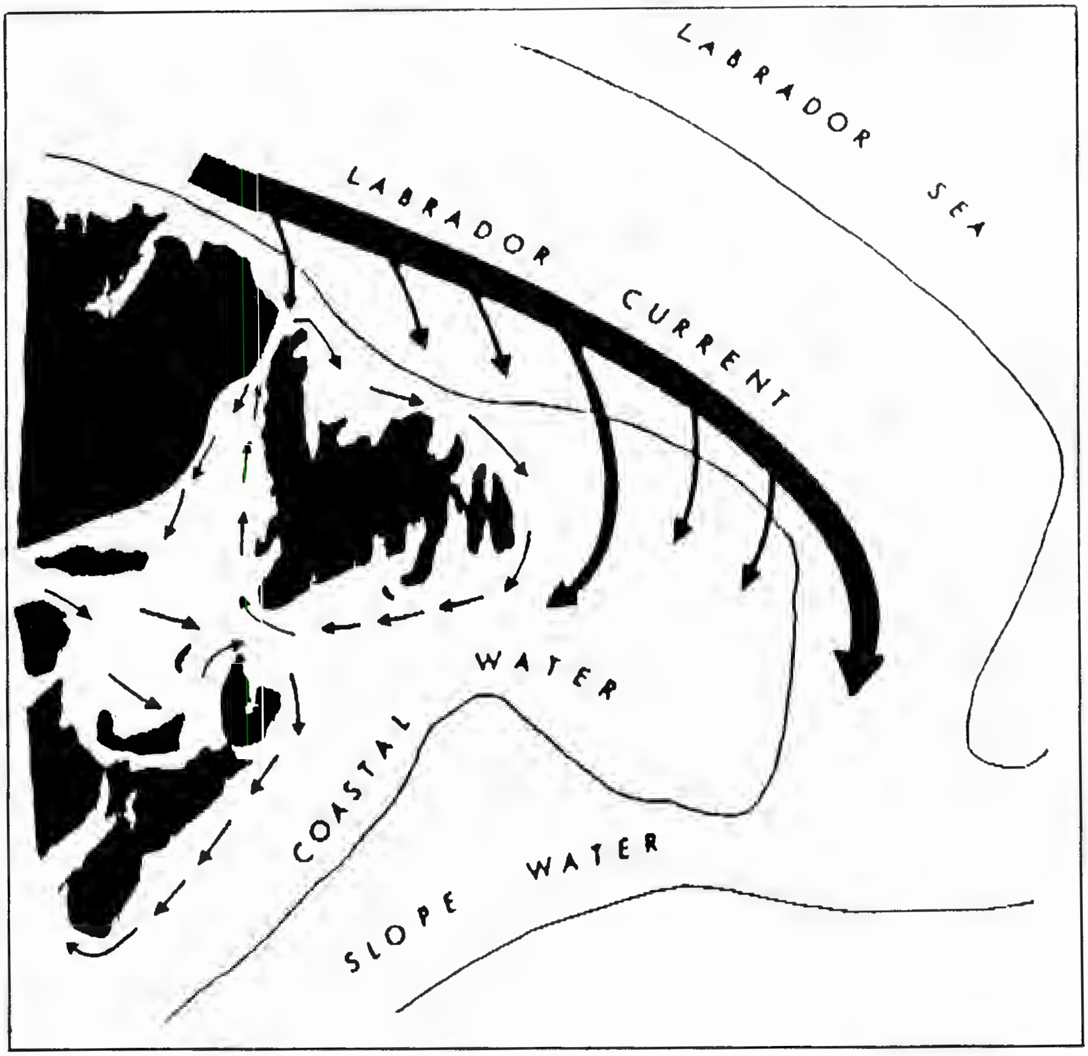


TABLE 3.5: DAILY MAXIMUM AND MINIMUM TEMPERATURES RECORDED AT NEARSHORE MARINE STATIONS. (Sources: Dobson and Petrie 1982; Dobson and Petrie 1983; Dobson and Petrie 1984; Dobson *et al.* 1981; Dobson *et al.* 1985; Walker *et al.* 1986; Walker *et al.* 1987; Newfoundland Department of Fisheries, unpublished data)

ZONE	MARINE STATION	RECORDING DEPTH (m)	BOTTOM DEPTH (m)	DAILY TEMPERATURE (°C)		RECORDING PERIOD
				Maximum	Minimum	
ZONE 3	Croque Harbour	5.0	-	12.2	5.6	July 17 - August 10, 1987
		15.0	-	12.1	3.8	July 17 - October 6, 1987
	Westport	1.0	-	16.0	0	June to January, 1987
		10.0	-	13.0	-2.0	May to December, 1987
	Pacquet	14.0	-	13.0	3.0	May 29 - November 11, 1987
		4.0	-	13.0	3.0	May 29 - September 9, 1987
	La Scie	9.0	27.0	11.6	2.1	June 20 - August 17, 1987
ZONE 4	Harry's Harbour	1.0	-	13.0	2.0	June 8 - December 13, 1983
		1.0	-	12.0	2.5	June 14 - December 18, 1984
		1.0	40.0	15.0	-	July 1 - December 12, 1985
		10.0	-	10.0	4.0	June 9 - September 15, 1983
		10.0	40.0	15.0	-	July 2 - October 10, 1983
	Comfort Cove	9.0	-	10.0	-2.0	December 17 - May 16, 1984
	Hillgrade	10.0	-	15.0	-1.0	June 9 - December 6, 1983
	Bay of Exploits	2.0	10.0	14.5	-	June 24 - July 30, 1985
		1.0	1.0	25.0	0.0	June 22 - April 12, 1987
	Cape Freels	1.0	10.0	13.2	-	July 14 - September 27, 1985
		10.0	10.0	13.4	-	July 14 - September 27, 1985
		15.0	18.0	13.2	-	June 6 - August 17, 1987
	Laurenceton Bay	2.0	5.0	16.0	-	June 12 - August 21, 1987
	of Exploits	2.0	10.0	14.5	-	June 24 - July 30, 1985
ZONE 5	Stock Cove	9.0	-	15.0	-2.0	1983 - 1987
	Salvage Cove	1.0	-	15.0	-2.0	June - January
		10.0	-	13.5	-1.0	May - January
	Terra Nova	10.0	-	-	-1.5	December 8, 1982 - May 4, 1983
	National Park	20.0	-	-	-1.0	December 8, 1982 - April 7, 1983
	Swale Island	10.0	-	14.7	-1.4	June 21 - November 21, 1985; November 13, 1986; March 2, 1987; August 24 - November 23, 1987
	Spruce Pond	1.0	-	18.8	-	May 22 - September 26, 1985
	Lions Den, Chandler	10.0	10.0	13.5	0.2	June 21 - November 21, 1985
ZONE 6	Melrose	9.0	27.4	13.4	4.0	June 6 - October 19, 1987
		18.0	27.4	13.8	-	June 11 - October 19, 1987
		27.0	40.0	12.5	-1.6	June 4 - September 6, 1985
		27.5	-	14.0	4.0	September 6 - November 5, 1984
	Old Bonaventure	-	-	13.5	-	June 10 - August 10, 1987
	Gooseberry Cove	9.0	46.0	11.6	-1.6	June 4 - September 18, 1985
		18.0	-	15.0	-	June 9 - September 6, 1984
	Deer Harbour	18.0	-	6.0	-0.5	June 9 - August 22, 1984
	Sunnyside	10.0	-	15.0	-1.0	October 5, 1982 - November 16, 1983
		20.0	-	11.0	-1.5	October 5, 1982 - November 15, 1983
		33.0	-	11.0	-1.5	October 6 - November 20, 1982; April 25 - May 30, 1983; July 19, 1983 - November 10, 1983
	Chance Cove	9.0	-	15.1	-0.15	June 14 - August 13, 1984
		9.0	37.0	14.4	-0.1	May 28 - October 22, 1985
		27.0	-	18.6	-	May 18 - August 18, 1984
		27.0	27.0	12.8	-0.7	May 28 - August 22, 1985
	Bellevue	-	-	14.42	4.3	May 25 - October 20, 1983
	Heart's Desire	9.0	-	15.40	1.2	June 22 - October 17, 1984; September 15 - November 6, 1984
		9.0	42.0	5.0	-1.2	May 28 - July 2, 1985
		27.5	-	14.2	-0.8	June 21 - October 2, 1984
		27.0	42.0	12.5	-0.8	May 23 - September 16, 1985
	Winterton	9.0	15.0	14.9	-1.0	May 16 - July 31, 1987
	Grates Cove	27.0	51.0	12.4	0.9	June 3 - September 19, 1985
ZONE 7	Bay de Verde	1.0	10.0	8.8	4.9	June 29 - August 1, 1985
	Broad Cove	6.8	-	15.9	-0.05	May 23 - September 17, 1984
	Hibbs Cove	19.0	-	3.5 (average)	3.5 (average)	June 9 - June 21, 1983
	Harbour Grace	6.0	-	12.3	1.0	July 6 - December 13, 1983
		6.0	6.0	4.2	-0.5	December 6 - May 25, 1985
		6.0	6.0	13.0	-	June 4 - November 13, 1985

TABLE 3.5 (CONT'D.)

ZONE/MARINE STATION		RECORDING DEPTH (m)	BOTTOM DEPTH (m)	DAILY TEMPERATURE (°C) Maximum	Minimum	RECORDING PERIOD
ZONE 7	(CONT'D.)					
	Holyrood	9.1	9.1	14.1	-0.7	May 22 - November 13, 1985
		-	-	13.7	-1.1	May 22 - October 25, 1985
		10.0	10.0	16.1	-0.6	May 25 - November 25, 1984
		-	-	16.6	-0.9	May 25 - November 29, 1984
ZONE 8	Logy Bay	15.0	15.0	13.0	-1.5	June 5, 1984 - September 13, 1985
		15.0	37.0	13.5	5.2	July 18 - November 19, 1984
		15.0	37.0	12.1	-2.0	March 28 - September 19, 1985
		35.0	-	15.58	13.0	July 18 - September 15, 1980
		35.0	-	0.75	-1.0	December 30, 1980 - May 31, 1981
		22.0	37.0	13.3	2.2	July 18 - November 14, 1984
		22.0	37.0	12.7	-1.1	March 28 - September 17, 1985
		22.0	55.0	11.5	0.0	April 10 - August 18, 1985
		22.0	55.0	12.3	1.5	July 18 - October 31, 1984
		34.0	-	-	-1.5	October 18, 1982 - March 14, 1983
		37.0	37.0	10.6	-1.5	Various readings 1984 and 1985
		55.0	55.0	-	-0.8	May 10 - September 17, 1985
		55.0	55.0	6.8	-1.6	Sept. 17, 1985 - February 8, 1986
	Witless Bay	5.0	5.0	10.2	1.5	June 7 - August 16, 1982
	Mobile Bay	1.0	1.0	4.1	-0.4	December 11, 1984 - May 6, 1985
ZONE 9	Biscay Bay	1.0	-	20.73	16.27	June 29 - August 16
		-	-	21.8	9.1	May 29 - September 29
	St. Mary's	1.0	20.0	18.1	2.7	May 16 - October
		10.0	10.0	16.9	-1.9	May 9 - October 8
	Calinet	6.0	-	6.5	0.5	December 6 - May 6
		-	-	17.8	0.75	May 6 - September 5
	Holyrood Pond	9.0	-	16.8	-0.3	January 29 - October 21, 1986
		33.0	-	4.2	2.9	January 29 - October 21, 1986
	Spencer's Cove	9.0	-	15.92	-0.25	October 2, 1980 - January 18, 1982
ZONE 10	Shag Rocks	9.0	-	6.5	-1.0	November 23, 1982 - March 21, 1983
		9.0	-	15.0	-1.0	April 22 - October 5, 1983
		-	-	12.8	1.3	October 5, 1983 - January 17, 1984
		-	-	-	-0.2	January 17, 1984 - August 31, 1989
		14.0	-	15.0	0.5	April 16 - October 10, 1981
ZONE 10	(CONT'D.)					
	Arnold's Cove	5.0	5.0	15.7	3.6	June 7 - August 16, 1982
		9.0	-	20.1	-2.0	February 1, 1983 - November 1, 1984
		9.0	9.0	7.8	-1.4	November 1, 1984 - March 28, 1985
	Garden Cove	10.0	-	3.5	-1.9	December 16 - May 31, 1982
		10.0	-	16.0	3.0	May 10 - October 13, 1983
		10.0	-	18.1	0.4	April 2 - August 30, 1984
		10.0	10.0	8.2	-0.9	November 5, 1985 - April 28, 1986
		10.0	10.0	16.4	-1.2	May 6 - October 1986
		10.0	10.0	9.6	0.9	October 20, 1986 - January 15, 1987
	Corbin	9.0	-	16.62	5.0	June 18 - October 17, 1984
		9.0	9.0	15.2	0.8	May 5 - September 7, 1986
		9.0	9.1	7.9	-2.5	October 21 - February 19, 1987
	Little Mortier Bay	6.1	-	10.0	0.66	October 21, 1980 - February 8, 1981
		6.0	-	14.83	1.58	April 18 - October 3, 1981
ZONE 11	Long Harbour	1.0	14.0	14.0	3.0	May 29 - October 4, 1985
		10.0	14.0	13.3	2.4	May 29 - October 4, 1985
		22.0	36.0	10.5	-1.0	May 5 - October 23, 1986
		10.0	36.0	13.5	-0.6	May 11 - October 18, 1986
	Little Bay East	9.0	46.0	8.3	-0.6	October 15 - March 30, 1986
		18.0	46.0	8.0	-1.3	October 15 - March 28
	Conne River	1.0	1.0	22.6	5.6	May 26 - September 9, 1987
		1.0	1.0	20.1	8.1	May 13 - July 22, 1986
		1.0	7.5	14.7	4.8	May 15 - July 7, 1986
		9.0	10.0	14.6	0.7	May 21 - September 10, 1987
		9.0	10.0	20.2	7.3	May 21 - July 7, 1987
	Roti Bay	0.0	-	22.7	8.0	May 24 - December 23, 1987
		1.0	18.0	19.5	7.8	May 24 - December 23, 1987
		5.0	-	3.1	-0.3	January 22 - May 30, 1986
		5.0	-	16.9	4.0	May 24 - December 23, 1987
		10.0	-	12.1	2.0	May 24 - December 23, 1987
	Francois	5.0	22.0	3.3	-0.4	December 11, 1985 - April 14, 1986
ZONE 12	Dublin Cove	6.0	17.0	2.4	-1.1	December 12, 1985 - May 5, 1986
	S.W. Newfoundland	2.0	6.7	20.0	8.8	May 28 - October 10, 1987

TABLE 3.5 (CONT'D.)

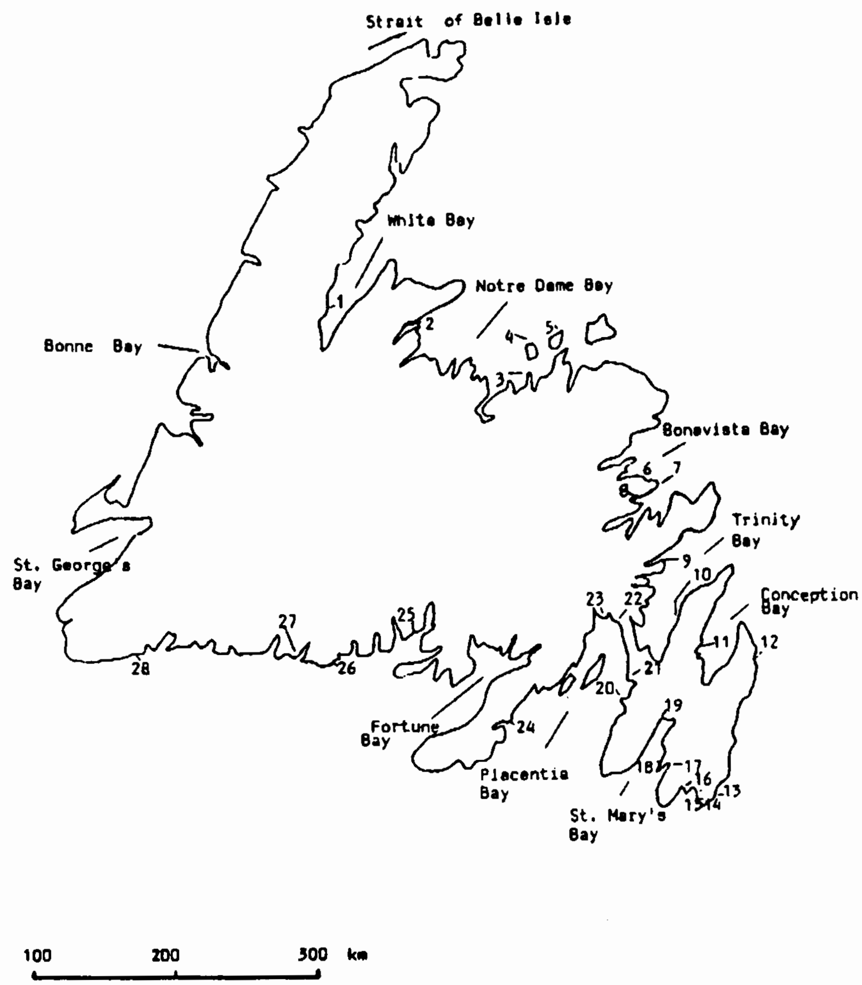
ZONE/MARINE STATION		RECORDING DEPTH (m)	BOTTOM DEPTH (m)	DAILY TEMPERATURE (°C) Maximum	Minimum	RECORDING PERIOD
ZONE 13	St. Georges Bay	19.0	-	15.0	1.58	May 16 - July 15, 1983
	Port au Port Bay	19.0	-	14.5	4.17	May 17 - September 12, 1983
		11.0	-	9.13	-1.7	February 13 - May 15, 1984
		11.0	-	18.4	5.0	June 26 - November 7, 1984
		18.0	-	17.6	4.6	May 29 - September 11, 1984
	Lark Harbour	19.0	-	14.3	6.17	June 10 - August 9, 1983
ZONE 14	Bonne Bay	34.0	-	16.17	7.92	May 11 - September 5, 1982
		19.0	-	14.75	6.5	June 9 - October 13, 1983
		21.0	-	17.23	-0.02	April 26 - October 20, 1984
		22.0	-	13.8	-2.3	May 1 - August 8, 1985
	Bellburn's	16.0	16.0	3.2	0.5	November 29 - December 23
		12.0	12.0	16.3	-1.1	April 30 - August 29
		16.0	16.0	16.1	-1.4	April 30 - August 29

TABLE 3.6: A SUMMARY OF MINIMUM WATER TEMPERATURE AT STATIONS THAT WERE ACTIVE IN NEWFOUNDLAND THROUGHOUT THE WINTER MONTHS, 1967 TO 1988.
(Sources: Dobson and Petrie 1982; Dobson and Petrie 1983; Dobson and Petrie 1984; Dobson *et al.* 1981; Dobson *et al.* 1985; Walker *et al.* 1986; Walker *et al.* 1987; Newfoundland Department of Fisheries, unpublished data)

ZONE	STATION	LOCATION Lat.	Long.	DEPTH (m)	SAMPLING PERIOD	EXTREME MEAN COLD WATER TEMPERATURE °C	# Days
3	Westport	50.12	56.60	1	17/10/84 - 30/12/84	L-1	2
				1	12/10/85 - 22/12/85	L-1	2
4	Harry's Harbour	49.70	55.93	1	18/10/84 - 18/12/84	-0.3	2
4	Comfort Cove	49.41	54.83	9	17/11/81 - 29/04/82	L-1	96
				9	04/12/84 - 11/04/84	L-1	96
				9	07/12/83 - 16/05/84	L-1	124
				9	18/09/84 - 17/02/85	L-1	50
				9	31/01/85 - 09/06/85	L-1	90
				9	19/11/85 - 23/04/86	L-1	126
				9	19/11/85 - 23/04/86	L-1	1
4	Hillgrade	49.57	54.70	1	07/10/83 - 02/01/84	-0.3	10
4	Herry Neck	49.63	54.58	1	17/10/84 - 19/12/84	-0.5	4
				1	04/10/85 - 02/12/85	-0.5	5
5	Stock Cove	48.71	53.76	4.5	18/12/69 - 23/02/70	L-1	5
				4.5	21/01/70 - 23/02/70	L-1	33
				9	22/03/72 - 21/04/72	L-1	14
				9	21/03/73 - 22/04/73	L-1	31
				9	18/11/81 - 20/04/82	L-1	18
				9	18/11/82 - 16/12/82	L-1	81
				9	06/12/83	L-1	8
				9	06/12/83 - 25/02/84	L-1	24
				9	01/01/85 - 04/06/85	L-1	79
				9	30/01/85 - 03/06/85	L-1	90
				9	18/11/85 - 20/04/86	L-1	50
				9	18/11/85 - 21/04/86	L-1	84
5	St. Chad's	-	-	0	15/12/71 - 13/01/72	0	3
5	Little Coldeast	48.58	53.80	8	21/11/85 - 11/05/86	L-1	104
6	Sunnyside	47.85	53.92	10	02/03/82 - 22/06/82	L-1	26
6	Heart's Desire	47.84	53.45	9	29/10/85 - 13/12/85	2.4	1
7	Harbour Grace	47.68	58.24	6	13/12/83 - 03/02/84	L-1	22
				6	13/11/85 - 30/04/86	L-1	7
8	Logy Bay	47.58	52.67	8	14/10/82 - 21/03/82	L-1	4
9	Drook Brook	46.67	53.24	0.5	31/07/84 - 04/01/85	0.2	6
9	Lower Drook Brook	46.67	53.24	1	18/12/85 - 06/05/86	0.1	1
9	Lower Freshwater River	46.77	53.35	1	18/12/85 - 06/05/86	-0.7	1
9	Upper Northeast River	46.77	53.35	0.5	05/07/86 - 13/12/86	-0.4	1
9	Holyrood	-	-		02/02/86 - 31/12/86	0.0	18
9	St. Mary's	46.92	53.57	1	05/11/85 - 17/02/86	L-1	23
				1	05/11/86 - 28/02/86	L-1	8
10	Colinet	47.19	53.58	6	14/10/82 - 06/12/82	4.2	1
10	Spencer's Cove	46.67	54.08	9	18/11/81 - 11/05/82	L-1	9
				9	18/11/81 - 11/05/82	L-1	14
10	Shag Rocks	47.42	53.83	9	17/01/84 - 09/05/84	-0.2	26
10	Arnold's Cove	47.75	54.00	9	01/11/84 - 29/04/85	L-1	48
10	Garden Cove	47.09	54.21	0	22/01/77 - 17/02/77	0.5	4
				0	12/01/78 - 02/02/78	0.3	1
10	Little Bay	47.73	55.00	0	19/01/77 - 25/02/77	L-1	28
				9	10/15/85 - 30/03/86	L-1	3
11	Roti Bay	47.79	55.07	0	14/01/88 - 30/04/88	L-1	1
				5	14/01/88 - 30/04/88	0.2	1
				5	22/01/86 - 30/05/86	-0.8	1
11	Francois	-	-	5	11/12/85 - 14/04/86	L-1	9
11	Grey River	-	-	6	11/12/85 - 25/01/86	0.0	45
12	Petites	-	-	6	12/12/85 - 04/05/86	L-1	13

L = Less than or equal to.

FIGURE 3.12: Coastal areas around Newfoundland at which winter water temperatures were recorded between 1967–1988.



1. West Port
2. Harry's Harbour
3. Comfort Cove
4. Hillgrade
5. Herring Neck
6. Stock Cove
7. St. Chad's
8. Little Coldeast
9. Sunnyside
10. Heart's Desire
11. Harbour Grace
12. Logy Bay
13. Drook Brook
14. Lower Drook Brook
15. Lower Freshwater Riverr
16. Upper Northeast River
17. Holyrood Pond
18. St. Mary's
19. Colinet
20. Spencer's Cove
21. Shag Rock
22. Arnold's Cove
23. Garden Cove
24. Little Bay
25. Ruth Bay
26. Francois
27. Grey River
28. Petites

approximately 1.7°C. Representative surface water temperatures for the month of July are indicated in Figure 3.13. As illustrated by this figure, the warmest Newfoundland coastal waters are within Bay St. George. The temperature decreases to approximately 8°C in the Strait of Belle Isle and is approximately 11°C along the east coast of Newfoundland.

Weekly average water temperature data from Roti Bay between June 1985 and April 1987, indicate that extreme surface water temperatures oscillated between -0.6°C and 20.3°C. Average weekly temperatures were consistently below zero between December and March during the study years. Below 3 m, the temperatures did not dip below zero. At the 10 m station, the extreme minimum winter temperature was 1.5°C, while the extreme maximum summer temperature was 9.3°C.

3.2.2.7 Salinity

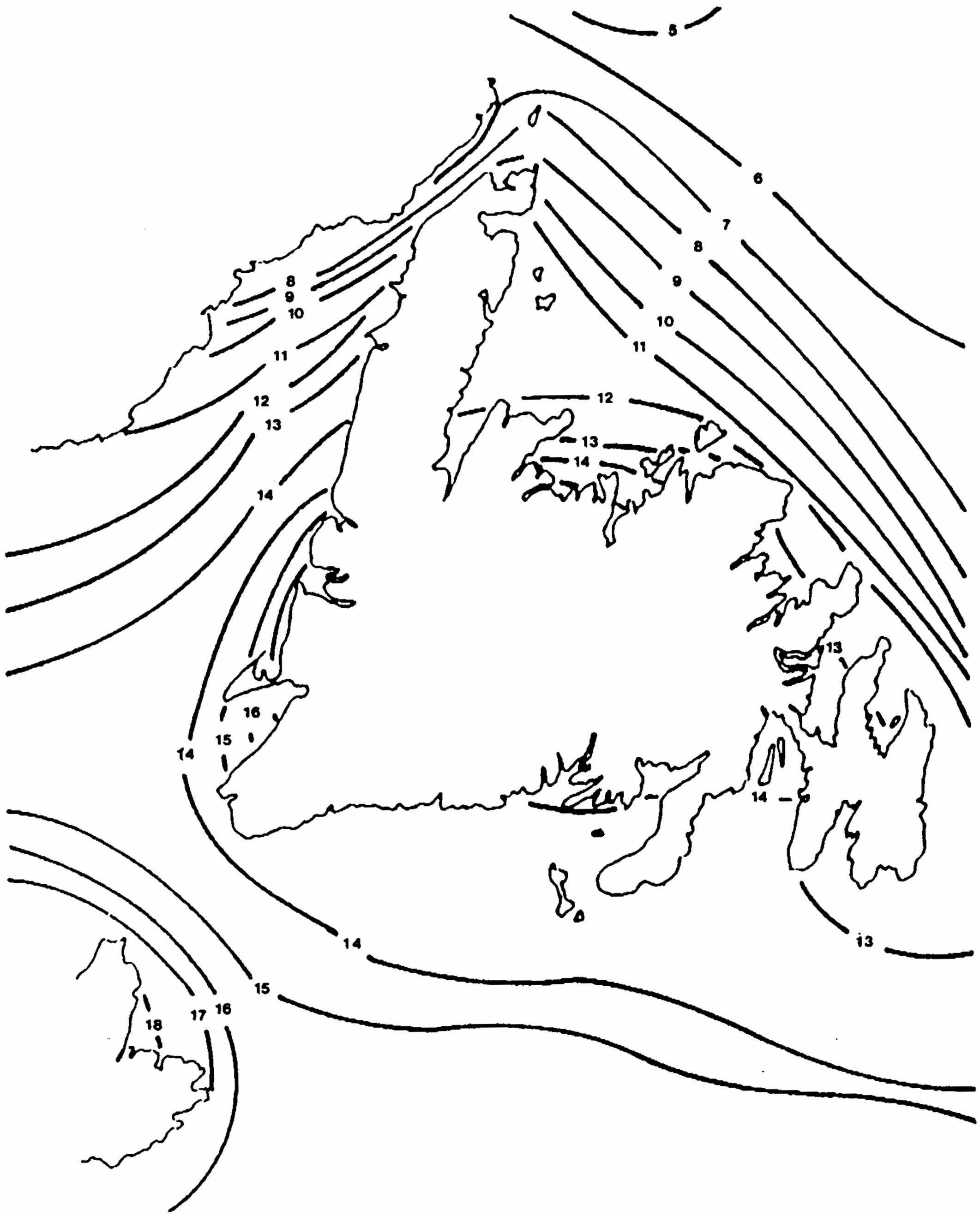
Seasonal salinity fluctuations can be expected in nearshore areas, particularly near the mouths of the major rivers. The fluctuations will be affected by precipitation, and the storage characteristics of the watershed. During the winter months, if there is ice cover, there will be stratification of the surface layers with freshwater being at the surface. During the spring break-up, freshwater input increases due to ice melt and drainage from the land. At this time, there is vertical mixing by winds that may cause salinities to decrease several meters below the surface.

Bays that can be expected to have low and fluctuating surface salinities as a result of large freshwater input from rivers include:

- the head of Bay of Exploits (Exploits River);
- Humber Arm, at the end of Bay of Islands (Humber River); and
- Gander Bay (Gander River).

Numerous smaller streams will affect other embayments on a local scale.

FIGURE 3.13: Representative surface water temperatures (°C), July. (Steele 1983)



3.2.2.8 Phytoplankton

Little research has been conducted in regards to primary productivity, plankton biomass and suspended particulate matter concentrations from inshore waters of Newfoundland. Most phytoplankton data is in the form of species check lists (e.g., Lackey and Lackey 1970) and university theses (Frecker 1972; Lin 1972; and Pauley 1982), and only recently has information on productivity been published. Pomeroy and Diebel (1986) note that low temperatures are not inhibitory to phytoplankton growth in Logy and Conception Bays. In these bays, there are spring blooms during April and May when the water temperatures are between -1 and 2°C. Primary productivity estimates made during the spring bloom in Conception Bay ranged from 1.5 to 9.9 mg C/L/hr. (Cook et al., no date given). Further work is being published by D. Diebel (personal communication) on Logy and Conception Bays. G. Moskovitz (personal communication) is publishing his 1975 research dealing with phytoplankton within Placentia Bay.

3.2.3 Summary of Marine Biophysical Conditions in Each Aquaculture Development Zone

Sheltered areas, currents and water exchange, ice conditions, temperature and potential water quality/pollution problems, predators, and siting conflicts are summarized in this appendix for each zone, except Zones 1 and 2. The conditions in the latter zones have been discussed in the text (Section 3.1, Labrador) and the marine biophysical conditions in these zones were not investigated further, based on the summary conclusions noted below.

3.2.3.1 Zone 1

Development and operation of an aquaculture venture north of Hamilton Inlet would be difficult, given the small population and infrastructure base and limited transportation facilties. In general, netpen fish culture or suspended mollusc culture is not advisable given the low water temperatures and long periods of ice cover. In addition, mollusc culture could be further impaired by low phytoplankton production.

3.2.3.2 Zone 2

The Happy Valley - Goose Bay area appears to be the best logistical base for aquaculture development and offers the best potential for finding a source of industrial waste heat. Lake Melville and Hamilton Inlet are generally not suitable for netpen fish culture or suspended mollusc culture because of fluctuating salinities and a long period of ice cover. Site limitations could be compounded by potential predation by ringed seals.

The area south of Lake Melville does not appear to be as logistically suitable as further north in Zone 2, but does possess a number of fish processing facilities and small communities. The likelihood of finding reliable waste heat sources appears low. Netpen culture during summer or suspended mollusc culture might be possible in sheltered areas on a localized basis. However, in general, the low seawater temperatures, long period of sea ice cover and potential low phytoplankton production suggest a poor capability. Land-based salmonid or marine fish culture might be considered in Zone 2 if a good waste heat or groundwater source is eventually identified. A potential groundwater source for freshwater production is being investigated in the Northwest River area.

3.2.3.3 Zone 3

1. Sheltered Areas

The coastline is rugged, often with steep, rocky-walled bays. For coastal areas north of Baie Verte, eastern exposures may be subject to heavy seas. Steep walls that line many bays, tend to provide shelter if the bays are not open to the east. Easterly winds prevail in summer and southeast and northwest winds prevail in the autumn in this zone. In winter, prevailing northwest and southeast winds tend to move pack ice offshore. Steele (1983) notes that much of Zone 3 is semi to moderately exposed to waves. As indicated by Figure 3.9, the maximum wave height reaches 14 m.

On the Baie Verte Peninsula, bays such as Woodstock, Baie Verte and Ming's Bight are relatively sheltered. The Department of Fisheries and Oceans (1986) notes that several bays within White Bay are sheltered and have good access, however, northeast gales cause heavy seas. Within White Bay, Sop's Arm, Seal Cove, Devil Cove and Bear Cove appear to have good protection from these conditions. Along the Northern Peninsula, there are numerous small bays, however, several of these are exposed to the east. Sheltered bays include Chimney Bay, Prince Edward Bay (near Burnt Village) and Drac Bay (near Main Brook).

The coastal areas along Zone 3 are of variable depths with the following giving an outline of this variability:

- Round Head has depths to 9 m;
- Ming's Bight has depths to 31 m;
- Baie Verte has depths to 22 m;
- Wild Cove has depths to 46 m;
- Seal Cove has depths to 21 m; and
- Little Cat Arm has depths to 29 m.

Depths in Canada Bay, near Roddickton, are up to 24 m. Beaver Cove has depths up to 31 m.

2. Currents and Water Exchange

During moderate weather, the current is generally northeast along the southeast shore of White Bay and southwest along the northwest shore. Many of the bays have complex eddying currents; for example, the tidal streams at the head of Chimney Bay are complicated by the large volume of water flowing into and out of the Northwest Arm. When the flood waters are moving north in the channel, the tide is rising at Old House Point. At this time the outgoing tide is still leaving the Northwest Arm. When the two streams meet, they cause eddying currents (Department of Fisheries and Oceans 1986). Tidal ranges are approximately 1 m.

3. Ice Conditions

Davidson (1985) indicates that for the years 1960 until 1984, the median limits of pack ice reached Zone 3 by early to mid-January. The zone was not free of pack ice until the end of May. Western prevailing winds keep the offshore areas along the eastern side of the Northern Peninsula free of pack ice for much of the winter. This influences the presence of seals and sea birds. Fast ice usually forms in bays before the arrival of pack ice.

Baie Verte freezes completely between the middle of December and early January. Ice normally breaks up in May, with extremes of an early thaw in April. The bay remains frozen until June 10.

4. Temperature

Seasonal temperature data are available for several near-shore locations in the southern portion of Zone 3 (La Scie, Pacquet and Westport and one location in the northern portion (Croque Harbour). These data are for the years 1983, 1984 and 1987 and extreme conditions are summarized in Tables 3.5 and 3.6. Average surface temperatures in this area can reach approximately 11-13°C during summer (Figure 3.13). Maximum temperatures can reach 12-16°C at 1-10 m depths.

5. Water Quality/Pollution

There are very few industries and the communities are very small in this zone. As indicated in Table 3.1, fish plants are found in many locations. Diesel generating stations are located in Westport, Roddickton, St. Anthony, Main Brook and Harbour Deep.

The communities of Roddickton and Main Brook discharge raw sewage to the marine environment and significant areas adjacent to these communities are currently closed to shellfish harvesting (J. Roberts, personal communication). Fleur de Lys Harbour is also contaminated with fecal coliform bacteria and the area is closed (J. Roberts, personal communication).

An asbestos mine is in operation at Baie Verte. Mining and exploration projects exist at Ming's Bight/Goldenville, Sop's Arm and Jackson's Arm and in Roddickton and Rambler (Economic Research and Analysis Division 1989). These could be or will be sources of pollution.

White and Roberts (1989) found molluscs to be contaminated by Paralytic Shellfish Poison in Jackson's Arm (White Bay).

6. Potential Predators

Grey seals (Halichoerus grypus), hooded seals (Cystophora cristata) and harp seals (Phoca groenlandica) have been taken near Roddickton (Beck 1983). Harp seals travel with the Arctic ice southward. By mid-January, they are normally widely dispersed along the eastern coast of Newfoundland for extensive feeding (Bowen 1985). Hooded seals whelp off the northeastern coast of Newfoundland (Sergeant 1985).

Common eider ducks (Somateria mollissima) have breeding colonies on the Grey Islands where there are approximately 200 breeding pairs. They overwinter in the area and usually migrate northward by July.

7. Potential Siting Conflicts

During the summer of 1988, the Canadian Wildlife Service (CWS) and a community development association in the Hare Bay area, sponsored a program to establish an eider duck feather business. Biologists were hired to gather and incubate common eider duck eggs. Since Eider ducks feed on mussels and would be considered undesirable predators by mussel growers, the CWS would likely strongly oppose mussel culture development in Hare Bay that would conflict with the eider duck enhancement program (P. Ryan, personal communication).

Fish plants in the zone each have small ports which should be expected to have navigation routes kept open to them. Ming's Bight, Sop's Arm, Jackson's Arm and Roddickton are areas of mineral exploration which could have marine navigation routes to them. The mine at Baie Verte is served by marine transport. Roddickton has a wood chip powered generating station that potentially requires shipped-in supplies. St. Anthony, La Scie and Pacquet are harbours which must have marine routes maintained to them. There is a ferry service between Jackson's Arm and Harbour Deep.

3.2.3.4 Zone 4

1. Sheltered Areas

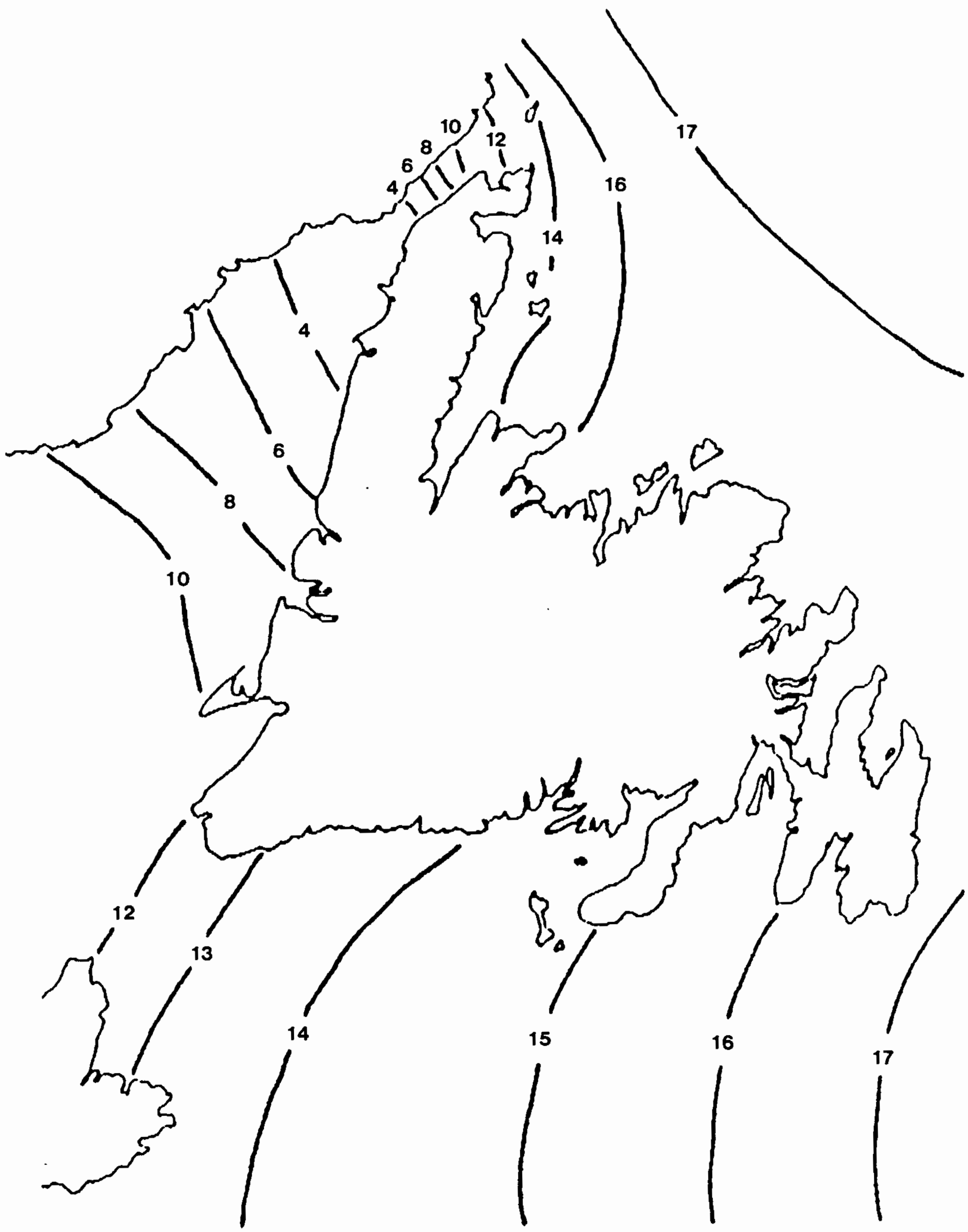
Notre Dame Bay has numerous embayments and protected locations amongst island clusters. Cape Freels is exposed to rough seas although the prevailing winds are from the west and therefore have a moderating effect upon seas that come in from the east. Occasionally there are strong easterlies that may persist for several days and may generate large waves that can do considerable damage along the coast (Steele 1983). Small bays occur around Fogo Island, but generally, the area is exposed to storms that might arise from three directions (west, north and east).

Depths are very variable and reach 75 m in protected parts of the Bay of Exploits.

2. Currents and Water Exchange

An extreme tidal range of 1.6 m may be expected in the Fogo Island area (Department of Fisheries and Oceans 1988b). A strong stream flows from Gander Bay at 2 knots during spring tides. There is also a very weak incoming stream. During neap tides, there is no tidal stream in this area. There may be sills in some areas (such as Charle's Arm) that may restrict water exchanges (T. Mills, personal communication).

FIGURE 3.9: Maximum wave height (m) in 1970. (Neu 1970 cited in Steele 1983)



In the Bay of Exploits area, the tidal streams set in and out of deep channels at rates of 2 knots at spring tides. Tides between several of the islands are influenced by shoals which cause rip tides and eddying currents.

When there are strong winds between northeast and southeast, the rate of the west-going stream (along the Southern Passage) during spring tides may increase to 2 knots which may overtake the eastward ebb tides causing water to flow westward for several hours. Currents near Cape St. John are usually very strong and generally set to the south.

3. Ice Conditions

The sea in the area of Cape Freels freezes in January and the ice often remains near the cape until June. The entire shoreline along Notre Dame Bay is usually frozen from early January until late in June. Ice north of Fogo Island is thick enough that an ice breaker must be used to keep the area clear for shipping. However, according to the Department of Fisheries and Oceans (1986), the water within Hamilton Sound is open to shipping for a longer period of time during the winter. Davidson (1985) indicates that this area is covered in pack ice between January and mid-May.

Drifting ice occurs throughout this area and the susceptability of locations to drifting ice can vary greatly over a local area given the complex nature of islands, bays, currents and depths (D. Walsh and T. Mills, personal communications).

4. Temperature

Average sea surface temperatures in this area can reach 14-15°C during summer (Figure 3.13). Seasonal temperatures have been recorded from several near-shore locations in Notre Dame Bay (i.e., Harry's Harbour, Comfort Cove, Hillgrade, and Bay of Exploits) and Cape Freels. Maximum temperatures at 1-10 m depths can reach 15-16°C during summer in the Notre Dame Bay area and 13-14°C near Cape Freels (Table 3.5).

5. Water Quality/Pollution

Abitibi-Price has a large pulp and paper mill in Grand Falls, which dumps effluent into the Exploits. At Gander, there is a sawlog operation and mining exploration is occurring at Point Leamington and on the Gander Bay Road. These activities may lead to mining in the future, which will create pollution loads.

Many communities along the watershed and estuary of the Exploits River discharge untreated sewage to the system and are likely sources of fecal coliform bacteria in nearby marine areas (J. Roberts, personal communication).

Small communities and fish plants are distributed along the coastline throughout the zone (Table 3.1). As previously noted, these sites could be sources of local pollution. If there isn't a strong current in the area, there may be an anoxic layer below where the offal is dumped. In 1989, the federal Environmental Protection Service (White and Roberts 1989) determined that the following areas were contaminated by high levels of coliform bacteria:

- Burnt Arm (near Botwood);
- portions of Upper Gut Arm (New World Island); and
- portions of Burnt Arm (New World Island).

In addition to the fish plants in smaller communities in this zone, the Economic Research and Analysis Division (1989) lists a wood mill in Springdale (Hall's Bay). Newfoundland and Labrador Hydro Limited have diesel generating plants in Zone 4 at Little Bay Islands and Bishop Falls.

White and White (1985) indicates that paralytic shellfish toxins were discovered in mussels at St. Patricks thereby indicating the presence of Gonyaulax excavata.

6. Potential Predators

Harp seals (Phoca groenlandica) and hooded seals (Cystophora cristata) are potential marine mammal predators in this zone. Winter flounder (Pseudopleuronectes americanus) is found in shallow waters. They are potential predators of mussels that are grown in bottom culture (Pitt 1984). Lobster (Homarus americanus), which are ubiguitous to this area, will eat giant sea scallops (T. Mills, personal communication). Small colonies of common murre (Uria aalge) have been found in Notre Dame Bay and other sea bird colonies are found on islands away from potential culture areas (Cairns et al., 1986).

7. Potential Siting Conflicts

Fishing vessel and other boat traffic can occur throughout the zone. Musgrave Harbour is a larger fishing community and many of the small communities are fishing villages. On Fogo Island, there are boat harbours at Seldom Cove and Tilting. Passages for boats would have to be kept clear to the fish plant and harbour areas.

All of the stretches between the islands may be considered to be passages for boats and therefore cannot be blocked by aquaculture gear. Hamilton Inlet is a navigation route. Lewisporte is a harbour that is at the head of Burnt Bay; major ferry and cargo services are run from Lewisporte. There are smaller ferry services between Fogo Island and terminals at Farewell, Pilley's Island and Newfoundland (see Figure 3.7).

There are two harbours at Bay of Exploits; the Upper Harbour is situated on the southeast part of the channel, whereas, the Exploits Lower Harbour is situated in the northwest part of the channel. St. John's Harbour is a cove on the eastern side of Thwart Island. Botwood, at the mouth of Exploits River, is a shipping port.

3.2.3.5 Zone 5

1. Sheltered Areas

Numerous inlets and bays such as: near Badger's Quay, Dark Cove, Traytown, Lethbridge, Port Blandford, and Southern Bay appear to be well protected from seas, winds and storms. Points such as Cape Bonavista and Cape Freels are subjected to extreme wave exposure. Blackhead Bay on the eastern side of Bonavista Bay is exposed to the north.

The following bays appear to be relatively deep: Southern Bay, Cannings Cove, Clode Sound, Newman Sound, Alexander Bay, Lockers Bay and Trinity Bay, with depths up to:

Southern Bay	65 m;
Sweet Bay	34 m;
Cannings Cove	31 m;
Clode Sound	78 m;
Newman Sound	17 m;
Alexander Bay	69 m;
Lockers Bay	28 m; and
Trinity Bay	31 m

Freshwater Bay appears to be too shallow over much of its extent and is also a navigation route.

2. Currents and Water Exchange

The tidal range can be expected to be between 0.2 m and 1.6 m and currents near Gambo are strong (Department of Fisheries and Oceans 1986). The outgoing tidal stream at the entrance to Freshwater Bay attains a rate of 1 knot, while the ingoing stream to this bay is weak.

3. Ice Conditions

Harbours in Bonavista Bay freeze over between approximately January 20 and March 20 with ice that is approximately 0.3 m thick. Pack ice begins to appear about February 15 and disappears toward the end of May. Near Trinity, pack ice arrives early in March and remains until April. Trinity Bay (within Bonavista Bay) is divided into two arms by a narrow peninsula. The northwest arm of the bay is generally frozen at the end of January, or at the beginning of February, and is open by mid-March; the southwest arm freezes regularly from mid-January until mid-May. Greenspond Harbour freezes during mid-January and is closed by thick ice during March. Pack ice appears during mid-March and leaves during May. The bays near Big Pool's Island freeze during January, the ice clears by early May. The sea near Cape Freels is generally frozen between January and May or June (Department of Fisheries and Oceans 1986).

4. Temperature

Average near-shore surface temperatures in this reach are between 13-14°C over summer (Figure 3.13). Maximum temperatures during summer at 1-10 m depths can reach 15-19°C (Table 3.5).

5. Water Quality/Pollution

Fish plants (Table 3.1) and smaller communities are potential sources of local pollution in the zone. Environmental Protection Service and Department of Fisheries and Oceans identified portions of Indian Bay, and Northeast Arm near Traytown as being contaminated by coliform bacteria (e.g., White and Roberts 1989). Two diesel generating stations are located in Bonavista Bay (St. Brendan's and Charlottetown). At Glovertown, a plant produces transportation equipment. At Eastport, there is a furniture business, which could contribute minor pollution.

6. Potential Predators

Grey seals (Halichoerus grypus) have been taken within Bonavista Bay near Cape Freels (Beck 1983). Eider ducks, great black-backed gulls, Atlantic puffins and black guillemots have colonies on Copper Island and along the shore extending from Spillars Point. Eider ducks and black guillemots are potential mussel predators.

7. Potential Siting Conflicts

There are numerous waterways mainly related to settlements and fish plants that must be kept open for navigation. A portion of the shoreline in this zone is the border of the Terra Nova National Park which could conflict with aquaculture development. There are scenic, diving, sport fishing, and pleasure boating areas that may be of concern.

3.2.3.6 Zone 6

1. Sheltered Areas

Department of Fisheries and Oceans (1986) does not indicate that extreme wind, swells or wave conditions occur in this zone. The northwestern peninsula of the Avalon Peninsula (Baie de Verde Peninsula) shelters Trinity Bay from many of the effects of swells, waves and winds. Waves and storms from the east are diverted around Grates Point and Trinity Bay, so that waves and storms from the northeast will be felt in the bay.

A swell nearly always sets in at Tickle Bay and with a northeast or east wind, the bay can be dangerous (Department of Fisheries and Oceans 1986). Heavy sea can occur in Hant's Harbour after a storm and strong easterly swells often develop in New Bonavista Harbour. There are, however, numerous protected inlets and bays such as:

- Goose Cove;
- Northwest Arm and Smith Sound;
- Southwest Arm;
- Deer Harbour;
- Bellevue Beach Provincial Park; and
- Heart's Delight.

Smith Sound, Random Sound and Bull Arm all have very deep water. Smith Sound has depths to 101 m; Northwest Arm of Random Sound has depths up to 61.0 m. Southwest Arm of Random Sound has depths to 143 m; Bull Arm has depths of 89 m. The bay between Bellevue Peninsula and Collier Point has depths to 16 m; Chapel Bay has depths to 42 m; and Dildo Arm has depths to 26 m.

Collier's Bay at the south end of Trinity Bay has depth ranges up to 16 m. The rest of the shore along the Baie de Verde Peninsula appears to be unsuitable for aquaculture, either due to lack of shelter or because bays are too shallow.

2. Currents and Water Exchange

The general tidal range is between 0.2 and 1.6 m (Department of Fisheries and Oceans 1986). Collier's Arm is a saltwater lake that is situated to the northeast of Tickle Bay which has an entrance onto Trinity Bay. The ebb tidal stream from Collier's Arm is strong. After east winds, currents form along the northwest shore of Trinity Bay. The head of Smith Sound is connected by a narrow, shallow channel to the head of Northwest Arm of Random Sound. This channel is approximately 0.6 m (Department of Fisheries and Oceans 1986) deep, however, strong currents are developed along the channel. After a heavy sea, an undertow develops along the eastern side of Hants Harbour.

3. Ice Conditions

Trinity Bay never freezes over, however, it normally fills with pack ice between mid-January and March, and clears between mid-March and April 20. At times, very little ice enters the bay, but at other times pack ice may persist until May 25. Icebergs may enter the bay as early as May and may remain until late in August when they usually run aground. Hant's Harbour rarely freezes over; but pack ice moves into the area by April. Heart's Content usually freezes over between the end of January and the middle of February; the bay is generally open by the end of March. Heart's Desire normally freezes over in February or early March and clears during the latter part of March. Pack ice moves into Heart's Desire about the middle of April and leaves by the beginning of May. Dildo Arm occasionally freezes during the middle or end of February and clears by the end of March. Pack ice enters Dildo Arm once every five years and usually doesn't last longer than one week. Most other harbour areas are frozen over between mid-January/early February and the end of April/early May.

4. Water Temperatures

Average sea surface temperatures reach approximately 13-14°C during summer (Figure 3.13). Maximum temperatures in nearshore areas at 1-10 m depths can reach 14-16°C (Table 3.5).

5. Water Quality/Pollution

Clarenville is a relatively large community of 3,000 near the head of Trinity Bay. The industries in this community include:

- Newfoundland Hardwoods Ltd. which operates a creosoting plant, a timber yard and an asphalt plant in Clarenville. Asphalt is brought in by tanker.

- The Imperial Oil Company and Irving Oil Company have tank farms near the Clarenville Harbour with gasoline and fuel oil storage tanks. The oil is discharged from ships via pipeline. The possibility of an oil spill would be a serious threat to an aquaculture development.

Clarenville dockyard has a large marine haulout slip with a capacity of 454 tonnes. A certain quantity of oil related, or other contaminates would likely be entering the water in the area as a result of repairs, dirty bilge water, etc.

Catalina Harbour is a large fishing centre in this zone. There are numerous small communities along the shores of Trinity Bay that could cause local coliform problems. The following areas were identified as being contaminated with coliform bacteria:

- portions of Northwest and Southwest Arms of Trinity Harbour;
- Goose Cove;
- Sunnyside;
- Bull Arm; and
- Collier's Arm and Broad Lake, at Bellevue (White and Roberts 1989).

Hydro plants are located at: Port Union, Lockston, New Chelsea and Heart's Content. A shale mine is located at Nut Cove and a slate mine is at Milton (Economic Research and Analysis Division 1989).

6. Potential Predators

Grey seals (*Halichoerus grypus*) have been taken in Trinity Bay. Sea bird colonies within Trinity Bay are located on a number of islands in Trinity Bay (North Bird Island, Elliston Point Island, South Bird Island, Green Island, Bellevue Island, Puffin Island and Baccalieu Island (Cairns *et al.* 1986.).

7. Potential Siting Conflicts

Every coastal community has a public waterway that must not be blocked. Clarenville is a larger harbour, therefore, any development that may obstruct the movement of ships will not be permitted. Navigation routes must be kept open for local fishermen. Bellevue Beach is a provincial park and use of the adjacent shoreline for aquaculture could be perceived as a conflict.

3.2.3.7 Zone 7

1. Sheltered Areas

Conception Bay is exposed to the northeast and has few sheltered locations, especially along the eastern shore. Several embayments offer some protection along the southwest edge of the bay. However, even these for the most part have relatively long fetches towards the northeast or north and can be subject to rough sea conditions (Department of Fisheries and Oceans 1986). Long Pond, at the head of the bay is dredged as a shipping harbour for Texaco Oil. Protected bays along the south end of the bay have relatively developed harbour facilities which could lead to navigational conflicts and possibly pollution problems.

2. Ice Conditions

The presence of ice in this zone is variable. Usually ice is present after mid-January and clears by mid-April. Some years no ice enters the bay while during others the ice can remain until late May.

3. Currents

The mean tidal range is approximately 1 m and can reach 1.4 m during large tides.

4. Temperature

Average sea surface temperatures reach approximately 13-14°C during summer (Figure 3.13). Maximum temperatures in nearshore areas at 1-10 m can reach 15-17°C (Table 3.5).

5. Water Quality/Pollution

There are numerous shoreline communities in this zone, and several types of industry:

- Cabonear (furniture manufacturing);
- Harbour Grace (leather goods and wood products);
- Bay Roberts (ship building);
- Coley's Point (ship building);
- Brigus (food products); and
- Paradise (ship building).

The industrial activity is located mainly in the embayments along the western and southern edge of Conception Bay.

6. Potential Predators

Seabird colonies are located near the head of Conception Bay on Kelly's Island and Little Bay Island (Cairns *et al.* 1986).

7. Potential Siting Conflicts

The protected bays along the south end of Conception Bay have relatively developed harbour facilities which could lead to navigational conflicts. Long Pond, at the head of the bay, is dredged as a shipping harbour for Texaco Oil.

3.2.3.8 Zone 8

1. Sheltered Areas

This zone is very exposed to the east, but has a number of small embayments offering some protection, though large ground swells can enter virtually all bays after easterly storms. Since these bays open to the east, normally only the heads of the bays would offer sufficient protection from severe conditions.

2. Ice Conditions

The heads of bays freeze during the winter for very short periods in this area, otherwise water stays open year round. Drifting ice occurs in this area and can remain as late as June 20 in some areas.

3. Currents

Currents in general are not strong in this area, but could be stronger in some bay areas. The mean tide range is approximately 0.9 m and can reach 1.4 m during large tides. Sea Consult (1985) indicates that the predominant currents are from the northwest and are a result of the Labrador current.

4. Temperatures

Average sea surface temperatures reach 13-14°C during summer. Most nearshore data are from the northern coastal area, primarily from Logy Bay. Maximum temperatures at this location have reached approximately 16°C (Table 3.5).

5. Pollution/Water Quality

Small communities are located at the heads of small bays throughout this area and could produce local coliform contamination. St. John's is a major harbour and would present major pollution risks.

6. Potential Predators

Major sea bird colonies are located mainly in the northern and central portion of this zone (Cairns et al. 1986). A large colony of common murres is located in Witless Bay.

7. Potential Siting Conflicts

Larger vessel traffic occurs in the vicinity of St. John's Harbour. Small boat traffic occurs in some bays having small communities and several more protected bays (e.g., Bay Bulls) provide anchorages for larger vessels during rough weather.

3.2.3.9 Zone 9

1. Sheltered Areas

This zone is comprised of two major bays, Trepassey Bay, to the east and the larger St. Mary's Bay to the west. Both bays are exposed to the south and the head of St. Mary's Bay is exposed to the southwest.

Within St. Mary's Bay, few sheltered locations are found along the west shore. On the east side, the sheltered areas are Holyrood Pond, St. Mary's Harbour, the head of Mall Bay, Salmonier Arm, the head of Colinet Harbour and the head of North Harbour.

2. Ice Conditions

Fast ice can be expected along the shores of Trepassey and St. Mary's Bays during mid-February (Seaconsult 1985). South and southwest winds blow ice into St. Mary's Bay and this can accumulate in the heads of the smaller bays and inlets. Generally, pack ice can be expected in St. Mary's and Trepassey Bays during February. Relatively large streams flow into Trepassey Bay (Biscay Bay, Portugal Cove and Northwest Arm of Trepassey Harbour) and St. Mary's Bay (Harricott Bay).

3. Currents and Water Exchange

Incoming currents to Trepassey Bay can at times be strong so that east-going streams along the east side of the bay can reach 2 knots (Fisheries and Oceans 1986).

4. Temperature

Average sea surface temperatures in this area reach 13-14°C in nearshore areas during summer (Figure 3.13). However, maximum temperatures can reach 20-22°C (in shallow parts of Trepassey Bay) and 17-19°C in parts of St. Mary's Bay (Table 3.5).

5. Pollution/Water Quality

There are relatively few major potential pollution sources in this area but smaller, local sources are located throughout. Fish processing plants and small communities are located around the bays (Table 3.1).

6. Potential Predators

Major seabird colonies are located within St. Mary's Bay (Little Colinet Island and Great Colinet Island) and at the mouth of Trepassey Bay (Cairns et al., 1986).

7. Potential Siting Conflicts

In Trepassey Bay, Biscay Bay is used as an anchorage and Trepassey Harbour is a port facility. Fishing vessel traffic can be expected to the fish plants located near the entrance to St. Mary's Bay (Figure 3.3) though these are generally away from sheltered waters that might be considered for aquaculture.

3.2.3.10 Zone 10

1. Sheltered Areas

Sheltered bays and island complexes are located along the south shore of Burin Peninsula and around the head of Placentia Bay. The east shore is more exposed, but has several large bays in the central portion (e.g., Long Harbour and Fox Harbour). The eastern shores of the Burin Peninsula are exposed to moderate to high wave energy (Hiscock 1981, cited [IN]: Newfoundland Environmental Consultants Ltd. 1986). Sheltered bays along the Burin Peninsula include: Burin Inlet, Mortier Bay, Boat Harbour to Paradise Sound, and Presque Harbour. Within Placentia Bay, sheltered areas are found generally around Merasheen Island and the head waters of the bay. Heavy seas can occur on the western side of the Merasheen Island during southwest gales (Department of Fisheries and Oceans 1986).

2. Ice Conditions

South and southwest winds can move drift ice into the bay as far as Come-by-Chance (Department of Fisheries and Oceans 1986). Fast ice usually forms in sheltered areas from mid-January to early April.

3. Currents and Water Exchange

Currents and tidal streams are erratic within Placentia Bay (Department of Fisheries and Oceans 1986). Currents of 2-3 knots are encountered in the bay during the approach of southeast gales while rates of 1.5 knots occur during good weather. The current through the narrows of Placentia Gut (on the east side of the bay) can reach 9 knots. Near Come-by-Chance, currents are normally 0.2-0.6 knots with maximums of 1 knot. Tides have an average range of 1.5 m and a maximum range of 2.5 m (Newfoundland Environmental Consultants Ltd. 1986).

4. Temperatures

Average surface temperatures can reach 14-15°C during the summer towards the head of Placentia Bay with slightly cooler temperatures along the south shore of the Burin Peninsula (Figure 3.13). Maximum temperatures of 18-20°C have been recorded at depths between 1 and 10 m at nearshore recording stations at the head of Placentia Bay (Table 3.5).

5. Potential Predators

Sea bird colonies are identified within Placentia Bay on Red Island (near Merasheen Island) and at Great Barasway (on the southeast side of the bay). Colonies are also located on the south side of the Burin Peninsula at Spanish Room Point and Middle Lawn Island.

6. Water Quality/Pollution

Major potential pollution sources are located in this zone. These are the oil refinery at Come-by-Chance and phosphorous chemical plant at Long Harbour. The phosphorous plant closed in mid-1989. Other industrial activities include ship building facilities at Marystown and Burin, a naval base and ferry terminal near Argentia; and, smaller communities are distributed around Placentia Bay that could produce local pollution.

7. Potential Siting Conflicts

Large vessel traffic can be expected to the oil refinery at Come-by-Chance, the ferry terminal and naval base at Argentia and the ship building facilities in Burin and Mary's Town. Smaller vessels can be expected at the fish plants on the Burin Peninsula and along the east side of Placentia Bay. Also, many of the deeper, sheltered waters amongst the Marasheen Islands are identified as vessel anchorages (Department of Fisheries and Oceans 1986).

3.2.3.11 Zone 11

1. Sheltered Areas

Much of this zone is comprised of protected inlets and coves. The north side of the Burin Peninsula is very exposed to the west. However, between the head of Fortune Bay and the western limit of the Zone 11, the coastline is highly indented. Deeper sheltered areas include small bays:

- at the east end of Fortune Bay, in Long Harbour and Belle Bay (e.g., North Bay and Mal Bay);
- near Harbour Breton from St. Jacques to Connaigre Bay;
- in Hermitage Bay;
- throughout Bay D'Espoir; and
- along the southern shoreline between Facheux Bay and Couteau Bay (at the western edge of the zone).

2. Ice Conditions

Fortune Bay at the eastern end of the zone does not freeze over though smaller bays within it do (Department of Fisheries and Oceans 1986). Field ice occurs off Grand Bank and Harbour Breton on the western edge of Fortune Bay at the end of February and is generally gone by late March or April. The heads of bays near Harbour Breton freeze over between the beginning of January and middle of April. Ice forms towards the head of Bay D'Espoir from early December to late March/early April. Field ice is found in Hermitage Bay from mid-February to the end of March.

3. Currents and Water Exchange

Currents are strongest in a westward direction near Burgeo and reach 1.5 knots after prolonged easterly winds. At the head of Fortune Bay, tidal streams can at times reach rates of 3 knots.

4. Temperature

Average sea surface temperatures can reach 14-15° during summer in this zone (Figure 3.13). Maximum temperatures at 1-10 m depths have reached 14°C in Long Harbour and 23°C near Conne River (Table 3.5).

5. Water Quality/Pollution

Major water pollution sources are not evident in this zone. Small communities and small harbours are distributed throughout the area concentrated at the western and eastern ends of the Burin Peninsula, near Harbour Breton and the head of Bay D'Espoir; and, Burgeo. Fish plants are located at the western end of the Burin Peninsula, and near Harbour Breton and at Burgeo.

6. Potential Predators

Sea bird colonies are located throughout the area, but concentrations of major predator species are not evident (Cairns et al., 1986). Seals occur in the area; concentrations are found near Harbour Breton and Grey River and in Big Barasway (near Burgeo).

7. Potential Siting Conflicts

Small vessel traffic can be expected near the small port facilities and fishing communities. Larger vessels can be expected at Grand Bank, Harbour Breton and Burgeo. Several small bays are identified as potential vessel anchorages near most ports (e.g., Harbour Breton and towards the head of Bay D'Espoir; Department of Fisheries and Oceans 1986).

3.2.3.12 Zone 12

1. Sheltered Areas

Generally, this zone is very exposed to rough seas from the south. Small, shallow bays occur along the western portion of the zone and several large bays (Bay Le Moine, Garia Bay and Le Poile Bay) occur along the eastern portion. Road access extends only through the western half of the zone. Amongst the larger bays, Garia Bay is relatively shallow over most of its area though depths of up to 14 m are used as vessel anchorages in some locations. Le Poile Bay and parts of Bay Le Moine are more exposed to the south, but have several deeper, sheltered areas along their lengths.

2. Ice Conditions

The heads of some bays freeze for short periods between mid-February and the end of March. Drifting pack ice generally does not occur. However, local drifting ice can accumulate at the heads of bays when pushed landward by the south winds (Department of Fisheries and Oceans 1986).

3. Currents and Water Exchange

The mean tidal range is approximately 1.1 m in this area and can reach 1.7 m during large tides. The tidal stream can be variable near Cape Ray reaching, at times, 2 knots. The stream is west-going during flood tides.

4. Temperature

The average sea surface temperatures reach 14-15°C during summer (Figure 3.13). A maximum temperature of 20°C has been recorded in this area at a 2 m depth (Table 3.5).

5. Water Quality/Pollution

Port aux Basques is an important local port facility with regular ferry service to the mainland. In addition, small fishing communities are distributed throughout the western portion of the area. Otter Bay (near Isle aux Morts) has been found to be contaminated by fecal coliforms (White and Roberts 1989).

6. Potential Predators

No major sea bird colonies or marine mammal populations are known to occur in this zone.

7. Potential Siting Conflicts

Most of the deeper sheltered waters along the western portion of the zone provide anchorages for local small vessels (Department of Fisheries and Oceans 1986). Sheltered areas in the larger bays in the eastern portion of the zone are also identified as anchorages.

3.2.3.13 Zone 13

1. Sheltered Areas

Most of this zone is exposed to the west and southwest. Major exceptions are near the head of St. George's Bay, within Port au Port Bay and in the Bay of Islands. Smaller areas are embayments located at the mouths of the Little Codroy and Grand Codroy Rivers though depths are shallow at these locations. Port au Port Bay is exposed to the north and northeast.

The central portion of the Bay of Islands has fetches greater than 10 km. Sheltered, deeper water occurs along the south shore (near Lark and York Harbours) and in portions of Humber Arm, Middle Arm and North Arm. Some shoreline areas, particularly in Middle and North Arms, are quite steep and nearshore anchoring could be difficult.

2. Ice Conditions

Moving river ice occurs in St. George's Bay and the head of St. George's Bay occassionally freezes (Department of Fisheries and Oceans 1986). The bay is generally clear by April. Port au Port freezes early in January. Ice forms in the main arms of Bay of Islands between the end of December and the end of January and breaks up in late April to early May.

3. Currents and Water Exchange

Currents reach 1 knot in St. George's Bay during flood tides and strong southeast winds. The currents in the Bay of Islands are generally weak, reaching 1.5 knots in the south central part of the bay and diminishing towards the end of Humber Arm. During spring tides, rates of 2 knots are reached in Goose Arm (Middle Arm).

4. Temperature

Average sea surface temperatures earch 17-18°C during summer in this area (Figure 3.13). Maximum temperatures in deeper water (10-20 m) have reached 14-15°C in George's Bay and Bay if Islands and 18°C in Port aux Port (Table 3.5).

5. Water Quality/Pollution

A number of locations have been found to have high coliform levels in shellfish in this zone:

- the St. George's River above Stephenville Crossing;
- portions of Picadilly Bay within Port au Port; and
- Lark Harbour, portions of York Harbour, and Humber Arm within the Bay of Islands (White and Roberts 1989).

The city of Corner Brook is situated at the head of Humber Arm; a pulp mill and other industries are located in this area. The Humber River discharges into the head of Humber Arm; consequently, fluctuating salinities occur along the Arm and occassionally elsewhere in Bay of Islands. In addition, small towns that could create local pollution problems are located on either side of Humber Arm.

6. Potential Predators

Colonies of seabirds occur in this area, but large colonies of potential predators are not apparent (Cairns et al., 1986).

7. Potential Siting Conflicts

Larger harbours are located at Stephenville and Cornerbrook and larger vessel traffic can be expected to those locations (Department of Fisheries and Oceans 1986). Smaller harbours and anchorages are located along the south side of Bay of Islands (such as Lark Harbour and Wood Island Harbour) and Humber Arm.

3.2.3.14 Zone 14

1. Sheltered Areas

Large portions of this zone are exposed to rough water. The only shelter is within Bonne, Hawke's, St. Margaret's and St. Barb's Bays, and parts of Pistolet Bay.

Throughout the summer, the prevailing winds are from the west to southwest and during the winter they are from the west to northwest, hence a great deal of wind and wave action may be expected along this coastal zone. Topography modifies the effects of the winds. The Strait of Belle Isle causes a funnelling effect that results in winds blowing along the length of the strait in a northeast or southwest direction at what may be twice the speeds of winds over adjacent ocean or Gulf of St. Lawrence areas (Department of Fisheries and Oceans 1986). Since the prevailing winds are generally out of the west, the wave height along the west coast is generally the lowest along the coastal areas of Newfoundland (Figure 3.9).

Many of the bays that would afford shelter for aquaculture are shallow. St. Paul's Inlet, Parson's Pond, Portland Creek Pond, Castor's River, St. Margaret's Bay and St. Barbe are bays having maximum depths of less than 5 m. Bonne Bay is the only deep water, sheltered bay in Zone 14 with depths ranging from 15 to 126 m. Parts of Milan Arm in Pistolet Bay are approximately 6 m. Shoreline areas in Bonne Bay are very steep in some areas and anchoring would be difficult.

2. Currents and Water Exchange

The rate of flow in most of the open area of the Gulf of St. Lawrence rarely exceeds 1 knot. From Bay of Islands (49°13'N, 58°22'W) to Pointe Riche (50°42'N, 57°25'W), the current is somewhat constant with a rate of approximately 1 knot. It is stronger near the land than offshore and in the vicinity of bays and inlets is deflected by the inflow and outflow of tidal streams. Currents in the area are stronger than usual before a southwest wind and may slacken before a northeast wind. In the area from Pointe Riche to Eskimo Island (51°19'N, 57°43'W) and the southwest end of the Strait of Belle Isle, the currents are variable and uncertain. The currents through the Strait of Belle Isle are highly variable, mainly set by tides which may approach 3 knots in the west entrance. The strongest streams occur on the north side with diminishing rates toward the southern shore where rates do not usually exceed 2 knots. Under normal conditions, the currents in the western entrance of the Strait of Belle Isle, near the Labrador coast are 0.6 knots while the current is typically 0.7 knots over the rest of the channel (Department of Fisheries and Oceans 1986).

3. Ice Conditions

Much of the ice which affects Zone 14 is formed in the Gulf of St. Lawrence. Ice formation begins in the coastal waters of southern Labrador during December.

Formation along the west coast of Newfoundland is slow and it is not uncommon for the entire area from Cape Ray to Pointe Riche to be clear of ice in early February and the rest of the gulf to be covered with ice. The ice is predominantly 15 to 30 cm thick. Melting begins in the second half of March and by early April there is open water as far north as Bay of Islands. By the end of April, the ice has receded past Pointe Riche and by June much of the ice is gone in the Strait of Belle Isle. Although the depth of the Strait of Belle Isle is limited to approximately 55 m, occasionally small icebergs are able to move through the strait (Department of Fisheries and Oceans 1986).

4. Temperature

Average surface temperatures during the summer range from 15-16°C in the southern areas to 9-10°C in the northern areas (Figure 3.13). Very little subsurface water temperature data has been collected for this zone. The maximum temperature recorded is 16.3°C (Table 3.5). In Bonne Bay in 22 m of water, the maximum temperatures recorded have been 14-17°C.

5. Water Quality/Pollution

Along the coast in Zone 14, there are scattered small communities that produce sewage which is discharged into the Gulf of St. Lawrence with little or no treatment. There is potential for fecal coliform problems in these areas. Several of these coastal communities also have fish processing plants that often attract populations of scavenging sea birds which increase the coliform counts. White and Roberts (1989) conducted a bacteriological water quality survey and a sanitary survey for sources of pollution in growing areas within Hawkes Bay, Hawke Flat, Hawke Harbour and Port Saunders. The waters surrounding these sites were found to be acceptable.

There are no major manufacturing industries north of Corner Brook (Economy Research and Analysis Division 1989). At Daniel's Harbour, there is a zinc mine that may cause local contamination.

6. Potential Predators

Small colonies of eider ducks occur in the northern part of this zone (Cairns et al., 1986). Grey seals (Halichoerus grypus), hooded seals (Cystophora cristata) and harp seals (Phoca groenlandica) are found in this area. Large breeding grounds for hooded seals and harp seals occur off the northern part of the Northern Peninsula (Sergeant 1985).

7. Potential Siting Conflicts

Western Brook Pond has a charter boat service with two boats that make one or two runs down the lake each day. There is a scheduled ferry service across Bonne Bay from Woody Point to Norris Point and between St. Barbe and Labrador. Also, portions of Bonne Bay are adjacent to the shoreline boundary of Gros Morne National Park. Large fishing boat harbours are present in Rocky Harbour, and Port au Choix and many communities along the west coast have fish plants. Waterways leading to these facilities must be kept clear for boat access and related activities. There are cod, salmon, winter flounder and lobster fisheries along the west coast.

3.3 FRESHWATER BIOPHYSICAL CONDITIONS

3.3.1 Labrador

Water quality for selected lakes and rivers in Labrador are summarized in Table 3.7. The largest river system in Labrador is the Churchill River (flows range from approximately 253 m^3/sec to 6,820 m^3/sec) draining into Lake Melville. The water in this river and the other waterbodies for which data are available appears to be slightly acidic (mainly pH 6 - 7, though the Churchill River fluctuates between pH 5.5 and 7.5), and very low alkalinity.

Limited data on groundwater potential and quality are available for Labrador. Potential well yields in the Northwest River have been estimated to be approximately 500 litres per minute (K. Guzzwell, personal communication). Groundwater

TABLE 3.7: **SUMMARY OF SELECTED WATER QUALITY PARAMETERS FOR SELECTED LAKES AND RIVERS IN LABRADOR.**
(Sources: Inland Waters Directorate and Newfoundland Department of the Environment, 1982; Inland Waters/Lands Directorate 1987; Inland Waters Directorate and Newfoundland Department of the Environment 1988)

ZONE	NAME	DATES SAMPLED	COORDINATES	FLOW RATE (m3/sec)	pH (pH UNITS)	TURBIDITY JTU	ALKALINITY TOTAL (mg/L)	SULPHATE DISSOLVED TOTAL (mg/L)	OXYGEN DISSOLVED (mg/L)	COPPER EXTRACTABLE (mg/L)	ZINC EXTRACTABLE (mg/L)	CADMIUM EXTRACTABLE (mg/L)	MERCURY EXTRACTABLE (mg/L)	LEAD EXTRACTABLE (mg/L)
2	Caribou Lake (Naskaupi River)	July 5, 1980	N54°22'35", W62°12'29"	-	6.8	0.5	9.0	2.0	-	0.002	0.006	L0.001	-	L0.002
2	Churchill River at Muskrat Falls	12 dates 1980-1985	N53°15'29", W60°45'00"	253 (6820)	5.5 (7.5)	0.9 (31.0)	2.6 (7.6)	1.0 (2.6)	8.8 (14.0)	L0.002 (0.016)	L0.002 (0.030)	L0.001 (0.002)	L0.02 (0.05)	L0.002 (0.002)
2	Goose River	July 10, 1981	N53°22'30", W60°25'00"	-	6.5	3.4	2.8	2.1	-	L0.002	L0.002	L0.001	-	0.002
2	Gosling Lake	July 10, 1981	N53°25'00", W60°22'00"	-	6.3	6.8	3.5	6.9	-	0.002	0.004	L0.001	-	0.005
2	Grand Lake near Beaver River outlet	July 8, 1981	N53°46'00", W60°51'00"	-	6.7	3.0	3.5	3.7	-	0.002	0.005	L0.001	-	0.005

L = Less than.

temperatures in this area are approximately 4-6°C (G. Wilton, personal communication). Water quality records indicate the water is basic (pH 7.6 - 8.4) and has relatively high hardness (120 - 140 mg/L) and alkalinity (150 - 170 mg/L).

As indicated in Section 3.2.1, surface water in Lake Melville can reach 18°C, though deeper waters (below 100 meters) remain less than zero.

3.3.2 Island of Newfoundland

3.3.2.1 Groundwater

Within Newfoundland, there was no legislation prior to 1983 requiring the registration of water well drilling records. Therefore, there is a scarcity of good quality information concerning well depths, lithography and yield. Much of the available information is restricted to the Avalon Peninsula. However, Shawmont Newfoundland Ltd. (1979) conducted a thorough analysis of existing geological maps and reports, and aerial photographs in order to determine the quantities of available groundwater that could be expected at various sites around the island. This study indicated that portions of the west coast have the greatest potential for high yield wells of any formation on the island. The Atlantic Development Board (cited [IN]: Shawmont Newfoundland Ltd. 1979) indicates that yields exceeding 75 litres per second (4,500 litres per minute) may be obtained from wells that are drilled in, or near solution channels that have developed within limestone and dolomite beds along the west coast. This is in comparison with predicted yields of less than 0.75 litres per second (45 litres per minute) from wells that are drilled in other parts of the island.

3.3.2.2 Surface Water

The Water Quality Branch of Environment Canada and the Water Resources Division of the Department of Environment of the Government of Newfoundland and Labrador have been conducting a long-term study of the quality of surface waters. Records are kept of 50 variables which include temperatures, dissolved gases, hardness, pH and heavy metals. Unfortunately, not all of these variables are measured at each site. These data may be accessed through the computerized National Water Quality Data Bank (NAQUADAT) while data from between 1965 and 1980 is summarized in report form (Water Quality Branch and the Department of Environment 1982). Water quality for selected rivers and lakes is summarized in Tables 3.8 and 3.9, respectively.

These data indicate riverine temperature maxima that exceed 20°C at all stations. This exceeds the maximum acceptable temperatures for maintaining salmonids (this report). Cooler waters may be obtained from wells or from thermally stratified lakes during the summer. Lakes that are deeper than 15 m, generally have summer thermoclines. During winter, an abundant supply of 4°C water is usually necessary to maintain desirable salmonid growth rates, however, the limited data indicate that a hypolimnion zone may be absent in all but the deepest lakes. For example, Shawmont Newfoundland Ltd. (1983) notes that West Pond, Halls Bay may vary between 1°C and 2°C over its 29 m depth.

Water samples indicate low pH values (i.e., less than 6.5) and relatively soft water for most streams in Newfoundland (Water Quality Resources Branch and Department of Environment 1982).

Generally, the concentrations of copper, lead, zinc, calcium, magnesium and iron are within the limits of salmonid tolerance (Shawmont Newfoundland Ltd. 1979). Total iron estimates exceed 1 mg/L (the maximum acceptable level for the production of salmonids) at two locations along the Exploits River (Water Quality Resources Branch and Department of the Environment 1982).

3.3.3 Summary of Surface and Groundwater Conditions in Each Aquaculture Development Zone

3.3.3.1 Zones 1 and 2

Freshwater data were not reviewed further for Zone 1 based on the poor potential for aquaculture development. Serious logistic constraints exist and large volumes of heated water that might assist production are absent.

TABLE 3.8: SUMMARY OF WATER QUALITY FOR SELECTED RIVERS IN INSULAR NEWFOUNDLAND.
(Sources: Inland Waters Directorate and Newfoundland Department of the Environment, 1982; Inland Waters/Lands Directorate 1987; Inland Waters Directorate and Newfoundland Department of the Environment 1988)

ZONE	RIVER NAME	RIVER LOCATION	EXTREME MINIMUM DAILY FLOW RATE (m3/sec)	TURBIDITY JTU	pH (pH UNITS)	ALKALINITY TOTAL (mg/L)	HARDNESS TOTAL (mg/L)	SULPHATE DISSOLVED (mg/L)	OXYGEN DISSOLVED (mg/L)	COPPER EXTRACTABLE (mg/L)	ZINC EXTRACTABLE (mg/L)	CADMIUM EXTRACTABLE (mg/L)	MERCURY EXTRACTABLE (mg/L)	LEAD EXTRACTABLE (mg/L)
3	Beaver Brook near Roddickton	N50°54'51", W56°09'27"	0.161 (186)	L0.1 (2.7)	5.8 (7.9)	15.6 (54.9)	17.1 (61.4)	2.0 (17.0)	- -	L0.001 (0.02)	L0.001 (0.02)	L0.001 (0.005)	L0.05 (0.08)	L0.001 (0.012)
3	Cat Arm River at Lake Outlet	N50°04'33", W56°55'21"	- -	L0.1 (2.8)	4.6 (7.0)	L0.5 (3.1)	1.4 (6.8)	1.1 (7.0)	- -	L0.001 (0.020)	L0.001 (0.017)	L0.001 (0.002)	L0.05 (0.10)	L0.001 (0.012)
3	Indian Brook near Springdale	N49°30'00", W56°05'30"	- -	L0.1 (27.0)	5.3 (7.8)	3.4 (18.6)	7.3 (21.1)	1.6 (7.8)	9.1 (9.1)	L0.001 (0.17)	L0.001 (0.016)	L0.001 (L0.01)	L0.05 (0.16)	L0.001 (0.007)
4	Exploits River at Grandfalls	N48°55'50", W55°40'05"	80.6 (618.0) 11.8 (281.0)	L0.1 (7.0)	4.1 (8.2)	L0.5 (17.2)	2.8 (11.5)	1.3 (62.4)	8.5 (8.5)	L0.001 (0.160)	L0.002 (0.20)	L0.001 (L0.01)	L0.05 (0.24)	L0.002 (0.07)
4	Exploits River 22.5 km SW of Badger	N48°50'45", W56°16'00"	- -	0.4 (25.0)	5.1 (6.6)	L1.0 (4.6)	- -	2.8 (5.6)	- -	L0.1 (0.09)	0.06 (0.12)	- -	- -	L0.01 (0.06)
4	Exploits River at Windsor	N48°55'45", W55°42'30"	- -	L0.1 (14.5)	4.4 (6.7)	L1.0 (9.4)	- -	2.8 (5.9)	- -	L0.01 (0.71)	0.06 (0.12)	- -	- -	L0.01 (0.03)
4	Exploits River at Old Fox Farm	N48°58'30", W55°33'00"	- -	0.5 (15.0)	0.4 (6.8)	2.8 (17.3)	- -	2.6 (6.0)	- -	L0.01 (0.06)	0.02 (0.13)	- -	- -	L0.01 (0.03)
4	Exploits River near Bishops Falls at TCH Bridge	N49°01'15", W55°27'15"	- -	0.6 (25.0)	4.2 (7.2)	L0.5 (69.0)	3.5 (3.5)	2.6 (11.9)	- -	L0.01 (0.16)	0.014 (0.93)	L0.001 (0.001)	L0.05 (L0.05)	0.003 (0.07)
4	Exploits River at Badger	N48°58'24", W56°02'06"	- -	0.2 (2.2)	5.4 (6.4)	L1.0 (4.0)	- -	3.0 (4.0)	- -	L0.01 (0.01)	0.02 (0.06)	- -	- -	L0.01 (L0.01)
4	Gander River near Glenwood	N49°01'00", W54°51'00"	- -	L0.1 (5.4)	4.7 (8.4)	L0.5 (14.1)	1.6 (34.0)	L0.5 (15.5)	7.3 (9.2)	L0.001 (0.05)	L0.002 (0.03)	L0.001 (0.01)	L0.05 (0.15)	L0.001 (0.007)
4	Ragged Harbour River from Hwy. 330 near Musgrave Harbour	N49°23'47", W54°05'30"	0.084 (173.0)	0.1 (2.3)	5.3 (7.5)	0.8 (14.0)	5.0 (18.0)	1.0 (5.0)	6.0 (12.0)	Total L0.01 (L0.04)	Total 0.01 (0.25)	Total L0.01 (L0.01)	- - -	Total L0.01 (0.026)
5	Middle Brook from Hwy. 320 at Gambo	N48°48'22", W55°12'30"	- -	0.1 (3.2)	4.5 (6.5)	0.8 (5.0)	4.6 (6.8)	L1.0 (5.7)	6.2 (11.7)	Total L0.01 (0.06)	Total L0.00 (0.05)	Total L0.01 L0.01)	- - -	Total L0.01 (0.01)
5	Terra Nova River at Terra Nova	N48°30'25", W54°12'40"	- -	L0.1 (20.5)	4.5 (7.3)	L0.5 (5.3)	2.8 (19.8)	L1.0 (5.9)	8.8 (8.8)	L0.001 (0.09)	L0.001 (0.33)	L0.001 (0.001)	L0.05 (0.07)	L0.001 (0.007)
5	Southwest Brook from Hwy. 1 Terra Nova National Park	N48°36'16", W53°58'50"	0.040 (19.7)	0.2 (2.2)	5.0 (7.1)	L0.1 (12.2)	3.9 (14.3)	L1.0 (7.0)	3.2 (11.2)	Total L0.01 (0.96)	Total L0.00 (0.08)	Total L0.001 (L0.01)	- - -	Total L0.01 (0.021)
5	Southern Bay River from Hwy. 230 at Southern Bay	N48°22'45", W53°40'35"	L0.040 (26.5)	0.1 (11.0)	4.5 (7.0)	L1.0 (17.6)	5.6 (32.9)	L1.0 (300.0)	6.3 (15.1)	Total L0.01 (0.09)	Total L0.01 (0.09)	Total L0.01 (L0.01)	- - -	Total L0.01 (0.011)

TABLE 3.8: SUMMARY OF WATER QUALITY FOR SELECTED RIVERS IN INSULAR NEWFOUNDLAND.
(Sources: Inland Waters Directorate and Newfoundland Department of the Environment, 1982; Inland Waters/Lands Directorate 1987; Inland Waters Directorate and Newfoundland Department of the Environment 1988)

ZONE	RIVER NAME	RIVER LOCATION	EXTREME MINIMUM DAILY FLOW RATE (m3/sec)	TURBIDITY JTU	pH (pH UNITS)	ALKALINITY TOTAL (mg/L)	HARDNESS TOTAL (mg/L)	SULPHATE DISSOLVED (mg/L)	OXYGEN DISSOLVED (mg/L)	COPPER EXTRACTABLE (mg/L)	ZINC EXTRACTABLE (mg/L)	CADMIUM EXTRACTABLE (mg/L)	MERCURY EXTRACTABLE (mg/L)	LEAD EXTRACTABLE (mg/L)
7	Spont Cove BK from Hwy. 70 near Kingston	N47°48'45", W53°09'15"	0.007 (17.4)	0.1 (2.9)	4.8 (6.5)	0.4 (44.0)	3.6 (8.9)	L1.0 (6.4)	6.2 (11.5)	Total L0.01 (0.06)	Total 0.01 (0.07)	Total L0.01 (0.01)	- - -	Total L0.01 (0.19)
7	Heart's Content River from Hwy. 74 near Heart's Content	N47°50'45", W53°19'30"	- -	0.1 (3.2)	4.2 (5.8)	L0.1 (2.0)	2.3 (5.4)	1.9 (5.8)	6.1 (14.2)	Total L0.01 (L0.04)	Total L0.01 (0.73)	Total L0.01 (L0.01)	- - -	Total L0.01 (0.022)
8	Northeast Pond River near Portugal Cove	N47°38'06", W52°50'10"	- -	L0.1 (2.0)	3.9 (7.8)	0.4 (6.4)	3.6 (11.5)	L1.0 (7.0)	5.8 (9.3)	L0.001 (0.10)	L0.001 (0.25)	L0.001 (0.002)	L0.05 (0.13)	L0.001 (0.010)
8	Broad Cove Brook, St. Phillips	N47°34'15", W52°52' "	0.012 (20.9)	0.1 (7.4)	4.9 (6.5)	L0.1 (8.4)	5.6 (78.1)	1.1 (6.0)	6.0 (13.5)	Total L0.01 (0.04)	Total L0.01 (0.14)	Total L0.01 (0.02)	- - -	Total L0.01 (L0.13)
8	Mobile River, Mobile	N47°15'00", W52°51'00"	- -	0.1 (6.3)	4.5 (6.3)	0.2 (5.6)	3.9 (36.6)	L1.0 (6.0)	5.7 (16.6)	Total L0.01 (0.10)	Total L0.01 (4.42)	Total L0.01 (0.01)	- - -	Total L0.01 (L0.01)
9	Rocky River at Hwy. 6 Bridge at Colinet	N47°13'30", W53°34'06"	0.204 (348)	L0.1 (5.0)	3.6 (8.2)	0.0 (9.4)	2.8 (21.5)	1.6 (19.0)	10.2 (10.2)	L0.001 (0.07)	L0.001 (0.034)	L0.001 (L0.01)	L0.05 (0.90)	L0.001 (0.006)
9	Northwest Brook from Hwy. 10 at Trepassey	N46°45'33", W53°23'28"	- -	0.1 (2.8)	4.4 (8.0)	0.6 (36.0)	3.1 (8.9)	L1.0 (L5.0)	5.9 (15.2)	Total L0.01 (L0.02)	Total 0.01 (0.16)	Total L0.01 (0.01)	- - -	Total L0.01 (0.011)
10	Tides Brook Hwy. 222 Burin Peninsula	N47°07'40", W53°15'55"	- -	0.3 (4.8)	4.5 (8.9)	0.5 (19.0)	5.2 (12.1)	1.0 (7.5)	3.5 (13.1)	Total L0.01 (0.05)	Total L0.01 (0.23)	Total L0.01 (L0.01)	- - -	Total L0.01 (0.01)
10	Rattle Brook from Hwy. 210 near Boat Harbour, Burin Peninsula	N47°27'02", W54°51'16"	0.128 (37.7)	0.1 (5.6)	5.1 (6.3)	0.4 (22.2)	3.4 (8.7)	2.0 (L5.0)	6.1 (13.8)	Total L0.01 (0.10)	Total 0.00 (0.20)	Total L0.01 (L0.01)	- - -	Total L0.01 (0.01)
10	Garnish River near Garnish	N47°12'51", W55°19'45"	0.062 (144)	L0.1 (3.1)	4.8 (7.1)	0.0 (0.0)	3.1 (17.0)	1.1 (9.8)	6.5 (9.5)	L0.001 (0.024)	L0.001 (0.25)	L0.001 (0.01)	L0.05 (0.30)	L0.001 (0.010)
10	Piper's Hole at Mother's Brook	N47°55'36", W55°16'28"	0.083 (454)	L0.1 (44.0)	3.8 (7.5)	L0.5 (51.4)	3.0 (20.7)	L0.5 (11.0)	6.3 (9.1)	L0.001 (0.09)	L0.001 (0.06)	L0.001 (L0.002)	L0.05 (0.16)	L0.001 (0.012)
10	Paradise River near Terranceville at Hwy.	N47°44'15", W55°32'55"	- -	0.2 (3.0)	5.1 (7.0)	0.6 (30.8)	2.1 (11.2)	1.0 (5.0)	6.6 (13.8)	Total L0.01 (0.04)	Total L0.01 (0.04)	Total L0.01 (L0.01)	- - -	Total L0.01 (0.012)
10	Come-by-Chance River near Gambios	N47°55'06", W53°57'00"	0.051 (41.9)	L0.1 (6.3)	5.1 (7.2)	0.5 (8.8)	3.2 (14.6)	1.0 (8.0)	6.9 (8.4)	L0.001 (0.28)	L0.002 (0.079)	L0.001 (L0.01)	L0.05 (0.07)	L0.001 (0.012)
10	Northeast River from Hwy. 91 near Placentia	N47°16'25", W53°50'20"	0.265 (190)	0.3 (3.5)	5.4 (6.7)	0.4 (28.0)	5.0 (12.8)	2.0 (40.0)	5.8 (12.9)	Total L0.01 (L0.05)	Total 0.01 (0.05)	Total L0.01 (0.01)	- - -	Total L0.01 (0.017)
11	Buchans Brook SE of Buchans	N48°48'30", W56°47'00"	- -	1.0 (100.0)	3.9 (7.2)	L1.0 (6.6)	- -	5.5 (17.3)	- -	0.01 (0.10)	0.25 (1.30)	- -	- -	0.22 (1.80)

TABLE 3.8: **SUMMARY OF WATER QUALITY FOR SELECTED RIVERS IN INSULAR NEWFOUNDLAND.**
(Sources: Inland Waters Directorate and Newfoundland Department of the Environment, 1982; Inland Waters/Lands Directorate 1987; Inland Waters Directorate and Newfoundland Department of the Environment 1988)

ZONE	RIVER NAME	RIVER LOCATION	EXTREME MINIMUM DAILY FLOW RATE (m3/sec)	TUR-BIDITY JTU	pH (pH UNITS)	ALKAL-INITY TOTAL (mg/L)	HARD-NESS TOTAL (mg/L)	SULPHATE DISSOLVED (mg/L)	OXYGEN DISSOLVED (mg/L)	COPPER EXTRACT-ABLE (mg/L)	ZINC EXTRACT-ABLE (mg/L)	CADMIUM EXTRACT-ABLE (mg/L)	MERCURY EXTRACT-ABLE (mg/L)	LEAD EXTRACT-ABLE (mg/L)
11	Exploits River at Millertown	N48°45'05", W56°35'50"	- -	0.3 (30.0)	6.2 (6.6)	3.4 (5.1)	- -	3.3 (5.0)	- -	L0.01 (0.35)	0.02 (0.17)	- -	- -	0.01 (0.02)
11	Salmon River at at Long Pond	N47°56'39", W55°54'50"	3.11 ((402)	L0.1 (10.0)	4.3 (7.3)	L0.5 (31.5)	2.7 (33.3)	L1.0 (5.3)	- -	L0.001 (0.03)	L0.001 (0.15)	L0.001 (0.001)	L0.05 (0.13)	L0.001 (0.010)
12	Isle aux Morts River at Isleaux Morts	N47°36'51", W59°00'30"	0.343 (609)	L0.1 (3.0)	3.3 (7.0)	L0.5 (6.0)	1.6 (16.4)	- -	8.8 (8.8)	L0.001 (0.04)	L0.002 (0.05)	L0.001 (0.04)	L0.05 (0.21)	L0.001 (0.028)
13	Harry's River at Black Duck	N48°34'35", W58°21'50"	1.55 (688)	L0.1 (11.0)	6.7 (8.3)	19.8 (117.6)	24.7 (141.1)	L1.0 (17.0)	9.2 (9.2)	L0.001 (0.03)	L0.001 (0.02)	L0.001 (L0.01)	L0.05 (0.1)	L0.001 (0.010)
13	Upper Humber River near Reidville	N49°14'27", W57°21'40"	1.59 (1060)	0.1 (5.0)	4.6 (7.9)	2.3 (43.0)	3.6 (25.9)	1.6 (7.8)	9.0 (9.0)	L0.001 (0.014)	L0.001 (0.10)	L0.001 (L0.002)	L0.05 (0.1)	L0.001 (0.016)
14	St. Genevieve River near Forresters	N51°08'18", W56°47'30"	1.19 (64.6)	0.0 (1.8)	6.9 (8.2)	28.0 (89.0)	34.1 (108.9)	2.4 (8.0)	9.3 (9.3)	L0.001 (0.017)	L0.001 (0.08)	L0.001 (0.01)	L0.05 (0.06)	L0.002 (0.005)
14	Torrent River at Bistol's Pool Point	N50°36'27", W57°09'80"	1.98 (419)	L0.1 (3.1)	6.1 (7.7)	1.9 (50.8)	8.5 (68.4)	2.0 (12.0)	9.3 (9.3)	L0.001 (0.018)	L0.001 (0.10)	L0.001 (0.03)	L0.05 (0.15)	L0.001 (0.005)

TABLE 3.9: SUMMARY OF WATER QUALITY FOR SELECTED LAKES IN NEWFOUNDLAND.
(Sources: Inland Waters Directorate and Newfoundland Department of the Environment, 1982; Inland Waters/Lands Directorate 1987; Inland Waters Directorate and Newfoundland Department of the Environment 1988)

ZONE	RIVER NAME	DATES SAMPLED	RIVER LOCATION	pH (pH UNITS)	TURBIDITY JTU	ALKALINITY TOTAL (mg/L)	HARD-NESS TOTAL (mg/L)	SULPHATE DISSOLVED (mg/L)	COPPER EXTRACT-ABLE (mg/L)	ZINC EXTRACT-ABLE (mg/L)	CADMIUM EXTRACT-ABLE (mg/L)	MERCURY EXTRACT-ABLE (mg/L)	LEAD EXTRACT-ABLE (mg/L)
4	Deer Pond	Aug. 26, 1981	N48°31'18", W54°43'40"	6.3	0.3	2.1	-	35.0	0.002	0.006	L0.001	-	L0.002
4	Gander Lake at Gander	Nov. 11, 1980	N48°53'57", W54°46'00"	6.0	0.5	1.0	-	2.6	L0.002 (0.016)	L0.002 (0.030)	L0.001 (0.002)	L0.02 (0.05)	L0.002 (0.002)
4	Mark's Lake near South Outlet, Green Bay District	Nov. 8, 1980	N49°17'26", W55°49'55"	6.0	0.7	1.2	-	5.3	L0.002	L0.002	L0.001	-	0.002
7	Collier's Big Pond, Conception Bay	8 dates May-Nov., 1980	N47°24'00", W53°19'00"	5.7	0.5	0.7	4.0	1.0	0.002	0.004	L0.001	-	0.005
8	Soldier's Pond TCH near Butter Pot Provincial Park	7 dates May-Nov., 1980	N47°33'00", W52°40'59"	6.3 (6.2)	6.8 (1.3)	3.5 (1.5)	- (6.5)	6.9 (3.0)	0.002	0.005	L0.001	-	0.005
11	Red Indian Lake near Millertown	Aug. 23, 1980	N48°49'00", W56°33'00"	6.6 (6.7)	- -	3.8 -	- -	2.5 (2.4)	0.003 (0.007)	0.03 (0.04)	L0.001 (L0.001)	- -	0.005 (0.005)
11	Lloyd's Lake at Lloyd's River, West Grand Falls District		N48°21'50", W57°34'9"	6.6	0.4	3.4	-	2.5	-	-	-	-	-
11	Godaleich Pond at North End, Hermitage District	Nov. 7, 1980	N48°11'25", W56°07'50"	6.5	1.0	2.7	-	2.1	-	-	-	-	-
11	Gold Spring Pond at South End, Gurgeo and La Poile District	Nov. 7, 1980	N48°09'46", W56°19'00"	5.9	0.4	2.3	-	2.0	-	-	0.18	-	0.010
13	Corner Brook Lake at South Tip, Humber East District	Nov. 4, 1980	N48°48'20", W57°48'42"	6.7	0.2	6.2	-	2.5	-	-	-	-	-

Water quality data for lakes and rivers in Zone 2 are summarized in Table 3.7. These data are discussed in the text (Section 3.3.1) and are not discussed further in this appendix.

3.3.3.2 Zone 3

Stream flow and water quality data are summarized in Table 3.8 for three streams in this zone (Beaver Brook near Roddickton, Cat Arm River at Lake Outlet, and Indian Brook near Springdale). These data indicate Cat Arm River has low pH, alkalinity and hardness. Beaver Brook and Indian Brook also have low pH's but alkalinity and hardness is generally higher, particularly Beaver Brook.

Water temperatures in surface water bodies can be high at periods during the summer. For example, temperatures at 1 m depth in Indian Pond Lake (Baie Verte Peninsula) occasionally reach 25°C. Temperatures appear to average 17-19°C during July and August.

There are no recorded descriptions of springs in this zone. The northern peninsula contains the largest areas of carbonate rocks in the province (Nolan, White and Associates 1979; and Shawmont Newfoundland Ltd. 1979). Limestone solution cavities are found in some areas which affect surface water drainage patterns and it is believed that water producing zones could be found in fissures and/or these solution cavities. Yields of up to 182 L/min. may be expected from such bedrock aquifers (Nolan, White and Associates 1979).

In general, the carboniferous sediments along the western portion of the island are characterized by relatively high hardness and have a pH between 7.0 and 8.0. Concentrations of major ions are variable, and in cases where carboniferous evaporite deposits are encountered, high sulphates, hardness and chlorides may render the water unpotable. This is a common occurrence in the Carboniferous Codroy Group in the St. George's area in the south of Zone 14.

3.3.3.3 Zone 4

Water quality data are summarized in Table 3.8 for the Exploits River, the Gander River and Ragged Harbour River (near Musgrave Harbour) and in Table 3.9 for three lakes (Mark's Lake, South Outlet, Green Bay District; Deer Pond and Gander Lake at Gander). The river waters appear to be poorly buffered with relatively large changes in pH. Similarly, the lakes exhibit low pH and alkalinity. Surface temperatures can reach more than 20°C on some waterbodies in this zone. Water temperature on Salmon Brook (Glenwood) reached a maximum temperature of 25°C during August. Shawmont Newfoundland Ltd. 1979 indicate that the aquifer potential can be considered poor in this area. They also indicate that where available the groundwater generally will be characterized by low pH (5.0 - 7.0) and extremely low alkalinity and hardness, though areas having alkaline volcanic geology could have soft groundwater with higher pH (8.0).

3.3.3.4 Zone 5

Water quality data are summarized in Table 3.8 for four streams in this zone (Middle Brook at Gambo, Terra Nova River, Southwest Brook in Terra Nova National Park and Southern Bay River at Southern Bay). The pH, alkalinity and hardness values are low in all cases. The data indicate very low flows for Southwest Brook and Southern Bay River. Summer surface water temperatures can be very high in this area. Water temperatures recorded at 1m depths have exceeded 22°C at several locations along the Terra Nova River including the Terra Nova Fishway. At one location a temperature of 24°C was recorded at 2m depth. Temperatures greater than 25°C have been recorded at 1m depths on the Middle Brook Fishway near Gambo. Shawmont Newfoundland Ltd. 1979 indicate that the aquifer potential in this area is poor.

3.3.3.5 Zone 6

Surface flow, water quality and temperature data are not available for this zone. Shawmont Newfoundland Ltd. 1979 indicate that this area generally has a low aquifer potential and that groundwater quality will generally display low pH (5.0 - 7.0), alkalinity and hardness.

3.3.3.6 Zone 7

Water quality data for one lake in this zone (Collier's Pond) is shown in Table 3.9. These data indicate low pH, alkalinity and hardness. Stream flow and water quality data for two streams are shown in Table 3.8 (Spent Cove Brook and Heart's Content River). In both cases the pH is very low, and Spent Cove Brook has very low flow. Shawmont Newfoundland Ltd. 1979 indicate for the Avalon Peninsula that generally there is a low aquifer potential and that groundwater has low pH (5.0 - 7.0).

3.3.3.7 Zone 8

Stream flow and water quality for three streams are shown in Table 3.8 (Northeast Pond River near Portugal Cove, Broad Cove Brook at St. Phillips and Mobile River) and water quality for one pond is shown in Table 3.9 (Soldier's Pond near Butter Pot). The pH is low in all cases. However, water hardness appears to be high in Broad Cove Brook and the Mobile River compared to other streams.

3.3.3.8 Zone 9

Stream flow and water quality data for two streams are shown in Table 3.8 (Rocky River at Colinet and Northwest Brook at Trepassey). The pH in these streams appears to fluctuate greatly (from approximately pH 4.0 to pH 8.0) indicating an unstable buffering ability. Surface water temperatures have lower maxima compared to streams in other areas, but at times have been close to 20°C. Maximum summer temperatures are:

- Upper Freshwater River 18.9°C;
- Lower Northeast River 19.6°C;
- Upper Northeast River 16.8°C;
- Northeast River 19.8°C; and
- Drook Brook 15.5°C.

3.3.3.9 Zone 10

Stream flow and water quality data for seven streams is summarized in Table 3.8 (Tides Brook and Rattle Brook on the Burin Peninsula, Garnish River near Garnish, Pipers Hole at Matheris Brook, Paradise River at Terrenceville, Come-by-Chance River and Northeast River near Placentia). All streams have periodically low pH and in some cases large fluctuations between low and high levels. Similarly, alkalinity and hardness at times are very low. The Garnish River, Pipers Hole and Come-by-Chance have periodically low flows.

Surface water temperatures greater than 22°C have been recorded in one river in this zone (Northeast River, Placentia Bay) and have exceeded 25°C at the fishway in Grand Bank.

3.3.3.10 Zone 11

Stream flow and water quality data for three streams are shown in Table 3.8 (Buchans Brook near Buchans, Exploits River at Millertown and the Salmon River at Long Pond). Water quality data for four lakes are shown in Table 3.9 (Red Indian Lake near Millertown, Lloyd's Lake at Lloyd's River, Godaleich Pond at North End, Cold Spring Pond at South End). The pH in Buchan's Brook and the Salmon River indicates periodically low levels (pH 4.0–4.5). The pH at the Exploits River is higher, but the low alkalinity levels suggest lower pH levels can be expected periodically. For most lakes, the pH is low. The pH is also relatively high for Red Indian Lake and Lloyd's Lake compared to other lakes. Summer surface temperatures have exceeded 22°C in the Conne River. Further inland, in Headwater Pond, the temperatures have exceeded 24°C.

3.3.3.11 Zone 12

Stream flow and water quality data for the Isle aux Morts River are shown in Table 3.8. These data indicate adequate flows, but pH levels that periodically drop very low (pH 3.3).

3.3.3.12 Zone 13

Stream flow and water quality data for two streams (Harry's River at Black Duck and Upper Humber River near Reidville) are shown in Table 3.8 and water quality data for Corner Brook Lake are shown in Table 3.9. The pH for Harry's River is within acceptable limits for salmonid culture and the alkalinity and hardness is relatively high. The pH for Corner Brook Lake is also relatively high (pH 6.7). The pH for the Humber River periodically drops below 5.0.

3.3.3.13 Zone 14

Stream flow and water quality data for two streams (St. Genevieve River near Forrester's and Torrent River at Bristol's Pool Point) are shown in Table 3.8. The pH is relatively high for these streams, particularly for St. Genevieve River, but is within acceptable limits for salmonid culture.

As described for Zone 3, the northern peninsula contains the largest areas of carbonate rocks in the province (Nolan, White and Associates 1979; and Shawmont Newfoundland Ltd. 1979) and it is possible yields of up to 182 Litres per minute may be obtained from limestone bedrock aquifers (Nolan, White and Associates 1979).

3.4 LITERATURE CITED IN SECTION 3.0

Arklie, A. 1989.
Provincial Department of Transportation, Manager. Personal communication.

Beck, B. 1983.
The grey seal in eastern Canada. Underwater World. Department of Fisheries and Oceans. Ottawa. 8 pp.

Bowen, W.D. 1985.
The harp seal. Underwater World. Department of Fisheries and Oceans. Ottawa, 8 pp.

Brown, R.G.B. 1979.
Reports on 1978 surveys of seabirds in Labrador, Canadian Wildlife Service. 87pp.

Buchanan, R.A., and M.G. Foy. 1980.
Offshore Labrador studies, plankton, nutrients, chlorphyll, phytoplankton and ichthyoplankton. Atlantic Biological Services Ltd. 293pp.

Cairns, D.K., R.D. Elliot, W. Threlfall and W.A. Montevecchi. 1986.
Researcher's guide to Newfoundland seabird colonies. Memorial University of Newfoundland Occasional Papers in Biology. No. 10. Memorial University of Newfoundland. St. John's, Newfoundland. 50 pp.

Cook, R.H., F. Sander and R.E. Drinnan (no date given).
Atlantic marine water resources: their utilization and potential for aquaculture. Fisheries and Environmental Sciences, Biological Sciences Branch, Scotia-Fundy Region. Internal Report. 59 p.

Davidson, L.W. 1985.
The ice climatology of the Newfoundland bays. Prepared for: Department of Development and Tourism, Physical Planning Specialty Team, Government of Newfoundland and Labrador. Seaconsult Ltd. St. John's, Newfoundland. 301 pp.

Department of Development and Tourism. 1987.
Fish products of Newfoundland and Labrador. Department of Development and Tourism of the Newfoundland and Labrador Provincial Government. 54pp.

Department of Fisheries and Oceans. 1986.
Sailing directions. Newfoundland. Eighth Edition. Department of Fisheries and Oceans. Ottawa. 436 pp.

Department of Fisheries and Oceans. 1988a.
Sailing directions: Labrador and Hudson Bay. Sixth edition. Department of Fisheries and Oceans, Ottawa. 458p.

Department of Fisheries and Oceans. 1988b.
Canadian tide and current tables 1989. Volume I. Atlantic coast and Bay of Fundy. 50p.

Diebel, D. 1989.
Scientist, Marine Sciences Research Laboratory, Memorial University of Newfoundland. Personal communication.

Dobson, D., B. Petrie and S. Butlers. 1981.
Temperature records from Newfoundland 1967-1978. Bedford Institute of Oceanography, Dartmouth, Nova Scotia. (No page count given.)

Dobson, D., and B. Petrie. 1982.
Long-term temperature monitoring program 1981. Bedford Institute of Oceanography, Dartmouth, Nova Scotia. 297p.

Dobson, D., and B. Petrie. 1983.
Long-term temperature monitoring program 1982, Newfoundland Region. Bedford Institute of Oceanography, Darmouth, Nova Scotia. 335p.

Dobson, D. and B. Petrie. 1984.
Long-term temperature monitoring program 1983, Newfoundland Region. Canadian Data Report of Hydrography and Ocean Sciences. No. 21. Bedford Institute of Oceanography. Dartmouth, Nova Scotia. 411 pp.

Dobson, D., B. Petrie, and P. Stead. 1985.
Long-term temperature monitoring program 1984, Newfoundland Region. Canadian Data Report of Hydrography and Ocean Sciences. No. 34. Bedford Institute of Oceanography. Dartmouth, Nova Scotia. 333 pp.

Economic Research and Analysis Division. 1989.
The economy 1988. Cabinet Secretariat, Executive Council of the Provincial Government of Newfoundland and Labrador. St. John's, Newfoundland. 200 pp.

Frecker, M.F.P. 1972.
A comparative study of the phytoplankton populations of polluted St. John's Harbour and unpolluted Aquaforte Harbour, with emphasis on eutrophication. MSc Thesis. Biology Department. Memorial University of Newfoundland. St. John's, Newfoundland. 178 pp.

Gregory, D.N., E. Verge, D. Dobson and C. Smith. 1988.
Long-term temperature monitoring program 1987 Scotia-Fundy, Gulf of St. Lawrence and Newfoundland. Canadian Data Report of Hydrography and Ocean Sciences. No. 65. Bedford Institute of Oceanography. Dartmouth, Nova Scotia. 497 pp.

Guzzwell, K. 1989.
Groundwater Branch, Newfoundland Department of the Environment, St. John's.

Inland Waters Directorate and Newfoundland Department of Environment. 1982.
Water quality data Newfoundland 1965-1980. Environment Canada. Ottawa. Government of Newfoundland and Labrador. St. John's, Newfoundland. 147 pp.

Inland Waters Directorate and Newfoundland Department of Environment. 1988.
Water quality data Newfoundland 1981-1988. Environment Canada. Ottawa. Government of Newfoundland and Labrador. St. John's, Newfoundland. 462 pp.

Inland Waters/Lands Directorate. 1987.
Historical streamflow summary Atlantic provinces to 1986. Environment Canada. Ottawa. 260 pp.

Lackey, J.B. and W.E. Lackey. 1970.
A late summer checklist of the marine microbiota around Logy Bay, Newfoundland. Can. J. Zool. 48:789-795 pp.

Lin, Y.H. 1972.
An annual cycle of phytoplankton, with special reference to the diatoms and armoured dinoflagellates, at Logy and Robin Hood Bays, Avalon Peninsula, Newfoundland, February 1970 - January 1971. MSc Thesis. Biology Department, Memorial University of Newfoundland. St. John's, Newfoundland. 142 pp.

MacLaren Atlantic Ltd. 1977.
Report on biological literature review of the Labrador Sea Region for Imperial Oil Ltd., Aquitaie Co. of Canada, Canada Cities Services Ltd., and Arctic Mac Laren Atlantic Lt. Moncton. 95pp.

Macpherson, A.G. and J.B. Macpherson. 1981.
The natural environment of Newfoundland, past and present. Memorial University of Newfoundland, Canada. Memorial University Printing Services. 265 pp.

Markham, W.E. 1980.
Ice atlas. Eastern Canadian Seaboard. Atmospheric Environment Services. Environment Canada. Toronto. 96p.

Mercer, D.J. 1986.
Population: 1981 (Map) Geography Department, Memorial University of Newfoundland. St. John's Newfoundland.

Mills, T. 1989.
Mussel Farmer. Botwood. Personal communication.

Moskovitz, G. 1989.
Scientist, Marine Sciences Research Laboratory, Memorial University of Newfoundland. Personal communication.

Newfoundland and Labrador Hydro Limited (unpublished data)

Newfoundland Department of Fisheries (unpublished data)

Noland, White and Associates. 1979.
Hydrogeology of the Great Northern Peninsula. Prepared for Newfoundland Department of Consumer Affairs and Environment, Water Resources Branch. Water Resources Report 2-1 Groundwater Series.

Owens, E.H., and E.R. White. 1982.
Spill response manual for the coast of Northeast Newfoundland. Woodward-Clyde Consultants, Victoria, B.C. 90 p.

Pauley, K.E. 1986.
Carbon uptake and turnover rates of phytoplankton in Newfoundland coastal waters. MSc Thesis. Biology Department, Memorial University of Newfoundland. St. John's, Newfoundland. 95 pp.

Pitt, T.K. 1984.
Winter flounder. Underwater World. Department of Fisheries and Oceans. Ottawa. 3 pp.

Pomeroy, L.R. and D. Diebel. 1986.
Temperature regulation of bacterial activity during the spring bloom in Newfoundland coastal waters. Science 233:359-361p.

Power, B. 1989.
District Director, Environmental Protection Service, Environment Canada, St. John's, Newfoundland. Personal communication.

Roberts, J.
Environmental Quality Officer, Conservation and Protection Branch, Environment Canada, St. John's, Newfoundland.

Ryan, P. 1989.
Biologist, Canadian Wildlife Service, St. John's. Personal communication.

Seaconsult. 1985.
B.P. Resources Canada Limited. East coast project contingency plan. Volume II: physical environment description and oil spill trajectories. Volume III: environmental sensitivities and oil spill counter measures. St. John's, Newfoundland (no pages given).

Sergeant, D.E. 1985.
The hooded seal. Underwater World. Department of Fisheries and Oceans. Ottawa. 6 pp.

Shawmont Newfoundland Ltd. 1979.
Feasibility and site selection study for a multi-purpose fish rearing facility on the island of Newfoundland. Volume one - site selection. Prepared for Fisheries and Environment Canada, St. John's, Newfoundland. Report No. SMR-4-79 St. John's Newfoundland. 265p.

Steele, D.H. 1983.
Chapter 11. Marine ecology and zoogeography. [IN]: South, G.R. (Ed.) Biogeography of the island of Newfoundland. Dr. W. Junk Publisheres. The Hague, the Netherlands. pp 421-466.

Sutterlin, A.M. 1988.
The feasibility of using cooling water from the Roddickton Generating Plant for aquaculture. Submitted to the Great Northern Peninsula Development Corporation, Plum Point, Newfoundland.

Thompson, R.J., and D.A. Aggett. 1981.
A biological and oceanographic description of the Labrador Sea region. Marine Science Research Laboratory. Memorial Unversity of Newfoundland. St. John's, Newfoundland. 138pp.

U.S. Navy. 1986.
Sea ice climate atlas. Volume II Arctic east. NAVAIR 50-IC-541. Naval Oceanography Command Detachment. Ashville. 145 p.

Walker, R.E., D. Dobson, and P. Stead. 1986.
Long-term temperature monitoring program 1985: Scotia-Fundy, Gulf of St. Lawrence, and Newfoundland. Canadian Data Report of Hydrography and Ocean Sciences. No. 49. Bedford Institute of Oceanography. Dartmouth, Nova Scotia. 521 pp.

Walker, R.E., D. Dobson and P. Stead. 1987.
Long-term temperature monitoring program 1986, Scotia-Fundy, Gulf of St. Lawrence and Newfoundland. Bedford Institute of Oceanography, Dartmouth, Nova Scotia. 529p.

Water Quality Branch and Department of Environment. 1982.
Water quality data, Newfoundland 1965-1980. Department of Environment, Water Resources Division. St. John's, Newfoundland. Inland Waters Directorate, Atlantic Region, Water Quality Branch. Ottawa. 147p.

White, D. 1989.
Director, Inspections Services Branch, Department of Fisheries and Oceans, St. John's, Newfoundland. Personal communication.

White, D.R.L., and A.W. White. 1985.
First report of paralytic shellfish poisoning in Newfoundland. 511-516 pp. [IN]: Anderson, White and Badden (Eds.). Toxic Dinoflagellates. Elsevier Science Publishing Co. New York.

White, D. and J. Roberts. 1989.
Approved and contaminated locations: bivalve molluscan shellfish growing and harvesting areas, Province of Newfoundland. Department of Fisheries and Oceans. St. John's, Newfoundland. 40 pp.

Wilton, G. 1989.
Researcher for Arctic char culture project, Cain Corporation, Labrador. Personal communication.

APPENDIX A

SALMONID SPECIES

APPENDIX A - SALMONID SPECIES

TABLE OF CONTENTS

A.0 SALMONID SPECIES

A.1 ATLANTIC SALMON (SALMO SALAR)

A.1.1 State of Culture Technology

A.1.1.1 Status of Development in Newfoundland

Atlantic salmon culture is currently being undertaken at several locations in Newfoundland:

- in a large, freshwater hatchery at Bay D'Espoir, utilizing waste heat from a hydroelectric power plant;
- in commercial saltwater sea cages in Roti Bay near Bay D'Espoir; and
- in a pilot landbased pump ashore facility at Holyrood Pond.

Culture is also being undertaken on a smaller scale as part of regional enhancement projects. The potential for salmon culture has been investigated for several industrial waste heat sources (Sutterlin 1988), for nearshore marine areas (Marine Sciences Research Laboratory 1980; Dobrocky Seatech 1986; Dobrocky Seatech 1982; Scarth 1977) and for freshwater areas (Shawmont Newfoundland Ltd. 1979). Existing facilities are reviewed briefly below.

1. Bay D'Espoir Hatchery and Growout Facilities

The Bay D'Espoir hatchery can produce 200,000-250,000 Atlantic smolts and expansion is possible (Sutterlin, personal communication). Other species (rainbow trout and Arctic char) are being grown at the facility. The hatchery utilizes waste heat from seven turbine generators at the Bay D'Espoir hydroelectric facility, allowing selection of heating options for different fish developmental stages (Sutterlin 1981).

Roti Bay is a relatively small, protected bay (2.5 km x 0.4 km) containing 11 designated netpen sites (Watkins, personal communication). In 1988, four sites were occupied; three by commercial producers and one by the provincial Department of Fisheries. The bay has depths of close to 40 m, with three sills across the width creating sub-basins. In winter, maximum ice thickness is up to 1 m. The ice tends to insulate the water below, preventing winter chilling, and provides relatively easy access to the pens by snow mobile. Potential grow-out locations in the vicinity of Roti Bay are being monitored for future usage.

2. Holyrood Pond

A small landbased test facility is located on the shore of Holyrood Pond. Water is pumped from two depths (10 m and 30 m), for seasonal temperature control, to supply one indoor tank and one outdoor tank (M. St. Croix, personal communication). Attempts to raise fish in netpens over winter at this location were not successful. Given the thermal conditions that exist in the pond (i.e., relatively warm, 3-4°C, temperatures that persist at depth over winter), considerable interest exists for developing a commercial landbased facility.

3. Regional Enhancement Projects

Salmon enhancement projects have been undertaken on a variety of Newfoundland streams (e.g., Salmonier, Terra Nova, Exploits and Conne Rivers and at Black Brook). The projects have included construction and operation of spawning channels, stream-side incubators, stream and lake stocking, and experiments with fry held in rearing channels and floating lake cages (Pepper, personal communication; and Pepper et al. 1987). The potential for holding and reconditioning Atlantic salmon kelts as either broodstock or food fish has been investigated (Crim, personal communication; and Pepper and Parsons 1987). A comprehensive salmon resource development plan for stock enhancement has been prepared (Pratt 1984).

A.1.1.2 Production Options

Salmon can be cultured throughout their life cycle (farming) or can be cultured for the freshwater portion only of their life cycle, after which they can be released for migration to ocean-feeding grounds (ranching).

1. Salmon Farming

Salmon farming normally is comprised of a freshwater component, for smolt production and a saltwater component to grow the smolts out to market size (aspects are well described in general references such as Sedgewick 1988 and Edwards 1978). A single farm operator might possess a smolt production facility or an adult growout facility, or might own and operate both facilities. The decisions for developing a facility at a particular site include biophysical conditions for fish growth and facility operations and, to the extent possible, proximity to growout locations (in the case of smolt production) or to the smolt hatchery (in the case of the growout facility). The siting decisions for a smolt production facility to supply farms can differ from those for a smolt production facility to support ranching activities, as outlined below. Adult growout is undertaken most commonly in marine cage facilities, but also in marine landbased facilities and, more recently, in freshwater.

2. Salmon Ranching

Ranching can be undertaken utilizing natural stocks or can involve introducing new species or stocks to a potential growing area (Thorpe 1980; McNeil and Bailey 1975). For example, attempts were made in the 1950's and 1960's to transplant Pacific pink salmon to the Avalon Peninsula (Lear 1980) and have recently been considered as part of the general salmon resource development strategy for Newfoundland (Pratt 1984). Salmon ranching is undertaken both as public activities to supply fish for wild capture in commercial and recreational fisheries, and as private commercial ventures whereby the grower harvests all salmon upon their return. In either case, the objective of ranching is normally to provide facilities during early life history stages to improve fish survivals prior to their migration to the sea. Ranching usually involves development of hatchery facilities for egg incubation and/or smolt rearing and for capture of returning adults. In concept, the actual components and functioning of such a facility can vary greatly, from simple streamside egg incubators (whereby fry move directly to a stream after emerging from the incubator) to facilities that include egg incubation, adult holding and growing parr for release as smolts.

These separate components (juvenile production, juvenile release, adult recapture, and adult holding) do not necessarily have to occur at the same location. For example, adult holding and final smolt growout can take place in estuarine netpens.

The basic biophysical siting requirements for a commercial ranching operation are similar for the egg and smolt components of a salmon farm. Differences could include a higher freshwater volume requirement, since more smolts are likely required given the lower marine survival amongst ranched fish, and a trapping or capture facility for returning adult fish. However, a critical siting requirement for private ranching, but not farmed smolt production, is the manageability of fisheries that might intercept the returning fish. Ideally, a ranching facility will be located in a coastal area where there is no fishing activity and commercial fishing is not expected to develop. A minimum requirement is that nearby fishing effort will result in negligible capture of returning salmon. If nearby fishing effort is relatively large, some form of area or seasonal control would be required to assure the operator of a satisfactory return. This is normally difficult in most areas given the common property nature of wild fisheries resources and the establishment of traditional or historical fishing activity. One option, of course, is to allow only the traditional fisheries groups to develop a ranching operation within their region.

A.1.1.3 Culture Methods

As described above, salmon culture normally involves a freshwater, smolt production component, and/or a saltwater, growout to harvest component. Important facility features for freshwater production and saltwater production, additional facility design considerations and biological management considerations, are outlined in this subsection.

1. Freshwater Production

Freshwater production technology for salmonids is relatively well established compared to seawater culture and descriptions are provided in a number of general references (e.g., Huet 1986; Piper et al.; and Leitritz and Lewis 1981). Basically, a commercial freshwater production facility incorporates:

- an incubation area;
- early fry rearing units;
- smolt grow-out units;
- an office/lab area; and
- a feed and equipment storage area.

Usually these components are located on the same site but occasionally not. For example, the water volume requirements for incubation are small relative to the requirements of the parr and smolts. Consequently, a low-volume water supply with proper temperature and water quality characteristics might be utilized for the egg incubation/early fry rearing while a different water supply is used for the larger fish. Also, smolt are usually produced in tanks or raceways but other concepts for smolt rearing include the use of lake netpens (as indicated above) and floating rearing units. Netpens can be placed in lakes for rearing smolts, where proper conditions exist (in particular, optimum temperatures, high oxygen levels and no plankton blooms; Sedgewick 1988). Floating freshwater raceways or rearing units have been considered where site conditions have not allowed placement of structures on shore (at least, at a reasonable cost; Myrseth 1988). These might be located in lakes or in coastal bays. Water is either taken from a shore source such as a stream or is pumped from a lake to supply the floating plastic-lined rearing units. Similar structures, on a much larger scale have been proposed for adult grow-out in seawater.

In general, major considerations for siting a freshwater facility are:

- adequate quantity of good quality water;
- suitable terrain conditions for construction;
- good road access;
- hydroelectric power and telephone communications; and
- an effluent discharge location that will not have discharge permit problems.

An adequate supply of good quality water is an essential site prerequisite, however, both water volume and quality requirements can be altered using techniques to reuse heat and oxygenate the water and manipulate the quality of the water (Allen and Kinney 1981). These are outlined below in subsection 3 (Facility Design Considerations).

2. Seawater Production

Seawater salmon farm facilities include floating containment units (netpens with flexible or rigid mesh), cage enclosures attached to the sea bottom and land-based grow-out tanks utilizing pumped seawater (Sedgewick 1988; Edwards 1978; and Beveridge 1987).

The most common salmon production units utilize floating netpens with flexible mesh, normally capable of withstanding 0.5 m to 1.5 m extreme wave heights. These units are basically comprised of a floating collar anchored to the sea bottom or, where conditions permit, to the shore. Nets to contain the fish are suspended from the collar. When choosing a site for netpen culture (or for choosing a netpen design to suit a particular site), non-biological factors to be considered include:

- protection from wind, waves and swells;
- currents;
- depths;
- access;
- support logistics;
- siting conflicts; and
- shore requirements.

The bottom-type must also be examined if grabbing-type anchors are used, though these are not common. For floating netpen operations, a landbased or floating work area and storage area for feed and equipment are normally constructed.

Most netpens in current use are designed for relatively protected bay and island areas. Some netpen systems have been designed for more exposed conditions, including open, deepwater areas (e.g., Seacon, Bridgestone, Farm Ocean, Ewos, Aquasystem; Myrseth 1988; Svealv 1988). Obviously, such systems should be considered only if good growing conditions exist offshore and suitable nearshore areas are not available. Submersible cages for salmon culture are also being experimented with to avoid undesirable surface conditions (Murphy 1987; and Beveridge 1987).

At a number of locations in Europe, North America and Iceland, large tanks have been constructed in marine shoreline areas for growing-out adult fish. These facilities pump seawater and often incorporate a combination of supplemental heat, recirculation and oxygenation. In concept, the facilities offer a high degree of control for biological and operational conditions (Anderson 1988), including factors that seriously affect siting of netpens (wind, waves and swells, currents, depths and physical conflict with other marine user groups). However, the capital costs are very high compared to conventional netpen facilities.

3. Facility Design Considerations

A variety of facility design technologies exist by which marginal features at a site can be made suitable (e.g., Allen and Kinney 1981; Wheaton 1985), including water reuse, water heating or cooling, oxygenation, and water quality control (refer to Table 2.5).

Water Reuse

Water reuse can involve using the same water in a series of fish containing units, or can involve recirculating water through part or all of a facility (Piper *et al.* 1982). The use of recirculated water is currently applied in both freshwater and saltwater land-based facilities. In concept, 80-95% of a facility's water supply can be recycled if only a small quantity of good quality water is available or if the water is to be heated. This means only 5-15% of the facility's water volume needs are required from outside. Generally, a recirculation system might incorporate (Bruin *et al.* 1981; Sutterlin *et al.* 1984; and Piper *et al.* 1982):

- a settling system or filter for removing solid waste;
- a filter for removing nitrogen compounds;
- a system to oxygenate the water before reuse; and
- a sterilizing unit to kill pathogens.

Recirculating, independent rearing tanks are now being developed and marketed.

Heating

Water that is cooler than the optimum desired at a given facility can be heated by direct heating or by alternate means, such as using waste heat from an industrial source (e.g., Glude 1978) or using heat pumps and/or exchangers where heat is available in a natural but poor quality water body (e.g., Sutterlin 1981; and Kjolseth 1981). Similarly, water that is too warm can be cooled. Heating or cooling might be applied to the entire facility water supply or only the supply for one component (e.g., egg incubation).

Oxygenation

When oxygen levels are low (a common problem with groundwater sources or when water is reused in a facility), oxygen content can be increased by a variety of methods (Colt and Tchobanoglous 1981; and Sowerbutts and Forster 1981). These range from gravity-flow tower aerators to mechanical aerators or blowers, to oxygen injection systems.

Water Quality Control

Water quality management might be required at a given site to improve the quality of incoming water, quality of discharge water and/or the quality of water reused within the facility. Water quality control might include (Piper et al. 1982):

- removal of solid material;
- removal or addition of dissolved material; and
- sterilization.

Solid material normally is removed by sedimentation (for larger particles) or filtering (for finer particles). Dissolved material, such as ammonia products, can be removed by bacteria biofilters or special filtering media (such as clinoptilolite clays) while other materials, such as calcium carbonate, might be added to increase the alkalinity and pH. If serious pathogens are known or thought to occur in a water supply or within the facility, water can be sterilized mechanically with ultraviolet light or chemically (e.g., ozone or chlorine treatment; Dupree 1981).

4. Biological Management Considerations

The technical viability of salmonid production facilities can be strongly influenced by the types of biological manipulation performed. The implications for Newfoundland are discussed in Volume II. Methods for control and improved management of salmonid reproduction and productivity are wide ranging and include stock and genetic selection, storage of gametes, changing the sex, manipulating the timing of reproduction, elimination of reproduction by sterilization procedures, hormone treatment, hybridization and transgenics. Two recent reviews describe these techniques in detail (Crim and Glebe 1988; Donaldson 1988). Of particular relevance to salmonid aquaculture development in Newfoundland are those techniques which prevent reproduction to insure conservation of local stock genetic integrity and which enhance productivity of cultured strains. These procedures fall into the following categories:

a) Genetics

- Stock Selection - the genetic stock yielding the greatest return on investment through low production costs and high marketability.
- Breeding - concentration of favourable genes associated with production traits.
- Triploidy - manipulation of chromozome number to control sexual development and limit introgression of genes from aquaculture escapement.
- Monosex Populations - use of salmonid heterogameity to produce all female populations for enhancing productivity. Also associated with triploid production.
- Hybridization - combining favourable traits from different parental species or strains.
- Transgenics - the introduction of foreign DNA into the egg/embro followed by genomic incorporation and possible expression.

b) Physiological

- Sterilization - destruction of reproductive tissues.
- Environmental Control of Reproduction - change of environmental cues to regulate spawning times.

- Manipulation of Smoltification and Time of Seawater Entry - involves photoperiod control, acclimation.
- Gamete Storage - includes cryopreservation of sperm and eggs for prolonged preservation of genetic material.
- Hormone Treatment - induced spawning using hormone or hormone analogues and steroid use for accelerating growth.

These are outlined briefly below.

a) Genetics

Stock Selection

Genetically distinct wild stocks of Atlantic salmon exhibit considerable variation in production traits such as growth rates and grilsing rates (Glebe et al. 1979; Saunders et al. 1983; Glebe and Saunders 1986). Even sub-populations within stocks, such as early and late-run components, appear to perform differently under marine cage culture conditions (Bailey 1988). Evaluation of local or intended culture stocks under the expected culture conditions is critical and given the state of development elsewhere (e.g., Norway and Scotland) delays will result in a less competitive and profitable position in regional and international markets.

Breeding

Selection has already led to major improvements in production characteristics for Atlantic salmon. The growth rate of this species has been improved by up to 7.7 %/year (Gjerde 1986). Other important characteristics which can be improved by genetic selection include age at maturity and flesh colour. New Brunswick has an established breeding program involving the New Brunswick Salmon Growers Association, Department of Fisheries and Oceans, and the Salmon Genetics Research Program. Similarly, the Department of Fisheries and Oceans, provincial Department of Fisheries and several integrated smolt producers/sea cage operators in Nova Scotia have initiated a stock evaluation and breeding program. Genetic improvement is required if a competitive position is to be established in light of the improvement in Norwegian cultured strains.

Triploidy

Chromosome set manipulation appears to have application for production of reproductively sterile salmonids. Of the various techniques (Crim and Glebe 1988), induced triploidy offers the most practical means to prevent maturation and its deleterious side effects such as reduced flesh quality and reduced growth. Similarly, this technique would eliminate concern over the introgression of genes from introduced stock into indigenous populations. The techniques are not as effective in Atlantic salmon in producing all sterile fish compared to treatments to rainbow trout (Sutterlin et al. 1987). Also, all triploid salmonids appear not to be as vigorous as their diploid conspecifics and triploid hybrids tend to show developmental abnormalities (Benfey and Donaldson 1988). As discussed in Volume II of the present study, until more reliable techniques for inducing triploidy in Atlantic salmon are developed, the chance of genetic introgression by introduced stocks is reduced by using chromosome manipulation techniques but not eliminated.

Monosex Populations

Monosex salmonid populations can be produced by direct administration of sex steroids or indirectly by fertilizing eggs with milt from sex reversed females (reviewed by Piferrer and Donaldson 1988). The latter is the generally accepted procedure due to the stigma (public) associated with direct steroid application. Currently 30% of all chinook reared in B.C. sea pens are monosex female produced by the indirect method (Donaldson, personal communication). Monosex female chinook have a reduced "jack" or early maturing component compared to mixed sex populations. This technique may have applicability to culturing Atlantic salmon grilse populations. However, at the present time, monosex Atlantic salmon milt is not available. There is no impetus in New Brunswick to develop populations since the salmon stock used for commercial culture has a minimal (less than 5%) grilse component.

Hybridization

Interspecific crosses involving Arctic char and Atlantic salmon have exhibited gonadal sterility in one or both sexes (Refstie and Gjedrem 1975; Glebe et al. 1986). Combining hybridization with triploidy induction may offer new opportunities for production of sterile crosses and increased embryonic survival. For example, triploid Arctic char - Atlantic salmon hybrids are sterile and survival to first feeding is better than diploid hybrids. This hybrid retains the fast growth characteristics of the char male parent and has improved salinity tolerance associated with the two maternal chromozome sets from the salmon parent. Sea cage trials have shown that Atlantic salmon grow and survive better than the triploid hybrids. Seawater performance of the pure char and diploid hybrids was poorer than the triploids. In general, hybrids may be more important to the aquaculture industry for their sterility (no gene introgression to wild populations) than for their performance traits which are intermediate to those of the parental species or strains.

Transgenics

Transgenic fish are produced by the introduction of foreign DNA into the egg or embryo in such a manner that it is incorporated into the genome (Donaldson 1988). Of relevance to Atlantic coast aquaculture, is the research on microinjecting the flounder antifreeze gene into the Atlantic salmon (Fletcher et al, 1988). With this gene, salmon may be able to survive the normally lethal cold water temperatures that preclude farming in most coastal areas of eastern Canada. Transgenic techniques as applied to fish are developmental and are not expected to be utilized commercially for at least a decade.

b) **Physiological**

As indicated at the start of this subsection, a number of methods are available to manipulate the physiological status of salmonids (including sterilization, environmental control of reproduction, manipulation of smoltification timing, genetic storage, hormone treatment to reduce spawning or accelerate growth). Only sterilization is discussed here given its possible use in Newfoundland to prevent early maturation and also reproductive mixing between escaped culture fish and wild stocks.

Methods currently under investigation for inducing sterility include auto-immunity, exogenous steroid treatment, surgical gonadectomy and irradiation. The most practical techniques for sterilizing large numbers of salmonids appear to be steroid (androgen) treatment during early life stages (Hunter and Donaldson 1985) and gamma irradiation of eyed salmonid eggs (Villarreal and Thorpe 1985). However, the incidence of sterility can be variable and, in the case of gamma irradiation, the permanence of sterility is in doubt. Studies on auto-immunity may result in the development of vaccines to limit gonadal development.

A.1.2 Siting Requirements for Culture Facilities

A.1.2.1 Biological Overview

A.1.2.1.1 Natural Distribution and Habitat

Atlantic salmon are found in cool temperate and sub-arctic streams and lakes in North America (between New York and northern Quebec), southern Greenland, Iceland and in Europe (between northern Spain and northwestern Russia; Scott and Scott 1988; and Scott and Crossman 1973). In the sea, some stocks from eastern North America reside in coastal waters while others migrate to feeding areas off the coast of Greenland. Most populations of Atlantic salmon are sea-run but landlocked populations occur in lake areas in eastern North America.

A.1.2.1.2 Life History Considerations

The species displays highly variable life history characteristics having important implications for culture (Edwards 1978; and Saunders and Schom 1985). For sea-run salmon, the length of time young spend in freshwater before migrating to the sea can vary considerably amongst populations. Typically, juveniles will remain in freshwater two to three years until the fish reach lengths of approximately 15 cm. However, in northern Quebec and Labrador streams, where temperatures are lower, juveniles might remain in freshwater for five to six years (Power 1981). The length of time fish spend in saltwater also varies greatly amongst populations and can range from one year to three years before spawning. Repeat spawning occurs and, consequently, fish can have much older "sea ages" (e.g., more than nine years; Scott and Crossman 1973). Life history stages that occur in freshwater and saltwater culture facilities are summarized below.

1. Freshwater Stages

Freshwater culture usually involves receiving and maintaining adult spawning fish, incubating eggs and alevins and rearing fry to smolt size.

Spawning

Generally, wild Atlantic salmon spawn in October and November in Canada (Scott and Scott 1988) and usually migrate into spawning rivers between spring (at the southern limit of their range) and early autumn (at the northern limit of their range). Spawning takes place in November in the south and the end of September in the north. A culture facility must allocate a certain proportion of its rearing space and water volume for holding broodstock, unless the broodstock is held and spawned in estuarine or marine pens. In some cases, spawned-out adults ("kelts") will die after spawning while in others they will survive to spawn in succeeding years. The proportion of repeat spawners varies amongst populations. The potential for maintaining and reconditioning kelts as ongoing broodstock or for food is being investigated (Pepper and Parsons 1987; and Johnston et al. 1987).

Egg and Alevin Development

Eggs are incubated in relatively cool water (2-8°C) over winter for several months. The duration of incubation depends largely on water temperature. Larval fish (alevins) remain in the incubation substrate for a further one to two months (again depending on temperature) before actively feeding. During culture, an adequate support medium, similar to gravel in nature, is used for proper alevin development (e.g., poultry nesting, gravel, etc.).

Fry Rearing

A critical period in Atlantic salmon culture is when fry emerge from the incubation substrate to begin feeding. At that time, water temperature must be relatively high (at least 8-9°C and preferably 10-14°C) to initiate feeding behaviour (Edwards 1978; and Saunders 1986).

Fry continue to grow in freshwater as parr until they become smolts at a size of 12-15 cm. Under natural conditions, the age at smolting is strongly influenced by environmental conditions, particularly temperature (Power 1981). Under culture conditions, the timing of smoltification can be manipulated by adjusting rearing temperatures and photoperiod conditions (Saunders et al. 1987; and McCormick et al. 1987). Generally, however, a proportion of the parr will become smolts one year after hatching and a proportion will become smolts two years after hatching (e.g., Sedgewick 1988; and Edwards 1978). Saunders (1986) indicates that the best growth for juvenile salmon occurs between 14 and 18°C.

2. Saltwater Stages

Both growth rates and survivals amongst fish grown in seawater can vary significantly amongst strains (Gunnes and Gjerdem 1978; and Standal and Gjerde 1987). As with other life history characteristics, the Atlantic salmon age at maturity is highly variable. The maturation patterns can vary greatly amongst stocks (Saunders and Schom 1985; Power 1981) and is of particular concern for culture of Newfoundland stocks. Fish can mature as:

- parr (usually male) before migrating seaward;
- grilse, after spending one winter in seawater; and
- salmon, after spending two to four winters in seawater (salmon can spawn repeatedly and might spend three years in seawater before spawning for the second time).

In some cases, fish also mature in the first autumn after spring placement in saltwater (Sutterlin et al. 1978).

Male parr maturation varies amongst populations but has been reported as high in some streams, particularly in eastern Newfoundland (Dalley et al. 1983; and Myers et al. 1986). Myers et al. (1986) indicate a size threshold for 1+ parr of 70-72 mm, above which male maturation is likely. Glebe and Saunders (1986) indicate that strains having late maturing sea-age parents yield fewer mature parr.

Grilsing can be a serious problem during farm production and stocks having high grilse proportions should be avoided (Edwards 1978; and Sedgewick 1988). Power (1981) indicates high grilse proportions amongst stocks from Newfoundland and Labrador, with a lower proportion amongst stocks in north shore Gulf of St. Lawrence and Anticosti/Gaspe. In general, fewer grilse are noted in large rivers compared to smaller ones.

A.1.2.2 Requirements for Freshwater Facilities

Important biological and physical siting requirements are summarized in Table 2.3 (general requirements) and Table 2.4 (water quality requirements) and are described briefly below.

A.1.2.2.1 Biological Factors

1. Water Temperature

Peterson et al. (1977) suggest an optimum temperature for egg incubation and alevin development of 6-8°C. Some studies indicate Atlantic salmon tolerate relatively cold water conditions (0.15-1°C) for incubation compared to other salmonids (Wallace and Heggebert 1988). However, Peterson et al. (1977) indicate relatively high mortalities at egg incubation temperatures of 2°C (compared to temperatures between 4 and 8°C).

Saunders (1986) indicates that the best growth for juvenile salmon occurs between 14 and 18°C. Apart from brief exposure, the lower lethal temperature for adult Atlantic salmon is -0.7°C and the upper lethal temperature is 27.8°C (Saunders

1986). However, growth will be reduced on either side of the optimum, and essentially ceases at 4°C. Tolerance to stress is poor below 2°C and above 20-21°C, so that risks of disease problems increases. Therefore, temperatures at a site should not have extreme temperatures beyond 4°C and 20°C.

Ideally, two water temperatures would be available, one for incubation and a second for fry rearing (i.e., 6-8°C for egg incubation and alevin development, and 14-18°C for fry-to-smolt development). A variable temperature capability allows selecting optima for egg development, fry first-feeding, smolt growth rate, and inducing smoltification.

If water cannot be heated by other means, selection of a single optimum temperature criterion is difficult given the minimum requirements for reasonable egg development and initiation of first feeding and upper tolerance levels for eggs. Ten to 11°C allows reasonable growth rates for fry but at the upper limit for disease and other problems during egg development. However, as indicated in Section A.1.1.3 (Facility Design Considerations), for actual site development, heat can be applied to cooler waters (or warmer waters can be cooled), though this is an additional cost factor.

2. <u>Dissolved Oxygen and Other Gases</u>

Ideally, oxygen would be at 100% saturation and the total gas pressure (oxygen plus other gases such as nitrogen and argon) would be less than 103% (Sigma Environmental Consultants 1983). Sometimes water supplies, particularly groundwater, have oxygen saturation much less than 100%. In these cases, aeration towers, aerators and/or oxygenators can be used to elevate the oxygen to levels approaching saturation. This means that minimum acceptable oxygen saturation at a site could be zero if other conditions warrant development of the site. Aeration towers can also be used to remove unwanted gases such as nitrogen and argon, which can cause serious harm (gas bubble disease) when found in relatively high concentrations at total gas pressures above 103% saturation.

3. Water Quality

A list of water quality values used for preliminary screening of salmonid hatchery locations is shown in Table 2.4. If empirical values fall outside these values, the sites might not be rejected since in most cases actions can be taken to improve the conditions. If surface water is used, the site should not be downstream or near (in the case of lakes) known or future sources of pollution (including sources of metals, pesticides, hydrocarbons or excessive nutrients). Pollution sources can be industrial, municipal or local (including runoff from agricultural areas).

A.1.2.2.2 Physical Factors

1. Water Supply Type and Quantity

An optimum water source would be a large volume spring having no resident fish species (to avoid disease transfer problems) and located at sufficient elevation to supply water to the hatchery by gravity (Piper et al. 1982).

Exact water volume requirements depend on production objectives and decisions to reuse water within the facility (discussed in Sections A.1.1.2 and A.1.1.3). However, in general, a site having 0.5-1.0 m^3/sec. would have a good water supply for commercial smolt production.

Two factors could reduce this requirement; the presence of lakes having suitable conditions (temperature, oxygen, access and no likelihood of plankton blooms) for smolt growout in netpens (discussed under point 3 below); and the use of recirculation. If good quality water is available at water volumes less than that necessary to meet the production objectives, current technology enables recirculating up to 95% of the water though recirculating lesser amounts (70-90%) help to reduce risks. This means that a minimum suitable water volume might be in the order of 0.02-0.05 m^3/s.

2. Terrain Conditions

A potential site must not be subject to flooding, must be suitable for clearing and levelling at moderate cost, and have good drainage. Also, ideally the water supply to the facility would be by gravity, avoiding the need for pumps.

3. Lake Netpens

Lake areas can be used for some or most of the juvenile growout where adequate temperature, oxygen and other siting factors (such as depth, wind and wave exposure, lake ice conditions and absence of phytoplankton blooms) allow. The latter factors are similar to physical requirements described for saltwater netpens (Section A.1.2.3.2), but greater care is required to avoid nutrient loading and possible induced phytoplankton problems given the absence of tidal flushing in lake areas.

A.1.2.2.3 Logistic and Other Requirements

As for saltwater cage and landbased facilities, ideally a community suitable for supplying labour and supplies would be located nearby, the site would be accessible by road and have hydroelectric power and telephone communication. Normally, road access and hydroelectric power connections are minimum desirable features at a freshwater site. The acceptable distance from a nearby support community will depend greatly on other site attributes. Communication can be undertaken by radiophone, if telephone lines are not nearby.

A.1.2.3 Requirements for Saltwater Facilities

Important biological and physical siting factors are summarized in Table 2.2 and are described briefly below.

A.1.2.3.1 Biological Factors

1. Temperature

Optimum growing temperatures for Atlantic salmon in saltwater are not clearly defined, but appear to be between 10°C and 16°C, or approximately 14°C (Saunders 1986). Saunders (1986) suggests acceptable temperatures are between 4 and 20°C and speculates that the optimum is lower than that for juveniles (14-18°C). For Pacific salmon, 10°-15°C is considered good, while temperatures above 21°C are considered poor (Caine et al. 1987). Extreme lethal temperature limits for Atlantic salmon are -0.7°C and 27.8°C (Saunders 1986). Minimum acceptable average temperature to ensure adequate growth is 4°C and to prevent low temperature stress problems is 2°C. The maximum acceptable temperature will depend to some degree on the oxygen content of the water and the presence of phytoplankton, pathogens or other sources of stress in the environment. Serious problems can develop as average temperatures rise above 20-21°C.

2. Oxygen

Ideally, the water column would be saturated at all times of the year and oxygen concentrations would not drop below 8.5 mg/l (Caine et al. 1987). As a minimum to obtain high oxygen levels, sites should not be prone to high temperatures for prolonged periods, to phytoplankton blooms (creating oxygen depletion in surface waters), to anoxic bottom conditions which might periodically cause oxygen depletion at the surface, or prolonged periods of slack water during the tidal cycle. Sites should not go below 5.0 mg/L oxygen or 60% saturation.

3. Salinity and nearby Hydrology

Ideally, salinities would be relatively high (e.g., greater than 24 ppt.) and would have almost no daily fluctuations (Caine et al. 1987). Poor sites would have salinities of less than 15 ppt. and have daily fluctuations of more than 5 ppt.. Those salinities would be acceptable for holding smolts temporarily to acclimate to saltwater conditions (for example in estuarine netpens). Once fish have acclimated to higher salinity conditions, strong fluctuations can create physiological stress. Therefore, embayments near large streams or rivers should be avoided. Freshwater lens formation should not extend more than 1 m below the surface.

4. Phytoplankton Blooms

Phytoplankton can affect salmon directly through mechanical means (such as gill damage from spicules on certain diatoms) and toxic means (such as toxins released by dinoflagellates) or indirectly by oxygen depletion. Phytoplankton blooms that could affect salmon are not felt to be common in Newfoundland coastal waters (Sutterlin, personal communication) Ideally, phytoplankton known to be harmful to finfish will not be present near the site. These would include diatoms such as *Chaetoceros convolutus*, and dinoflagellates such as *Heterosigma akashiwo* and *Gyrodinium aureolum*. Minimum site requirements would be that seasonal temperature, salinity and nutrient conditions at the site would not be conducive to blooms of such species.

Under ideal conditions, sites would not have conditions expected to produce acute algal blooms that would lead to serious oxygen reduction at night or over several days in the water column. Minimum conditions would be no reports of such blooms based on several years of observation.

5. Pollution

Clearly, a site should be located well away from known or future sources of pollution (Caine *et al.* 1987; Beveridge 1987). Types of potentially serious pollutants include metals, pesticides and hydrocarbons. These could be industrial, municipal or local sources (including marinas, harbours and upland runoff from agricultural areas) and can affect either the health or marketability of the fish.

6. Predators

Ideally, concentrations of potential predators will not be located within a substantial distance of the site (e.g., within 10 km). These include marine mammals (seals), and sea birds such as herons and cormorants. A minimum requirement would be that no large concentrations, such as seal rookeries or sea bird nesting areas, are located near the site (e.g., within 5 km; Caine *et al.* 1987).

7. Fouling Organisms

Ideally, potential fouling organisms (such as algae, mussel and barnacle larvae, bryozoans, macrophytes and jelly fish) would be low in abundance with no observations of serious fouling nearby.

A.1.2.3.2 Physical Factors

1. Netpen Facilities

Exposure to Wind Wave and Swell Conditions

Ideally, the sites would be well protected from all winds and would have no swells and minor wave action (Beveridge 1987). Winds are important because they produce wind-driven waves, but also because they influence working conditions (both in terms of wind strength and chill factors) at the site. Good locations would have almost no fetch for waves to develop, yet adequate water exchange around the cages (as described below), such as around island clusters.

Site conditions that allow waves to build will be influenced by local topography and wind conditions. Bad locations would have periodic exposure to wave heights greater than 1.5 m. A site having a fetch of approximately 10 km and exposure to worst case wind strengths of 110 km/hr or alternatively, a lesser fetch (e.g., 6 km) but a higher worst case wind velocity (140 km/hr) could have such conditions (Beveridge 1987). This does not mean sites having greater wave height cannot be used. Cage designs are such that structures are available that can withstand wave heights greater than 2 m and even open ocean conditions (Beveridge 1987; Svealv 1988). However, these cages are normally more costly and such site conditions more difficult to work on.

Currents and Water Exchange

Ideal currents will be such that they are uniform and constant, are not strong enough to cause distortion of nets or shifting of moorage systems, but are of sufficient velocity to supply the oxygen needs of the fish and remove fecal material (Beveridge 1987). A good location would have maximum currents of approximately 0.2

knots (10 cm/s) during slackwater and 1 knot (50 cm/s) at peak flow (Table 2.2). A poor location would have almost no flow at slack water and/or flows greater than 2 knots at peak flow.

The presence of shallow sills in proximity to a site should be avoided if they create basins of low exchange water below the cages (Caine et al. 1987). These basins can contain low oxygen levels and hydrogen sulphide gas, and under certain conditions, the poorly oxygenated bottom water can rise to the surface.

The type of bottom material can often indicate the strength of bottom currents. Muds and silts normally indicate low or no currents along the bottom, while substrate of larger size indicate stronger currents.

Water Depth and Bottom Conditions

Over the last decade, definitions of suitable water depths have steadily increased as operating experience at sites has also increased. In general, the bottom of the cages should be 15-20 m or more above the sea bottom during extreme low tides. Lesser heights might be acceptable if bottom currents are strong so that fecal and food material are rapidly dispersed. A minimum acceptable depth below the cages is 10 m (Caine et al. 1987) and the maximum depth will be determined by the cost and difficulty of placing anchoring gear (eg. bottom slope) verses shore attachment.

Ice Conditions

Ideally, a site would be ice-free. Problems at culture sites in Newfoundland have occurred mainly during thaw and breakup; drifting ice has caused physical damage and site access has been hampered by fragile, changing ice conditions and water formation over ice (R. Hoyles, Newfoundland Department of Fisheries, personal communication). If netpens are located in an ice-bound location, the ice should be subject to minimal shifting or drifting due to strong winds or currents during breakup. Regardless, the site should not be subject to intrusion by ice flows from outside areas (e.g., Arctic pack ice).

Sites having ice cover must have some mechanism to allow continual or periodic removal of a portion of the ice to allow fish to stabilize their swim bladders with surface air.

A maximum criterion for suitable ice depth is not defined in the literature, but is perhaps in the order of 1 m. In Newfoundland, the ice has been found to provide an insulating barrier. A minimum criterion would be sufficient thickness to safely carry the weight of people and light equipment (e.g., 0.2 m).

Potential Siting Conflicts

Normally, a site must comply with Transport Canada regulations preventing obstruction of navigable waterways. Therefore, a site must be chosen away from known anchorages or traffic areas (which might include passenger and cargo vessels, fishing boats, pleasure craft or float planes). Other potential conflicts can occur in relation to objections by upland owners or activities (e.g., permanent or recreational residences and federal or provincial parks).

2. Landbased Facilities

Landbased facilities avoid several serious siting requirements (e.g., Anderson 1988) for netpens such as high wind, wave and swell conditions, currents, predators and phytoplankton blooms (as long as the water is filtered). Many factors (such as temperature, salinity, oxygen, influence of pollution sources outlined in the preceding subsection) are essentially the same for both netpen siting and landbased siting. Ideally, a high volume source of heat (e.g., heated cooling water) would be available nearby so that pumped seawater can be heated.

Water Depth

Depth can be important on a site-specific basis, particularly where a high differential exists between surface and sub-surface temperatures. Placement of water intakes at different depths (as at Holyrood Pond, described in Section A.1.1), allows selection of different temperatures. Greater depths might be required if the shore is subject to violent wave action or ice scouring.

Water intake structures are an important capital cost component for landbased facilities and costs are strongly influenced by the length of pipe required to reach suitable depths. Consequently, the cost of pipe to reach the desired depths can affect the financial viability of a facility.

Ice Conditions

Suitable sites must allow placement of water intake structures away from ice scour areas. If rearing or other facilities are to be placed near the shoreline high tide limits, they also must not be susceptible to scouring. As with pen structures, a surface layer of stable ice might be positive by insulating the underlying water.

Shoreline Terrain Conditions

Shoreline terrain conditions must be adequate for construction of the shore-based rearing units and auxiliary facilities. Ideally, sub-surface geology would consist of a potential filtering material (such as coarse sandstone) so that a seawater well could be constructed (Anderson 1988).

Potential Siting Conflicts

A landbased facility avoids the potential large-scale conflicts with marine traffic created by a floating netpen facility. However, placement of an intake pipe likely would not be permitted in a designated anchorage area.

Effluent Discharge

Unlike a netpen facility, a landbased facility becomes a source of single-point effluent discharge and must therefore comply with local effluent quality requirements. These usually require, as a minimum, removal of solid material.

A.1.2.3.3 Logistic and Other Requirements

Site logistics, access, power and communications requirements are for the most part the same for both a landbased and netpen facility. However, road access and main-line hydroelectric power to a landbased site are particularly important to reduce risks associated with critical site problems (such as pump failure).

1. Logistics

Ideally, production sites would be adjacent to processing facilities and these in turn would be adjacent to a major airport for shipment to the marketplace. In addition, the sites would be located near a fish feed plant and a community capable of supplying labour and material needs. Normally, housing for personnel (usually the site manager) is required at or very near the growout location.

Minimum acceptable conditions are more difficult to define and must be weighed relative to other site features (such as temperature conditions) that might be positive. However, if other factors were equal, farm sites located more than four hours from a logistic center, by cargo boat (in the case of pen sites) or by truck, would be poor. Good sites would be located within half an hour transportation time from a logistic center.

Ideally, the sites would be located close to an hydroelectric power line and telephone lines. If not, power to the site must be supplied by a generator, a stream turbine, if a suitable stream is close to the site, or if the site conditions are suitable, solar panels. Communications would have to be by radio phone.

2. Access

Access is important both for day-to-day operations and for site security. Ideally, the sites would have cages connected to the shore by walkways and there would be paved road access. Otherwise, the sites should be accessible within 10-20 minutes by boat from the shore access point.

A.2 RAINBOW TROUT (Oncorhynchus mykiss)

A.2.1 State of Culture Technology

A.2.1.1 Status of Development in Newfoundland

Rainbow trout culture in Newfoundland began in 1887, with the construction of a hatchery at Upper Long Pond near St. John's (Driscoll 1981). This was followed by construction of a hatchery (for fry stocking) at Murray's Pond (1900), and a hatchery with raceways and a grow-out pond at Hopehall (mid 1970's) and attempts at "pothole" farming near Kilbride (early 1980's). Rainbow trout fingerlings are currently produced at the Bay D'Espoir Hatchery and are grown out in marine cages in nearby Roti Bay. Murray's Pond Club has an operational hatchery and a fish-out pond for members and Rainbow Trout Farm Ltd. (near Hopehall) breeds and raises trout for a fish-out pond and for sale as fresh and processed fish.

The Rainbow Trout Farm Ltd. was initally a pilot project, but is now a commercial "u-catch" and grow-out (to pan-size) facility, currently holding approximately 70,000 fish. The operation is comprised of a hatchery, indoor fibreglass tanks, three indoor cement raceways, three long and covered run-of-the-river raceways and a large outdoor pond containing small netpens. The water supply (apart from the run-of-the-river raceways) is piped, gravity-fed surface water. The presence of IPN in the system has prevented utilization of stock from the farm in other grow-out locations (L. Lahey, personal communication).

A.2.1.2 Culture Methods

A.2.1.2.1 Production Options

Rainbow trout are cultured in both freshwater and saltwater and culture methods are extensively described in general literature (e.g., Huet 1986; Stevenson 1987; Leitritz and Lewis 1980; Klontz et al. 1979). Saltwater culture methods (netpens and landbased tanks) are basically the same as those used for salmon (Edwards 1978). Freshwater culture methods are also basically the same as those used for salmon

(Section A.1.1.3), however, generally a greater variety of growout facilities are used. These range from intensive systems using tanks, raceways, lake netpens, and earthen ponds to larger extensive man-made or natural ponds, including "pothole" lakes (e.g., Castledine 1987; Saskatchewan Department of Parks, Recreation and Culture 1988). Harvesting can be undertaken directly by the operator or by allowing the public to fish for the trout on a fee basis. Extensive culture requires that fish utilize the natural foods in a pond and therefore, stocking densities are normally low. Fish are normally grown to a fingerling or larger size in intensive culture facilities before placement in the extensive growout ponds. The size to which the fish are grown prior to placement in the extensive facilities is determined in part by the projected harvest size and timing and expected growth within the pond. Problems with extensive facilities include, at times, the imparting of a muddy flavour to reared fish, fish kills during summer (resulting from plankton blooms) or winter (ice formation preventing oxygen exchange), predator control and weed control.

A.2.1.2.2 Biological Management Considerations

The biological management considerations outlined for Atlantic salmon (A.1.1.3) broadly apply to other salmonids, such as rainbow trout. However, the relative performance of rainbow trout stocks under freshwater and marine culture conditions has not been thoroughly evaluated, even though the rainbow trout is the salmonid species of preference for freshwater culture.

In saltwater, physiological problems associated with osmotic imbalance and maturation and reduced market value, have relegated the rainbow trout to a second place position after Atlantic salmon in terms of production levels. In Norway, only about 5-10% of annual salmonid production is rainbow trout and the proportion has been declining. As the world market price for Atlantic salmon continues to fall, it is likely that interest in rainbow trout will be renewed.

As with Atlantic salmon, selection during domestication led to major improvements in production characteristics for rainbow trout; the growth rate of rainbow trout has been improved by up to 5%/year (Gjerde 1986).

For producing sterile production fish (discussed for salmon in Section A.1.1.3), the commercial success of triploid rainbow trout has been established (Bye and Lincoln 1986). Triploid females are particularly useful because ovarian development is reduced to a greater extent that testicular development (Small and Benfey 1987). Monosex (female) milt is required to produce 100% female eggs in which triploidy is then induced by usually heat shock, pressure shock or anaesthetic gas (e.g., nitrous oxide). As with salmon, all triploid salmonids appear not to be as vigorous as their diploid conspecifics.

The importation of all female milt from a commercial "disease free" stock is a rapid method of producing all female rainbow triploids. This does result in some genetic dilution of the local egg-donor stock. However, the benefits in terms of triploid sterility and no interbreeding with local wild stocks or establishment of wild breeding populations through escapement outweigh this disadvantage.

A.2.2 Siting Requirements for Culture Facilities

A.2.2.1 Biological Overview

A.2.2.1.1 Natural Distribution and Habitat

Rainbow trout are endemic to Western North America, but have been introduced to new locations throughout the world including Atlantic Canada. Introductions to Newfoundland began late in the last century (Scott and Scott 1988). Rainbow trout are comprised of both freshwater populations and sea run populations. The fish supports a worldwide freshwater culture industry and is grown commercially in saltwater in most areas where salmon are grown. The species utilizes a variety of freshwater habitats, and in saltwater, migrates long distances similar to salmon.

A.2.2.2 Life History Considerations

1. Freshwater Stages

As indicated earlier, the species has a long history of culture and consequently, has a high degree of domestication and refinement of culture practices, described in numerous general sources (e.g., Leitritz and Lewis 1981; Stevenson 1987; Edwards 1978; and Huet 1986).

Spawning

Normally, rainbow trout spawn in the spring, usually at temperatures between 10° and 15°C (Scott and Crossman 1973). However, through genetic and environmental manipulation, spawning can occur almost throughout the year (Leitritz and Lewis 1981).

Spawning normally takes place after two years of age. Spawning may take place more than once. In culture, specialized broodstock are maintained and egg-takes in different seasons often occur (Stevenson 1987). Anadromous populations in the wild usually return to spawn in home rivers after two to three years in the sea (Hart 1973). Repeat spawning occurs.

Egg and Alevin Development

Egg and alevin requirements are similar to those outlined for other salmonids (such as those described for Atlantic salmon, Section A.1.2). However, optimal temperatures are higher, between 10°C and 12°C (Stevenson 1987). At 10°C, eggs hatch in approximately 30 days; temperatures below 4°C and above 18°C are not well tolerated. Alevins develop into fry after a further two to six weeks.

Growout

Temperature requirements for Atlantic salmon, rainbow trout and Arctic char are summarized in Table 2.6. Apart from temperature requirements, the general fry rearing requirements of rainbow trout are similar to other salmonids

(Klontz et al. 1978; Piper et al. 1982; Leitritz and Lewis 1981). However, oxygen consumption during culture can be higher for rainbow trout (Liao 1971). During culture, feeding is initiated within one to two days, since a delay can cause the fry subsequently to go off food, resulting in mortality. As with other salmonids, water depths are normally kept low at this stage (10 cm). In the wild after emergence, fry move within several months from stream spawning areas to lakes. Some may remain in streams (Scott and Crossman 1973). For culture, the preferred growing temperatures are approximately 15-16°C; growth essentially stops at 4°C (Stevenson 1987). In the wild, rainbow trout are known to grow in lakes that reach 21°C in the surface layers (Scott and Crossman 1973). However, growth essentially ceases above 20°C (Klontz et al. 1979). The upper lethal temperature of some strains is 24°C.

2. Saltwater Stages

Attempts were first made in the early 1900's to grow trout in saltwater in Norway. This was not common until the 1950's. Commercial production became widespread and was expanded into the mid 1970's (Edwards 1978).

Growout

Rainbow trout must be relatively large (e.g., above 50 g) to tolerate transfer to seawater. Once that size is reached, the fish adapt to saltwater generally throughout the year (Edwards 1978). In nature, most steelhead (the sea-run strain of rainbow trout) spend two to three years in freshwater before migrating to the sea as smolts. Once acclimatized to seawater, rainbow trout growth is rapid (often greater than salmon) and high densities are tolerated (10-25 kg/m^3; Stevenson 1987). Using normal seawater, rainbow trout in Scandanavia are brought to a 3 kg size after four years of age. Using heated water, this growout period is reduced to three years of age (Edwards 1978).

Maturation

In the wild, fish mature mainly between three and five years, with some males maturing as early as one year and some females maturing as late as six years

(Scott and Crossman 1973). In culture, final maturation usually takes place in freshwater. Mature fish are often stripped of eggs when mature at two years. Many culturists wait to strip at three years since the eggs are normally larger (Stevenson 1987).

A.2.2.3 Biological and Physical Siting Requirements

The siting requirements for intensive freshwater and saltwater culture of rainbow trout are basically the same as those described for salmon (Section A.1) except for differences in temperature requirements, as shown in Table 2.6.

However, rainbow trout are occassionally grown under extensive conditions in natural or man-made freshwater ponds. Normally, fish are raised to a fingerling size in the more intensive facilities, then are placed in the ponds where they are grown to harvest size either for harvest by farm personnel or fishing out on a fee basis. The siting requirements of such ponds for rainbow trout culture are outlined below (Castledine et al. 1984; Saskatchewan Department of Parks, Recreation and Culture 1988).

A.2.2.4 Size and Depth

The size and shape of the ponds are not fixed and will be influenced by production objectives and whether stocking densities will at times be maintained above natural levels. An optimum size of 2,500 m^2 (one quarter of a hectare) has been suggested (Freshwater Institute, no date), but small lakes of several hectares can be used. Water depth must be great enough to allow fish to avoid extreme temperature and oxygen conditions in summer and winter. These conditions must be assessed on a site-by-site basis. However, depths of 3-4 meters are likely required for fish raised over the summer only and up to 7-8 meters for fish raised over the winter.

A.2.2.5 Temperature

As described earlier, the optimum temperatures for trout growth are between 15 and 16°C. Above 18°C, the growth rate is reduced and stress can develop at higher temperatures especially if oxygen levels are low. Temperatures above 20-21°C and below 2-4°C are generally avoided. Therefore, during the summer, water should remain lower than 20-21°C at depths greater than 1-2 meters.

A.2.2.6 Oxygen

Normally, the water should be 80-100% saturated with oxygen and levels should not drop below 4 mg/L. Since the ponds normally don't have inlet and outlet streams, oxygenation is by photosynthesis and wind action. Consequently, sites should have good exposure to wind. A certain level of plantlife is necessary for oxygen production through photosynthetic activity. However, as discussed below, large amounts of plantlife can have serious negative effects, including oxygen depletion.

Oxygen depletion can be a serious problem over winter. Ice prevents oxygenation at the water surface and, together with snowcover, blocks sunlight which limits photosynthetic activity.

A.2.2.7 Vegetation

Vegetation can be in the form of shoreline plants, floating weeds and algae. These in turn provide habitat for food organisms and oxygen. The quality of vegetation is determined by the levels of available nutrients (nitrogen and phosphorous) and the summer growing conditions, mainly temperature and light. Ideally, the pond will not be subject to excessive vegetative growth over summer. Excessive algae growth can result in extremely high oxygen demands when the algae die after using up available nutrients in the pond. They can also contribute to nighttime oxygen depletion, when both plants and animals are utilizing oxygen for respiration, and to a muddy flavour in fish flesh. Excessive weed formation can contribute to oxygen problems, but can also hamper fish harvesting and pond maintenance activities.

A.2.2.8 Water Quality

Normally, slightly alkaline waters (pH 7-8) are more productive than acidic waters and are preferred for pond farming. Excessively alkaline water (pH greater than 9), however, is normally not suitable. High levels of nitrogen and phosophorous based nutrients must be avoided to prevent excessive plant growth during summer.

A.3 ARCTIC CHAR (Salvelinus alpinus)

A.3.1 State of Culture Technology

A.3.1.1 Status of Culture in Newfoundland

Arctic char are presently being raised commercially at two hatchery facilities (Bay D'Espoir Hatchery Ltd. and at a location near Port Rexton, on Trinity Bay) and are being assessed for culture at three locations in western Newfoundland (Isle Aux Morts, Roddickton and Deer Lake) and several locations in Labrador (Goose Bay and Northwest River). Arctic char have also been raised at the Ocean Science Center (Logy Bay) of the Memorial University of Newfoundland.

A.3.1.2 Culture Methods

Arctic char culture in Canada was first attempted in the late 1800's (MacCrimmon 1984) and has been undertaken historically in Europe (i.e., Scandinavia and Switzerland) for stocking purposes (Brown 1983 and Huet 1986). However, the technology for this species has advanced more slowly than for other salmonid species. The potential for commercially farming char has been investigated in both Canada and Scandanavia. Myrseth (1988) estimates Scandinavian commercial production in 1988 to be 100 tons in Norway, 200 tons in Sweden, and 100 tons in Finland. Commercial production has been concluded to be technically viable in Canada (Papst and Hopky 1983) and commercial production is either underway at a pilot level or is being planned throughout the country. Early efforts in both Canada and Europe have concentrated on producing smaller pan-sized fish (300-400 gm) but production of larger sizes is expected (Myrseth 1988; and Byrnes, personal communication).

In eastern Canada, a broodstock and research program has been developed at the Huntsman Marine Science Centre. Three commercial fish farms in New Brunswick and one in Prince Edward Island are associated with the Huntsman Marine Science Centre and possess broodstock. Arctic char are also now being raised in Nova Scotia, Quebec, Maine, and elsewhere in Canada (Manitoba, Saskatchewan, British Columbia and the Yukon).

A.3.1.3.1 Production Options

Arctic char are being raised in facilities that are basically the same as for other salmonids. Most efforts to develop commercial production has concentrated on the freshwater stages because early studies on adaptability of char for sea-cage culture showed they had limited seawater tolerance (Gjedrem 1975). However, recent studies at the Huntsman Marine Laboratory indicate that both freshwater and saltwater culture are possible (DeLabbio et al. 1989).

1. Freshwater Production

In freshwater, culture experience indicates (Papst and Hopky 1983; Wallace et al. 1988; Papst and Hopky 1989):

- given the small fry size, particular care must be taken to provide a good quality, small-sized feed during the early feeding stages;
- growth and survival is best at relatively high rearing densities (60-100 kg/m^3);
- temperature requirements are generally lower than for other salmonids;
- a large size-variation develops early amongst reared fish and grading does not appear to improve the growth performance of smaller-sized fish; and
- a critical impediment to the growth of a commercial industry in Canada is the absence of an abundant, disease free egg supply.

Char as a typical schooling fish, are very tolerant of high densities and can make better use of tank rearing space than the more territorial Atlantic salmon and rainbow trout. At low densities, char tend to crowd together and underutilize rearing space. For example, Atlantic salmon reared at densities exceeding 30 kg/m^3 experience poor growth and higher mortalities than at lower densities (Babtie, Shaw and Morton 1986), while, as indicated above, char do well at densities of 60-100 kg/m^3.

2. Saltwater Production

Early studies of Arctic char in seawater found mortality, especially during the first winter, was higher and growth lower than for Atlantic salmon reared under similar conditions. However, the genetic background (landlocked or anadromous) of the char strains studied was in doubt and the numbers of fish used in the study were low. More recent studies (DeLabbio and Glebe 1988; and Reinsnes and Wallace 1988) have shown satisfactory seawater growth (relative to Atlantic salmon) is possible among the approximately 50% of the population which continue to feed well when introduced to seawater cages. Similarly, mortality over the first winter was lower amongst these groups.

The conclusion drawn was that if char of 50-60 g were placed in seawater cages in May/June, then a major component of the population would grow as well as Atlantic salmon. This result, coupled with the superior performance of specific strains in enriched seawater challenges, indicates that genetic improvements could result from selection of broodstock based on seawater performance. Sexual maturity has been implicated in excessive over-wintering mortality and poor growth among sea-cage reared char (Wandsvik and Jobling 1982). Among wild stocks, landlocked populations tend to mature precociously relative to anadromous stocks (Reinsnes and Wallace 1988).

Age at maturity among anadromous stocks is later and tends to be more variable than for landlocked strains. For example, Fraser River (Labrador) stock produces 50% more maturing individuals in the second culture year than does the Nanyuk (N.W.T.) stock studies (Glebe, unpublished data). Selection of the superior strains, based on these criteria, salinity tolerance and maturity, would yield better results under commercial culture. Optimum densities in seawater cages have not yet been determined.

A.3.1.3.2 General Biological Management Considerations

The biological management considerations outlined for Atlantic salmon (Section A.1.1.3) and rainbow trout (Section A.2.1.2) apply to Arctic char. Like rainbow trout, the relative performance of Arctic char stocks under freshwater and marine culture conditions has not been thoroughly evaluated. Norway, Sweden and Canada have programs designed to investigate char stocks for culture potential. Concurrent market studies for this species are proceeding in the same countries.

As discussed for Atlantic salmon, interspecific crosses involving Arctic char and Atlantic salmon are being studied and have exhibited gonadic sterility in one or both sexes (similar results have been obtained for brown trout and char crosses; Refstie and Gjedrem 1975; Glebe et al. 1986). As described in Section A.1.1.3 for Atlantic salmon, combining hydridization with triploidy induction may offer new opportunities for production of sterile crosses and increased embryonic survival.

A.3.2 Siting Requirements for Culture Facilities

A.3.2.1 Biological Overview

A.3.2.1.1 Natural Distribution and Habitat

Arctic char is an anadromous species having both sea-run and landlocked populations (Scott and Crossman 1973). The species is found in northern latitudes throughout the northern hemisphere and has the most northern distribution of all salmonids (McCart 1980). In Labrador and Newfoundland, the sea-run populations extend from the northern portion of the Island of Newfoundland to the northern tip of Labrador, and landlocked populations are found throughout the same area and in lake systems in more southern areas of Newfoundland (Scott and Scott 1988).

A.3.2.1.2 Life History Considerations

Considerable variation in size is evident within the landlocked populations. This has led to genetic strains of three distinct forms: dwarf, normal and large char within many populations (Nordeng 1983). Anadromous char are less variable in size, but have what may be considered a more varied life history strategy in that some stocks appear to go through a "smoltification" process which pre-adapts them to seawater residence (Reinsnes and Wallace 1988).

Normally, seaward migration takes place in spring or early summer with the same fish returning to freshwater several months later in late summer/early fall. This pattern is repeated annually except in the year they spawn, when they remain over the summer in freshwater. Whilst in saltwater, the fish are not believed to move very far from the home stream.

1. Spawning

Spawning generally takes place in September and October, but can occur as late as December in Newfoundland (Scott and Scott 1988). Sea-run fish begin returning to river areas between late July and September; the more southerly the latitude, the later the timing of return. Spawning takes place at temperatures of approximately 4°C (Scott and Crossman 1973). Females from southern populations tend to spawn each year, but females from northern areas will spawn every second or third year.

2. Egg and Alevin Development

Under natural conditions, eggs normally incubate at 0-2.2°C (Scott and Scott 1988). The upper lethal temperature has been identified as 7.8°C, but is higher (more than 12°C) at least for some strains (Baker 1981). Nonetheless, 8°C is recommended as a safe upper limit. Gjedrem and Gunnes (1978) indicate the following egg and alevin development times (day-degrees) for char in culture:

Fertilization to Eying	230
Fertilization to Hatch	515
Hatch to Swim-up	250

These were comparable to other salmonids, including Atlantic salmon and rainbow trout, incubated under similar conditions.

3. Juveniles in Freshwater

Young Arctic char typically reside in rivers and lakes until they reach approximately 15 cm, when they first migrate to the sea. These fish might be five to seven years old depending on the local growing conditions. Growth under natural conditions is described as very slow. However, under culture conditions growth can be similar to or better than other salmonids (Gjedrem and Gunnes 1978; Papst and Hopky 1983; and Wandsvik and Jobling 1982).

Reported mean-specific growth rates during the first 200 days of feeding for progeny of wild char stock generally exceeded those of the more domestic rainbow trout reared under similar conditions (Papst and Hopky 1983). Maximum sizes approaching 300 g were achieved by char in this time period. As expected, however, the size variation among the "less domestic" char was greater. This suggests that husbandry procedures (such as grading) and breeding should be utilized to reduce this variability.

4. Maturation

In the wild, sea-run char are usually relatively old when they mature (e.g., 12-14 years in some populations) at lengths of 40-50 cm (Scott and Scott 1988). Under culture conditions, Papst and Hopky (1984) indicate that maturation can occur in four years. They futher indicate that the size of mature adults was considerably smaller than the size of mature adults in the wild population (by approximately 10-30 cm).

A.3.2.2 Requirements for Freshwater Facilities

A.3.2.2.1 Biological and Physical Requirements

The biological and physical requirements for char culture, apart from temperature and density, appear to be similar to those required by other salmonids (Papst and Hopky 1983), such as those outlined for Atlantic salmon (Section A.1.2.2).

Arctic char require temperatures at their different life history stages lower than those required by other salmonid species at respective stages (Table 2.6). A water temperature of 4-5°C seems to be most favourable for egg and sac fry development. Temperatures should be raised gradually to 8-9°C to coincide with the initiation of first feeding. Subsequent optimum grow-out temperatures should approximate 12°C (Reinsnes and Wallace 1988).

Arctic char appear to be the fastest growing of all salmonids at low temperatures (less than 12°C; Wandsvik and Jobling 1982). Studies in Norway have found superior growth among char relative to Atlantic salmon at temperatures ranging from 6-12°C (Reinsnes and Wallace 1988). Based on growth performance in these studies, a 1 kg market size char would be possible after two years of freshwater growth. Growth of the cold water adapted char is also superior to rainbow trout at these temperatures. Char fry will initiate feeding at temperatures as low as 2-3°C. This means that char do not require costly supplemental heating as do Atlantic salmon which will only initiate feeding at higher temperatures (e.g., 10-12°C).

A.3.2.2.2 Logistical and Other Requirements

Again, these requirements are basically the same as those described for Atlantic salmon (Section A.1.2.3).

A.3.2.3 Requirements for Saltwater Facilities

Production experience in saltwater is very limited (as described in Section A.3.1.2). As commercialization proceeds, rearing facilities in general are likely to be similar to those used for Atlantic salmon. However, operating strategies might differ based on recent studies that suggest differences in salinity tolerance resulting from the type of rearing environment used (DeLabbio et al. 1989). As described in Section A.3.2.2, an important difference between Arctic char and other salmonids is the rearing temperature. Seawater (brackish water) temperatures should be approximately 12°C for optimum growth.

A.4 LITERATURE CITED IN APPENDIX A

A.4.1 Atlantic Salmon

Allen, J.L. and E.C. Kinney. 1981.
Proceedings of the bio-engineering symposium for fish culture. Fish Culture Section of the American Fisheries Society and Northeast Society of Conservation Engineers. 307 pp.

Anderson, J.M. 1988.
Land-based salmon farms. Aquaculture Association of Canada, Bulletin 88-3. 14-17 pp.

Bailey, J.K. 1988.
Relative growth of early and late-run Saint John River stocks in sea cages. Salmon Genetics Research Program. Ann. Rep. 1987/88.

Benfey, T.J. and E.M. Donaldson. 1988.
Triploidy in the culture of Pacific salmon. [IN]: Aquaculture International Congress and Exposition Proceedings, Vancouver, British Columbia, September 6-9, 1988. 549-554 pp.

Beveridge, M.C. 1987.
Cage aquaculture. Fishing News Books Ltd. Surrey, England. 352 pp.

Bruin, W., J.W. Nightingale, L. Mumaw and D. Leonard. 1981.
Preliminary results and design criteria from an on-line zeolite ammonia removal filter in a semi-closed recirculating system. [IN]: L.J. Allen and E.C. Kinney (Eds.). Proceedings of the Bio-Engineering Symposium for Fish Culture. Fish Culture Section of the American Fisheries Society (Bethesda, Maryland) and the Northeast Society of Conservation Engineers. 92-96 pp.

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

Colt, J.E. and G. Tchobanoglous. 1981.
Design of aeration systems for aquaculture. [IN]: L.J. Allen and E.C. Kinney (Eds.). Proceedings of the Bio-Engineering Symposium for Fish Culture. Fish Culture Section of the American Fisheries Society and Northeast Society of Conservation Engineers, Bethesda, Maryland. 138-148 pp.

Crim, L. 1989.
Scientist, Fish Reproduction and Aquaculture Broodstock Management, Marine Sciencies Research Laboratory. Personal communication.

Crim, L.W. and B.D. Glebe. 1988.
Reproduction in teleosts for "Methods in Fish Biology" Moyle and Schreck (Ed.). In press.

Dalley, E.L., C.W. Andrews, and J.M. Green. 1983.
Precocious male Atlantic salmon parr (Salmo salar) in insular Newfoundland. Can. J. Fish. Aquati. Sci. 40:647-652 pp.

Dobrocky Seatech Ltd. 1982.
A review of existing environmental conditions at Holyrood Pond, St. Mary's Bay, in relation to a potential aquaculture venture. Submitted to: Fisheries and Oceans Canada, Northwest Atlantic Fisheries Centre, St. John's. 21 p plus appendices.

Dobrocky Seatech Ltd. 1986.
Final report. Salmonid aquaculture in western Newfoundland. Project report FDB/GR-1985-86-20. Prepared for the Department of Fisheries and Oceans. Development Branch. Gulf Region. 114 p plus appendices.

Donaldson, E.M. 1988.
Science and the future of aquaculture. Proceedings Aquaculture International Congress, Vancouver, B.C.

Dupree, H.K. 1981.
An overview of the various techniques to control infectious diseases in water supplies and in water reuse aquacultural systems. [IN]: L.J. Allen and E.C. Kinney (Eds.). Proceedings of the Bio-Engineering Symposium for Fish Culture. Fish Culture Section of the American Fisheries Society (Bethesda, Maryland) and Northeast Society of Conservation Engineers. 83-89 pp.

Edwards, D.J. 1978.
Salmon and trout farming in Norway. Fishing News Books Limited. Surrey, England. 195 pp.

Fletcher, G.L., M.A. Shears, M.J. King, P.L. Davies and C.L. Hew. 1988.
Evidence for antifreeze protein gene transfer in Atlantic salmon (Salmo salar). Can. J. Fish. Aquat. Sci. 45:352-357 pp.

Gjerde, B. 1986.
Growth and reproduction in fish and shellfish. Aquaculture 57:37-55 pp.

Glebe, B.D., J. Delabbio, P. Lyon, R.L. Saunders and S. McCormick. 1986.
Chromosome engineering and hybridization of Arctic char (Salvelinus alpinus) and Atlantic salmon (Salmo salar) for aquaculture. EIFAC/FAO Symposium on selection, hybridization and genetic engineering in aquaculture of fish and shellfish for consumption and stocking, Bordeaux. 27-30 May.

Glebe, B.D., T.D. Appy and R.L. Saunders. 1979.
Variations in Atlantic salmon (Salmo salar) reproductive traits and their implications in breeding programs. International Con. Explor. Sea. C.M. 1979/M:23, 11 pp.

Glebe, B.D., and R.L. Saunders. 1986.
Genetic factors in sexual maturity of cultured Atlantic salmon (Salmo salar) parr and adults reared in sea cages. [IN]: D.J. Meerburg (Eds.). Salmonid age at maturity. Can. Spec. Publ. Fish. Aquat. Sci. 89. 24-29 pp.

Glude, J.B. 1978.
The Pacific and Atlantic salmon, genera Oncorhynchus and Salmo. A literature review and analysis of the use of thermal effluent in culture of Pacific and Atlantic salmon. John B. Glude Aquaculture Consultant, Seattle, Washington.

Gunnes, K. and T. Gjerdem. 1978.
Selection experiments with salmon IV. Growth of Atlantic salmon during two years in the sea. Aquaculture 15:19-33 pp.

Hoyle, R. 1989.
Project Coordinator, Aquaculture, Newfoundland Department of Fisheries. Personal communication.

Huet, M. 1986.
Textbook on fish culture: breeding and cultivation of fish. Second edition. In collaboration with J.A. Timmermans. Translated by H. Kahn. Fishing News Books Ltd. Surrey, England. 438 pp.

Hunter, G.A. and E.M. Donaldson. 1985.
Contribution of ocean released sterile coho to the commercial and sports fishery. [IN]: Salmonid Reproduction: An International Symposium. R.N. Iwamoto and S. Sower (Eds.), Washington Sea Grant Program, University of Washington, Seattle.

Johnston, C.E., R.W. Gray, A. McLennan and A. Paterson. 1987.
Effects of photoperiod, temperature and diet on the reconditioning response, blood chemistry and gonad maturation of Atlantic salmon kelts (Salmo salar) held in freshwater. Can. J. Fish. Aquat. Sci. 44:702-711 pp.

Kjolseth, G. 1981.
Heat exchange from seawater and its use in a smolt production plant in the polar region of Norway. [IN]: Proc. World Symp. on Aquaculture in Heated Effluents and Recirculation Systems, Stavanger, 28-30 May, 1980. Vol. I. Berlin 1981. 327-346 pp.

Lear, W.H. 1980.
The pink salmon transplant experiment in Newfoundland. [IN]: J. Thorpe (Eds.) Salmon Ranching Academic Press, Toronto. 213-243 pp.

Leitritz, E., and R.C. Lewis. 1980.
Trout and salmon culture (hatchery methods). California Department of Fish and Game and University of California, Division of Aquacultural Sciences. California Fish Bulletin Number 164. 197 pp.

McCormick, S.D., R.L. Saunders, E.B. Henderson and P.R. Harmon. 1987.
Photoperiod control of parr-smolt transformation in Atlantic salmon (Salmo salar): changes in salinity tolerance, gill Na+, K+ - ATpase activity, and plasma thyroid hormones. Can. J. Fish Aquat. Sci. 44:1462-1468 pp.

McNeil, W.J. and J.E. Bailey. 1975.
Salmon rancher's manual. National Marine Fisheries Service, Northwest Fisheries Centre, Seattle. Processed report.

Marine Sciences Research Laboratory. 1980.
Bay D'Espoir aquaculture feasibility study. Volume II. Prepared for Bay D'Espoir Development Association and Newfoundland Department of Fisheries. MSRL Contribution No. 409.

Murphy, L. 1987.
Overwintering. [IN]: J.F. Roache (Ed.). From Atlantic Canada Aquaculture Workshop, Charlottetown, Prince Edward Island, February 10-12, 1987. Proceedings Volume II (Salmonids). General Education Series #5. 106-112 pp.

Myers, R.A., J.A. Hutchings and R.J. Gibson. 1986.
Variation in male parr maturation within and among populations of Atlantic salmon, Salmo salar. Can. J. Fish. Aquat. Sci. 43:1242-1248 pp.

Myrseth, B. 1988.
New species development and technological advances in aquaculture in Europe. [IN]: Aquaculture International Congress and Exposition, Vancouver, September 6-9, 1988. Congress Proceedings. Aquaculture International Congress and British Columbia Pavilion Corporation. 29-39 pp.

Pepper, V. 1989.
Biologist, Freshwater and Anadromous Program, Department of Fisheries and Oceans. Personal communication.

Pepper, V.A., T. Nicholls and N.P. Oliver. 1987.
Seminatural rearing of Atlantic salmon (Salmo salar) in Newfoundland. Can. J. Fish. Aquat. Sci. 44:337-347 pp.

Pepper, V.A. and P. Parsons. 1987.
An experiment on aquaculture potential of Atlantic salmon, Salmo salar L., kelts in Newfoundland, Canada. Aquaculture and Fisheries Management 1987, 18, 327-344 pp.

Peterson, R.H., H.C.E. Spinney and A. Sreedharan. 1977.
Development of Atlantic salmon (Salmo salar) eggs and alevins under varied temperature regimes. J. Fish. Res. Board Can. 34:31-43 pp.

Piferrer, F. and E.M. Donaldson. 1988.
Progress in the development of sex control techniques for the culture of Pacific salmon. Proceedings Aquaculture International Congress, Vancouver, B.C.

Piper, R.G., I.B. McElwain, L.E. Orme, J.P. McCraren, L.G. Fowler and J.R. Leonard. 1982.
Fish hatchery management. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 517 pp.

Power, G. 1981.
Stock characteristics and catches of Atlantic salmon (Salmo salar) in Quebec, and Newfoundland and Labrador in relation to environmental variables. Can. J. Fish. Aquat. Sci. 38:1601-1611 pp.

Pratt, J.D. 1984.
Salmon resource development in Newfoundland and Labrador. Canada Department of Fisheries and Oceans, St. John's, Newfoundland. 35 p plus Appendices.

Refstie, T. and T. Gjedrem. 1975.
Hybrids between salmonidal species: hatchability and growth rate in the freshwater period. Aquaculture 6:333-342 pp.

St. Croix, M. 1989.
Technician, Newfoundland Department of Fisheries. Personal communication.

Saunders, R.L. 1986.
The thermal biology of Atlantic salmon: influence of temperature on salmon culture with particular reference to constraints imposed by low temperature. [IN]: L. Nyman and B. Ericsson. Aquaculture in subarctic areas. Institute of Freshwater Research, Drottringholm, Sweden. Report No. 63.

Saunders, R.L., E.B. Henderson and P.R. Harmon. 1987.
Extended daylength during autumn enhances growth of juvenile Atlantic salmon. Proc. Ann. Meet. Aquacult. Assoc. Canada. 1:32-33 pp.

Saunders, R.L., E.B. Henderson, B.D. Glebe and E.J. Loudenslоger. 1983.
Evidence of a major environmental component in determination of the grilse: larger salmon ratio in Atlantic salmon (Salmo salar). Aquaculture 33:107-118 pp.

Saunders, R.L. and C.B. Schom. 1985.
Importance of the variation in life history parameters of Atlantic salmon (Salmo salar). Can. J. Fish. Aquat. Sci. 42:615-618p.

Scarth, D.H.C. 1977.
The potential of coastal lagoons for the cultivation of salmonids to marketable size. Bachelor of Arts Thesis, Department of Geography, Memorial University of Newfoundland. 87 pp.

Scott, W.B. and E.J. Crossman. 1973.
Freshwater fishes of Canada. Canada Department of the Environment. Fisheries Research Board. Bulletin 184, 966p.

Scott, W.B. and M.G. Scott. 1988.
Atlantic fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219. 731p.

Sedgewick, S.D. 1988.
Salmon farming handbook. Fishing News Books Ltd. Surrey, England. 207p.

Shawmont Newfoundland Limited. 1979.
Feasibility and site selection study for a multi-purpose fish rearing facility on the Island of Newfoundland. Prepared for Fisheries and Environment Canada, St. John's, Newfoundland.

Shepherd, B.G. 1984.
The biological design process used in the development of federal government facilities during Phase I of the Salmonid Enhancement Program. Canada Department of Fisheries and Oceans. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1275. 188p.

Sigma Environmental Consultants Ltd. 1983.
Summary of water quality criteria for salmonid hatcheries. Revised edition October 1983. Prepared for Department of Fisheries and Oceans. SECL 8067, 163 pp.

Sowerbutts, B.J. and J.R.M. Forster. 1981.
Gases exchange and reoxygenation. Proc. World Symp. on Aquaculture in Heated Effluents and Recirculation Systems, Stravanger 28-30 May, 1980. Vol. I. Berlin 1981. 199-217p.

Standal, M., and B. Gjerde. 1987.
Genetic variation in survival of Atlantic salmon during the sea rearing period. Aquaculture 66:197-207p.

Sutterlin, A. 1989.
Aquaculturist with the Bay D'Espoir Salmon Hatchery. Personal communication.

Sutterlin, A.M. 1988.
The feasibility of using cooling water from the Roddickton Generating Plant for aquaculture. Submitted to the Great Northern Peninsula Development Corporation, Plum Point, Newfoundland.

Sutterlin, A.M., J. Holder, and T.J. Benfey. 1987.
Early survival rates and subsequent morophological abnormalities in landlocked, anadromous and hybrid (landlocked X anadromous) diploid and triploid Atlantic salmon. Aquaculture 64:157-164 pp.

Sutterlin, A.M. 1981.
Diversion methods and water quality problems associated with the utilization of hydroelectric waste heat in salmonid culture. From Proc. World Symp. on Aquaculture in Heated Effluents and Recirculation Systems. Stravanger 28-30, May 1980, Vol. 1. Berlin.

Sutterlin, A.M., C. Couturier, and T. Deversaux. 1984.
A recirculation system using ozone for the culture of Atlantic salmon. Prog. Fish Cult. 46:239-244p.

Sutterlin, A.M., P. Harmon and B. Young. 1978.
Preocious sexual maturation in Atlantic salmon (Salmo salar) postsmolts reared in seawater impoundment. J. Fish. Res. Board Canada 35:1269-1272p.

Svealv, T.L. 1988.
Inshore versus offshore farming. Aquacultural Engineering. 7:279-287 pp.

Thorpe, J. 1980.
Salmon ranching. Academic Press, Toronto. 441 pp.

Villarreal, C.A. and J.E. Thorpe. 1985.
Gonadal growth and bimodality of length frequency distribution in juvenile Atlantic salmon (Salmo salar). Aquaculture 45:249-263.

Wallace, J. and T. Heggbert. 1988.
Incubation of eggs of Atlantic salmon (Salmo salar) from different Norwegian streams at temperatures below 1°C. Can. J. Fish. Aquat. Sci. 45:193-196p.

Watkins, L. 1989.
Manager, Bay D'Espoir Salmon Growers Cooperative. Personal communication.

Wheaton, F.W. 1985.
Aquacultural engineering. Robert E. Krieger Publishing Company. Malabar, Florida. 708 pp.

A.4.2 Rainbow Trout

Bye, V.J. and R.F. Lincoln. 1986.
Commercial methods for the control of sexual maturation in rainbow trout (Salmo gairdneri R). Aquaculture 57:299-309 pp.

Castledine, A.J. 1988.
Aquaculture in Ontario. Ontario Ministry of Natural Resources, Ministry of Agriculture and Food and Ministry of Environment. Toronto, Ontario. 1988 Revision. 80 pp.

Castledine, A.J., C.Y. Cho, H.W. Ferguson, J.D. Hynes and S.J. Slinger (Eds.). 1984.
Handbook of fish culture. Ontario Ministry of Agriculture and Food, Ministry of the Environment and Ministry of Natural Resources.

Driscoll, J. 1981.
Aquaculture methods in Newfoundland (an introduction). Newfoundland and Labrador Department of Fisheries, Development Branch. St. John's, Newfoundland. Report No. 24. 32 pp.

Edwards, D.J. 1978.
Salmon and trout farming in Norway. Fishing News Books Limited. Surrey, England. 195 pp.

Gjerde, B. 1986.
Growth and reproduction in fish and shellfish. Aquaculture 57:37-55 pp.

Hart, J.L. 1973.
Pacific fishes of Canada. Fisheries Research Board of Canada. Bulletin 180. 740 pp.

Huet, M. 1986.
Textbook on fish culture: breeding and cultivation of fish. Second edition. In collaboration with J.A. Timmermans. Translated by H. Kahn. Fishing News Books Ltd. Surrey, England. 438 pp.

Klontz, G.W., P.C. Downey and R.L. Focht. 1979.
A manual for trout and salmon production. Prepared for Sterling H. Nelson & Sons Inc., Murray Elevators Division, Murray, Utah. 22 pp.

* Leahy, L. 1989.
Owner, Rainbow Trout Farm Ltd., Hopeall. Personal communication.

Leitritz, E., and R.C. Lewis. 1980.
Trout and salmon culture (hatchery methods). California Department of Fish and Game and University of California, Division of Aquacultural Sciences. California Fish Bulletin Number 164. 197 pp.

Liao, P.B. 1971.
Water requirements of salmonids. Prog. Fish. Cult. 33(4)210 pp.

Saskatchewan Department of Parks, Recreation and Culture. 1988.
Aquaculture in Saskatchewan dugouts and ponds. Saskatchewan Department of Parks, Recreation and Culture, Fisheries Branch. 20 pp.

Scott, W.B. and E.J. Crossman. 1973.
Freshwater fishes of Canada. Canada Department of the Environment. Fisheries Research Board. Bulletin 184, 966p.

Scott, W.B. and M.G. Scott. 1988.
Atlantic fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219. 731p.

Small, S.A. and T.J. Benfey. 1987.
Cell size in triploid salmon. J. Exp. Zool. 241:339-342 pp.

Stevenson, J.P. 1987.
* Trout farming manual. Second edition. Fishing News Books Ltd., Farnham, Surrey, England. 259p.

A.4.3 Arctic Char

Babtie, Shaw and Morton. 1986.
Standardized Atlantic salmon smolt units. New Brunswick Department of Fisheries Report, July 1986.

Baker, R. 1981.
Survival and development of Arctic char eggs and fry at four different temperatures. From: Waste Heat Aquaculture Interim Report - 1981, prepared by M.H. Papst for Noval Technologies Ltd.

Brown, E.E. 1983.
World fish farming: cultivation and economics. Second edition. AVI Publishing Company Inc., Westport Connecticut. 516 pp.

Byrnes, J. 1989.
General Manager, Elders Aqua Farms Ltd., Winnipeg, Manitoba. Personal communication.

Delabbio, J. and B.D. Glebe. 1988.
The potential of Canadian Arctic char as a commercial mariculture species. International Symposium on Chars and Masu Salmon, Sapporo, Japan.

Delabbio, J.L., M. Sweeney, D.B. Glebe. 1989.
Effects of body size and male steroid treatment on seawater tolerance in Arctic char. World Aquaculture 20(1):77-78 pp.

Gjedrem, T. 1975.
Survival of Arctic char in the sea during fall and winter. Aquaculture 6:189-190 pp.

Gjedrem, T., and K. Gunnes. 1978.
Comparison of growth rate in Atlantic salmon, pink salmon, Arctic char, sea trout and rainbow trout under Norwegian farming conditions. Aquaculture 13:135-141 pp.

Glebe, B. 1989.
Director, Aquaculture, Huntsman Marine Science Centre, St. Andrews, New Brunswick. Unpublished data.

Glebe, B.D., J. Delabbio, P. Lyon, R.L. Saunders and S. McCormick. 1986.
Chromosome engineering and hybridization of Arctic char (Salvelinus alpinus) and Atlantic salmon (Salmo salar) for aquaculture. EIFAC/FAO Symposium on selection, hybridization and genetic engineering in aquaculture of fish and shellfish for consumption and stocking, Bordeaux. 27-30 May.

Huet, M. 1986.
Textbook on fish culture: breeding and cultivation of fish. Second edition. In collaboration with J.A. Timmermans. Translated by H. Kahn. Fishing News Books Ltd. Surrey, England. 438 pp.

McCart, P.J. 1980.
A review of the systematics and ecology of Arctic char in the western Arctic. Fish. Aquat. Sci. Tech. Report 935, Western Region, Winnipeg.

McCrimmon, H.R. 1984.
An overview of aquaculture in central Canada. [IN]: G.I. Pritchard (Ed.). Proceedings of the National Aquaculture Conference. Strategies for Aquaculture Development in Canada, St. Andrews, New Brunswick, July 10-14, 1983. Department of Fisheries and Oceans. Canadian Special Publication of Fisheries and Aquatic Sciences 75. 42-55 pp.

Myrseth, B. 1988.
New species development and technological advances in aquaculture in Europe. [IN]: Aquaculture International Congress and Exposition, Vancouver, September 6-9, 1988. Congress Proceedings. Aquaculture International Congress and British Columbia Pavilion Corporation. 29-39 pp.

Nordeng, H. 1983.
Solution to the "char problem" based on Arctic char in Norway. Can. J. Fish. Aquatic. Sci. 40:1372-1387 pp.

Papst, M.H., and G.E. Hopky. 1983.
Growth of Arctic char (Salvelinus alpinus L.) in a pilot commercial rearing system. Canada Department of Fisheries and Oceans. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1182. 16 pp.

Papst, M.H., and G.E. Hopky. 1984.
Development of an Arctic char (Salvelinus alpinus L.) broodstock. Aquaculture 43:323-331 pp.

Papst, M.H., and G.E. Hopky. 1989.
Aquaculture potential of Arctic char. Aquaculture Association of Canada. Bulletin 89-2:15-19.

Refstie, T. and T. Gjedrem. 1975.
Hybrids between salmonidal species: hatchability and growth rate in the freshwater period. Aquaculture 6:333-342 pp.

Reinsnes, T.G. and J.C. Wallace. 1988.
The Arctic char as a farmed fish. Feskeriteknologisk Forskningsinstitutt Rapport U.41. 34 pp. (Can. Transl. Fish. Aquat. Sci. No. 5404).

Scott, W.B. and E.J. Crossman. 1973.
Freshwater fishes of Canada. Canada Department of the Environment. Fisheries Research Board. Bulletin 184, 966p.

Scott, W.B. and M.G. Scott. 1988.
Atlantic fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219. 731p.

Wallace, J.C., A.G. Kolbeinshaun and T.G. Gunnes. 1988.
The effects of stocking density on early growth in Arctic char (Salvelinus alpinus L.). Aquaculture 73:101-110 pp.

Wandsvik, A. and M. Jobling. 1982.
Overwintering mortality of migratory Arctic char reared in seawater. J. Fish. Biol. 20:701-706p.

APPENDIX B

SHELLFISH

APPENDIX B - SHELLFISH

TABLE OF CONTENTS

B.0 SHELLFISH

B.1 BLUE MUSSELS (*Mytilus edulis*)

B.1.1 State of Culture Technology

B.1.1.1 Culture Development Within Newfoundland

The Ocean Sciences Center (previously the Marine Sciences Research Laboratory) of Memorial University surveyed mussel beds within the province to determine whether a sustainable yield could be maintained and a large industry could be supported (Sutterlin et al. 1981). At that time, a pilot mussel farm was established in Garden Cove to examine the feasibility of commercial mussel culture. Over the 1970's, potential culture sites were identified and spat collection trials were conducted within Notre Dame, Bonavista and Trinity Bays, and various grow-out gear was developed and tested. In 1981, the pilot mussel farm in Garden Cove was taken over by private interests, who established the first large-scale commercial mussel farm in Fortune Harbour, Notre Dame Bay (Atlantic Ocean Farms Ltd.).

Until 1985, only a few individuals were involved in mussel aquaculture. During that year, the province of Newfoundland and Labrador introduced an incentive program that provided small amounts of gear to interested parties so that they could experiment with mussel cultivation (Burford 1988). This program led to a dramatic increase in the number of established farms. At present, there are over 100 operations within Newfoundland which are actively involved in various stages of mussel production. Table B1.1 indicates the estimated production of cultured blue mussels in Newfoundland for 1988.

B.1.1.2 Culture Methods

Mussel culture is undertaken in many countries (e.g., United States [Maine], the Netherlands, Spain, France, Chile, New Zealand) and a number of culture methods are used commercially based on local conditions; these are outlined below. One method, longline culture, has been found to be the most suitable for use in Newfoundland (Sutterlin et al. 1981; Smith and Goddard 1988).

TABLE B1.1: THE ESTIMATED PRODUCTION OF CULTURED BLUE MUSSELS FOR 1988. (Source: Smith 1988)

SITE	ESTIMATED PRODUCTION (LBS.)
Charle's Arm, Botwood Peninsula*	50,000
Sandringham, Eastport Peninsula*	25,000
Burnside, Eastport Peninsula*	20,000
Burnt Arm, New World Island*	20,000
Burnt Arm, New World Island	65,000
Traytown, Eastport Peninsula	45,000
St. Jones within Trinity Bay*	20,000
Sunnyside, Trinity Bay*	10,000
Trap Cove, Roddickton	25,000
Fortune Harbour, Botwood Peninsula	200,000
Aquaforte, Southern Shore*	10,000
Grey Island, Connaigne Bay	5,000
TOTAL	495,000

* New producers in 1988.

B.1.1.2.1 Bottom Culture

Bottom culture is the simplest form of culture and is mainly carried out along the coasts of Germany, the Netherlands and the State of Maine. It involves the transfer of juvenile mussels, that have achieved shell lengths of between 8 and 13 mm, to suitable grow-out sites. The juveniles are spread over the bottom in shallow, subtidal waters. Mussels grown by this method are the most susceptible to predation by invertebrates such as starfish and crabs, and usually provide lower quality and quantity meat yields.

B.1.1.2.2 Bouchot Culture

This methodology was developed in France, and is described as a "near-bottom" method. Seed mussels are collected on ropes and after a period of a few weeks, are transferred to plastic net tubes. The flexible mesh tubes are wrapped around bare poles placed intertidally and the mussels are left to grow to marketable size.

B.1.1.2.3 Raft Culture

This methodology is extensively used by the Spanish. Spat are collected on ropes or a similar collecting material that is suspended in the water by wooden rafts. Due to their rapid growth, they must be thinned and transferred to socks in which they grow until harvested.

B.1.1.2.4 Longline Culture

This methodology is commonly used in Newfoundland. It is similar to raft culture in that spat is collected on material that is hung from the surface of the water. Suitable collection material includes plastic mesh, rope or twine. Rope is used in most commercial operations within the province due to its availability, cost and effectiveness.

As with raft culture, the mussels must be transferred to socks to prevent them from falling off the spat collection material. To prevent winter storm and ice damage, the mussel gear is sunk prior to ice formation.

During the mid 1970's, the Marine Research Sciences Laboratory of the Memorial University of Newfoundland experimented with raft culture as a means of spat collection and grow-out (Sutterlin et al. 1981). However, this form of culture was generally less successful than longline culture. At present, longline culture is used exclusively along the coasts of Newfoundland (Smith and Goddard 1988; and I. Burford, personal communication).

In Newfoundland, longline mussel culture utilizes the following basic equipment:

- 13-15 mm rope for mainlines and spat collectors;
- mussel socking in which to sock the seed mussels;
- floats to support collectors and socks; and
- an anchoring system to maintain the position of the farm.

Longline systems consist of a mainline that is anchored on both ends and supported by floats. Longlines are often established in bays that are less than 1 km in width so that they may be stretched from shore to shore and anchored by shore fastenings. Offshore anchors are used only if the culture is established in a bay that is too wide to permit shore fastenings. Shore fastenings are advantageous because they are less expensive than anchored longlines and are accessible for inspection and maintenance.

Flotation is provided by 205 litre (45 gallon) drums if the gear does not have to be sunk. Gear is sunk only if there is the possibility of damage due to fast or pack ice. If the ice is less than 45 cm thick, the gear is usually not in danger of being damaged and therefore does not have to be sunk (L. Green, personal communication). If the ice thickness is greater than 45 cm, flotation is provided by #2 styrofoam lobster buoys. These buoys are small enough to allow the gear to be sunk below the ice without the addition of a great deal of weight.

Similar systems are used for both spat collection and mussel grow-out. Several materials have been developed for spat collection, however, in Newfoundland, rope is normally used due to its performance, availability and low cost. Pieces of rope that are two or three meters in length are weighted and hung from the mainline. The spacing may be such that there are two or three ropes per meter hanging from the mainline. Spat collectors are hung prior to the spawn, which is usually during summer. After the spat have settled and have grown to a minimum size of 10 mm, they are stripped from the collectors and placed into socks.

Mussel socking is used for grow-out and is available in a variety of sizes. The mesh sizes that are most frequently used are 11 mm, 20 mm, and 25 mm. The choice of mesh size depends upon the size of spat that is available. The spat must be able to move through the mesh for reattachment to the outside surface of the socking material. For this reason, it is important that the correct mesh size is chosen. Experience has shown that the optimal density for filling socks is between 800 and 1,000 spat per meter (Smith and Goddard 1988). The production cycle to a minimum marketable size length of 5.5 cm takes approximately 18 to 36 months in Newfoundland.

B.1.2 Siting Requirements for Culture Facilities

B.1.2.1 Biological Overview

B.1.2.1.1 Life Cycle

In Newfoundland, blue mussels generally spawn between late June and late September when temperatures range from 12°C to 18°C (Sutterlin et al. 1981). Time of spawning is variable due to local environmental conditions such as temperature. The gametes are released into the water column where fertilization takes place. Subsequent development is positively temperature dependent. A summary of developmental stages and times is presented in Table B1.2. In this example the surface water temperature is 18°C.

TABLE B1.2: LIFE HISTORY OF *MYTILUS EDULIS* (AT 18°C).
(Sources: Sutterlin *et al.* 1981; and Lutz 1985)

DEVELOPMENTAL STAGE	APPROXIMATE TIME AFTER FERTILIZATION
EXTERNAL FERTILIZATION	0 Hours
EMBRYO	4 Hours
TROCHOPHORE LARVA	20 Hours
STRAIGHT-HINGE VELIGER	3 Days
VELICONCHA LARVA	5 Days
PEDIVELIGER LARVA	12 Days
PLANTIGRADE	20-30 Days
ADULT	2 Years

After fertilization, the organism passes through a series of important planktonic embryonic and larval stages before reaching the stage at which settlement has been completed (plantigrade). Embryonic cells begin to differentiate within four to five hours after fertilization, followed shortly by development of the planktonic trochophore larva. During the initial five days of development, the animal passes through several larval stages until the shell and shell hinge begin to thicken and the first concentric growth lines may be seen. The larva is then referred to as a veliconcha and during the veliconcha stage, the larva grows from approximately 11 mm to 25 mm in length (Seed 1980; Sutterlin *et al.* 1981).

Soon afterwards, "eye-spots" and a foot develop as the larva enters the pediveliger stage and is preparing itself for settlement. An animal that has settled and has not yet metamorphosed is referred to as spat. The settlement of spat is known as spatfall and generally begins in July and August. Settling continues for two to three months with the peak occurring between August and September (Sutterlin *et al.* 1981).

As metamorphosis takes place, byssal threads are secreted and the organs within the mantle cavity are reorganized. Throughout metamorphosis, the spat rely on accumulated energy reserves. Once metamorphosis is complete, the mussel is at the plantigrade stage and is no longer a larva. The adult shell, which is known as the dissoconch, is secreted as the mussel grows to maturity. In Newfoundland waters, maturity is usually reached within two years.

B.1.2.1.2 Factors Affecting Growth and Development

1. Larval Development

As indicated above, the pre-settlement stages of *M. edulis* are planktonic. Prior to the pediveliger stage, larvae exhibit positive phototaxic and negative geotaxic responses (Bayne 1965; and Sutterlin *et al.* 1981). For this reason, the near surface conditions of the water column are important in early development. The most important factors affecting larval development are: temperature, salinity and the availability of food.

In nature, these factors are not mutually exclusive in affecting the physiology of an animal. Bayne (1965) found that larval development was temperature dependent, however, salinity must also be considered. Brenko and Calabrese (1969) found that optimum growth of M. edulis larvae occurred at 20°C and salinities between 25 and 30 ppt. They found that growth rates decreased at temperatures above 25°C and below 10°C and at salinities higher than 30 ppt. Similar ranges in temperature for optimal growth are noted by Cook et al. (no date). Due to regional ice melt and drainage from watersheds around Newfoundland, it is not possible to make similar generalizations about salinities. However, one may expect settling to begin 20 to 35 days after spawning (Sutterlin et al. 1981).

The larval mussel feeds mainly upon suspended organic matter including phytoplankton. Bayne (1965) notes that the availability of food affects the rate of development of larval blue mussels. Both quantities and qualities of food are influenced by seasonality, depth and regional geography.

Unlike the earlier larval stages, the pediveliger larva responds to light and gravity by being negatively phototaxic and positively geotaxic. The animal searches for suitable substrate by withdrawing its velum and sinking. When it reaches the substrate, it uses its foot to crawl until it either attaches to the substrate by a byssus or withdraws its foot and swims off.

Spat favour filamentous substrates but will become attached to almost any hard or semi-hard surface as long as it is not toxic. If suitable substrate is not found, metamorphosis may be delayed for 12 to 22 days after which time the velum begins to degenerate and the animal stops feeding (Bayne 1965).

2. Juvenile Growth and Maturation

The growth of juvenile and adult mussels must be measured in terms of both length and weight. Growth in terms of length may be positive or zero, whereas, growth in terms of weight may be positive, zero or negative.

In terms of length, smaller animals grow at a faster rate than do large animals. At Garden Cove, Placentia Bay, Sutterlin et al. (1981) notes that when expressed as monthly increases, the smallest mussels averaged 25% increments per month compared to 8% per month for the largest mussels.

As with larvae, the growth of juveniles is positively dependent upon temperature. Over the geographic range of the blue mussel, growth rates vary considerably. The time required for wild mussels to reach the commercially accepted length of 5.5 cm may vary from less than two years to more than six years (Bayne and Worrall 1980). With blue mussels indigenous to the Labrador coast, however, very few animals grow to a length greater than 5.5 cm (Fletcher and Haggerty 1975). Within the Newfoundland context, cultured mussels are usually harvested between 18 months (T. Mills, personal communication) and 30 months (Smith 1988; D. Walsh, personal communication) after collection of spat. These differences in growth rates are due to differences in temperature regimes and the availability of food which are dependent upon geographic location.

Temperatures and other growing conditions in near-shore waters can be modified by bathymetry as well as by shoreline landforms. For example, when compared with many other mussel growing areas in Newfoundland, the mussels grown within Charles Arm, Notre Dame Bay, exhibit a relatively fast growth rate (T. Mills, personal communication). This is apparently due to the shoreline being lined by slate, which reflects sunlight thus warming the surface water, and by the presence of sills along Charles Arm, which hinder mixing by tidal water.

Growth in terms of weight is known to undergo pronounced seasonal oscillations that are related to cycles in storage and utilization of energy reserves, as well as the development and release of gametes (Bayne and Worrall 1980; and Lutz 1985). There is a significant loss of weight immediately following the spawn (Thompson 1979; and Bayne and Worrall 1980) since the gametes contribute greatly to the total weight of the animals. Positive growth occurs during the spring plankton bloom and during the summer as food reserves are being stored, while negative growth occurs during the winter as these reserves are being utilized for maintenance and gametogenesis.

B.1.2.2 Distribution of Stocks and Spatfall Areas in Newfoundland/Labrador

The combination of planktonic larval stages and the ability to delay metamorphosis are important dispersal mechanisms that allow blue mussels to attain a wide geographic distribution. Its latitudinal range extends from the 27°C surface water isotherm near Cape Hatteras to Labrador and into the fringes of the Canadian eastern arctic (Fletcher and Haggerty 1975; Incze et al. 1980; and Gilkinson, personal communication). Mussel populations may be found within several of the bays around Newfoundland, however, they vary considerably in size; with scattered colonies being the norm (Scaplen 1970; and Sutterlin et al. 1981). Wild mussel beds have also been located along the Labrador coast (Sandwich Bay, Alexis Bay, St. Michael's Bay and St. Lewis' Bay), however, very few of these animals were greater than 5.5 cm in length. The mussels therefore were of no commercial value (Fletcher and Haggerty 1975).

When in a good habitat, relatively few mussels are required to serve as broodstock since much of their pre-spawn weight comprises gametes. The gametes of small adults account for 20 to 30% of their total weight and as the animals grow this proportion increases until reaching 50 to 59% in the largest animals (Thompson 1979).

Care must be taken when choosing a mussel farming location on the basis of the presence of larvae within the water, because as previously mentioned, larvae may travel in the water column for days until they find a suitable substrate on which to settle. This would be a problem if bottom culture was being attempted. Conversely, the presence of adults does not ensure good spatfall. Sutterlin et al. (1981) summarize the results of mussel stock surveys undertaken in the late 1960's and early 1970's in Notre Dame, Bonavista, Trinity, Conception and Placentia Bays. Major mussel beds were found in:

- Notre Dame Bay (seven sites);
- Bonavista Bay (49 sites);
- Trinity Bay (one site);
- Conception Bay (one site); and
- Placentia Bay (one site).

Few pediveliger larvae were recovered from Bellevue (in Trinity Bay) during spatfall surveys, 1972 to 1976, even though a dense population exists. Historical evidence suggested that the mussels did spawn and that the gametes were normal during those years (Sutterlin et al. 1981).

B.1.2.3 Physical Siting Requirements

The siting requirements for blue mussel culture are summarized in Table 2.7 and described briefly below.

B.1.2.3.1 Exposure to Wind, Waves and Swells

Exposure to rough water and excessive winds can damage culture equipment, knock mussels off lines, cause anchoring problems, and create dangerous conditions for work and water travel. Therefore, sites facing ocean swells and prevailing winds are avoided. In more sheltered areas, fetch length combines with wind direction, velocity and duration in determining wave height. Under some circumstances, fetches from 1 to 2 km can produce wave heights of 0.6m, an ideal maximum for mariculture. Wave heights up to 1.2m may be acceptable for floating culture systems (Table 2.7) but fetches greater than 3-4 km should be avoided (Sutterlin et al. 1981).

The ideal site would be a tickle (narrows) between an island and the shore, between two islands or in a well protected bay where winter ice will melt in place rather than break up and drift. Sites should ideally be oriented perpendicular to the most severe wind vector (Sutterlin et al. 1981). In some cases, relatively rough seas can be avoided by using sub-surface longlines.

B.1.2.3.2 Currents and Water Exchange

Currents are important as they carry food to the mussels, however, excessive currents may cause displacement of gear and suspended culture equipment may tangle and wear prematurely. Suspended culture systems can handle varying current velocities, according to their design. Rafts are generally limited to about 0.5 kn (25 cm/s), while longlines with improved anchoring systems can utilize currents up to 4 kn (200 cm/s). New Zealand longline systems are generally designed for velocities up to 2.5 kn (125 cm/s) (Jenkins 1985).

Water exchange is important for removing nitrogenous wastes and mixing water thereby stabilizing temperatures and salinities, and maintaining high oxygen levels. In extreme situations, waters may either be stagnant or have currents too strong. In low-current sites (such as in bays constricted by topography or underwater sills), inadequate nutrients, excessive temperatures and accumulation of metabolic wastes may occur. Depending upon the temperature regimes that occur, incomplete water exchange may enhance the growth rates of the mussels. At a culture site in Charle's Arm, complete mixing is not allowed due to the presence of sills. This resulted in increased temperatures which directly increased the growth rates of the mussels as well as presumably causing an increase in phytoplankton production.

B.1.2.3.3 Ice Conditions

Both moving pack ice and moving shore ice can damage, destroy or displace gear (Sutterlin et al. 1981). Fast ice frequently occurs within the bays and fiords on all coasts. Preferrably, ice thickness will be less than 1 m, but thick enough to carry the weight of personnel and equipment. Ideally, no drifting ice (either pack ice or shore ice) would occur. If drifting ice occurs, the lines must be submerged, or alternatively, one can experiment with the use of wooden or rope booms or ice anchors (Beveridge 1987) to eliminate the problem of moving ice flows.

B.1.2.3.4 Water Depth and Bottom Type

The greatest growth of mussels will be within the top 5 m as the bulk of the phytoplankton production and warmer water is near the surface during the summer months. The water must be deep enough to allow the longlines to be submerged below the predicted ice depth, while being far enough above the bottom to prevent access by benthic predators. An optimum depth is approximately 10-20 m, while the minimum acceptable range might be from 4m to as much as 40m (Somers 1988; Jenkins 1985). Fine sediments can indicate low currents and water exchange in near bottom areas.

For suspended culture, the type of bottom is important to determine the type and size of anchoring systems. Rocky bottoms are difficult to anchor in, while firm mud, sand, clay and shell is best. Sand bottoms may require that anchors be buried with diver assistance (Hemming 1988).

If bottom culturing is being carried out, then the bottom must be hard, non-toxic and such that the mussels may easily be harvested.

B.1.2.3.5 Potential Siting Conflicts

As with finfish culture in netpens (Appendix A), a culture siting will not be allowed if it creates conflicts with the traditional commercial fisheries in the area, other navigational activities, or recreational interests.

B.1.2.4 Biological Siting Requirements

B.1.2.4.1 Temperature

Growth occurs between 3 and 25°C (Sutterlin *et al.* 1981): an optimum temperature for post-larval growth is 15°C, while 11-17°C is an acceptable range for growth (Bernard 1983). Blue mussels tolerate temperatures from 0-26°C (Mason 1972), but temperatures above 20°C can cause stress, sloughing and possibly mortalities (Somers 1988).

B.1.2.4.2 Salinity

During the spring and early summer ice melt, a layer of freshwater is created that may cause drastic changes in salinity (Sutterlin et al. 1981). This may have a harmful effect upon mussels that are cultured near the surface.

An optimum salinity for culture is 26 ppt. (Bernard 1983), while an acceptable range is 25–33 ppt. or even as low as 18 ppt. (Sutterlin et al 1981; Bernard 1983), though generally salinities lower than 22 ppt. or rapid fluctuations should be avoided. The lower salinities weaken byssal threads which can result in sloughing. Growth is inhibited lower than 10 ppt. (Sutterlin et al 1981; Somers 1988)

B.1.2.4.3 Water Quality

Important considerations for shellfish health are industrial, sewage and agriculture pollution. Industrial sources include pulpmill and chemical plant effluent, mining leachate, run-off sediments from logged watersheds, and accidental spills (e.g., oil tankers, etc.). Sewage pollution is discharged by municipalities, marinas and boats. Agricultural areas are potential sources of contamination by pesticides and fertilizers. Domestic livestock may be a source of bacterial and viral contaminants in run-off waters.

Mussels are filter feeders, and as such are known to concentrate viral and bacterial agents that may be harmful to man (Sutterlin et al. 1981). In areas that are contaminated with domestic sewage and feedlots, mussels can accumulate fecal bacteria and upon testing, reveal the presence of coliform bacteria. The presence of coliform bacteria is used as an indicator of potentially harmful human pathogens.

In order to harvest mussels the culture site must be approved in compliance with water quality regulations issued under the Federal Fisheries Act (Department of Fisheries and Oceans 1989). The federal Department of the Environment conducts comprehensive sanitary surveys of shellfish growing areas and classifies their suitability for harvesting. These surveys are undertaken as part of the Canadian Shellfish Sanitation

Program (CSSP) which is administered by a national committee comprised of representatives of the Department of Fisheries and Environment Canada (the Interdepartmental Shellfish Committee) and three regional committees (Atlantic, Quebec and Pacific). The regional committees are comprised of representatives from the same federal agencies and from provincial agencies. Under the CSSP, Environment Canada carries out tri-annual water quality inspections of each commercial mussel farm. In some cases, mussels found to be growing in a contaminated area can be held in an area of clean water until they depurate.

B.1.2.4.4 Plankton Conditions

1. Beneficial Plankton

There are several useful quantitative measures of overall food availability. The most commonly used estimates are: phytoplankton cell counts, total particulate matter, chlorophyll a levels, total particulate organic matter, and total particulate organic carbon. However, the tools necessary to make these estimates are not ususally available to the average aquaculturalist.

Suspended particulate matter is perhaps the easiest, but is difficult to quantify as a food index given the variability in composition. However, in general, 5-10 mg/L is an acceptable minimum; 90 mg/L is optimum and 400 mg/L a maximum (Bernard 1983; Sutterlin et al 1981). Minimum chlorophyll a values for acceptable growth are approximately 2 mg/l.

Another means of obtaining an indication of plankton abundance is through the measurement of the amounts of turbidity of the water (ie. Secchi Disc readings). If visibility extends to beyond 5 or 6 metres during most of the spring and summer, the water is probably not productive enough. If on the other hand, visibility is less than one metre there is probably an excess of inorganic particles and silt within the water. Execessive matter causes the mussel to produce pseudofaeces which reduces the animal's feeding efficiency, thus slowing the growth rate (Sutterlin et al 1981).

2. Harmful Plankton

The species of harmful plankton of most concern to mariculturists are those carrying the paralytic shellfish poison (PSP), namely Gonyaulax excavata and its relatives. Bivalves concentrate the toxin from these flagellates, with no apparent harmful effects to themselves. Humans who eat affected shellfish, however, can become severely or even fatally ill. The maximum level of PSP toxin allowed in shellfish meat in Canada is 80 micrograms toxin/100 g meat (Quayle 1969).

Gonyaulax excavata is found in Newfoundland. Resting cysts of this phytoplankter have been found in mud near (White and White 1985):

- L'Anse au Loup, Burin Peninsula
- St. Patrick's, Notre Dame Bay
- Olive Cove, Hermitage Bay
- Picarre, Hermitage Bay
- Hardy Cove, Hermitage Bay
- North Side, Harbour Grace
- S.S. Kyle Area, Harbour Grace
- Southside, Harbour Grace

Sites known to have blooms of this plankton must be avoided.

B.1.2.4.5 Predators and Fouling

1. Predators

The following is a list of mussel predators that are commonly found in Newfoundland (Sutterlin et al. 1981; and Gilkinson, personal communication):

Birds

- Common Elder Duck (Somateria mollissima)
- Great Black-backed Gull (Larus marinus)
- Terns (Sterna spp.)

- Razorbill (Alca torda)
- Murres (Uria aalge)
- Black Guillemot (Cepphus grylle)

Fish

- Cunner (Tautogolabrus adspersus)
- Winter Flounder (Pseudopleuronectes americanus)
- Eelpout (Lycodes spp.)

Invertebrates

- Green Sea Urchin (Strongylocentrotus droebachiensis)
- Crab (Cancer irroratus)
- Lobster (Homarus americanus)
- Whelks (Nucella lapillus and Buccinum undatum)
- Moon snail (Lunatia heros)
- Starfish (Asterias vulgaris and Leptasterias polaris)

For suspended culture, the three fish species are benthic so would not normally be a problem. The common Eider Duck appears to be perhaps the most serious concern. Sites having concentrations of these birds nearby should be avoided.

Some of the invertebrate species listed have pelagic larvae (starfish, sea urchin, crab and lobster). Starfish and crabs in particular, can cause serious problems on suspended cultures.

2. Fouling

Any unwanted organism that accumulates on the mussels or gear is considered to be a form of biofouling. In waters around Newfoundland, typical fouling organisms would be hydrozoans (Tubularia spp.), bryozoans (e.g., Electra pilosa) and kelp (Laminaria spp.). Even mussel spat that accumulates on the previous year's crop is considered to be a form of fouling.

B.1.2.5 Logistics and Other Requirements

1. Site Access

A good site must be accessible under all weather conditions in order to transport supplies in, ship product out and supervise equipment to avoid theft or vandalism. Considerations are good roads and protected water routes and air access. Costs of transport are important in site selection. For larger operations in remote areas, on-site housing might be required.

2. Support Community

Services such as power, telephones, product processing and social services for personnel should be considered. A nearby labour force, especially for seasonal culture work, is valuable.

B.2 GIANT SCALLOPS (*Placopecten magellanicus*)

B.2.1 State of Culture Technology

B.2.1.1 Status of Culture in Newfoundland

Scallop culture technology began in Japan in the mid-1960's. In the early 1970's, studies were undertaken in western Newfoundland to examine the potential for using the Japanese methods for culturing the giant scallops in that area because of drastic declines in the natural stocks. Since then, studies have been made in a number of coastal areas (Aggett 1981; Naidu and Cahill 1983). Those studies indicated that in general scallop culture was viable but that some techniques (i.e., growout in small suspended cages) would be costly given the high labour costs and slow rates of growth. Scallop farming is presently being undertaken at a pilot or research level at several marine locations (Port au Port, Fortune Bay and Notre Dame Bay).

Hatchery production of scallop seed has been researched at the Ocean Sciences Centre of Memorial University since 1987 (P. Dabinet, personal communication). Technical procedures for broodstock maintenance, spawning and fertilization, larval production and transfer of juveniles to growout sites have been developed and are being refined. Hatchery production has been between approximately 100,000 and 500,000 seed per year. Current objectives are to refine production methods so that optimum production conditions and operating costs can be identified and the viability of commercial operation can be assessed.

B.2.1.2 Culture Methods

In Newfoundland, scallop culture is undertaken in three general phases:

- Phase I - Spat Collection (Year 1, Fall);
- Phase II - Intermediate Culture (Year 2, Fall); and
- Phase III - Final Growout (Years 3 to 5).

These phases are described briefly below.

B.2.1.2.1 Phase I - Spat Collection (Year 1)

The main scallop spawning period occurs during September and October. It is important that spat collectors be set immediately prior to larval settlement to avoid the settlement of predators such as starfish (Asterias vulgaris). For example, in the Garden Cove area, this species of starfish spawns mainly during August and the larval period lasts for three to four weeks (Evans et al. 1973). Therefore, the best time for setting collectors is between late September and early October.

Spat will settle on a number of clean substrates but they become detached shortly afterward. In order to trap those that fall off, spat collectors are usually fine-meshed enclosures (onion bags) packed with monofilament gillnetting. The larvae are small enough to move through the 1.5 mm mesh and become attached to the gillnet filaments. By the time they lose their byssal threads, they are too large to fall through the openings in the onion bag. Collectors are fastened to between 15 and 20 m of rope and the collector lines are attached to floats anchored so that the collectors are 2 m above the bottom (Naidu and Cahill 1983; and D. and J. Caines, personal communication).

To avoid the settling of predator larvae on the collectors, spatfall prediction is important. Gonadal index (derived by weighing the gonad tissue, dividing this weight by the total weight of all of the soft parts and expressing the result as a percent) may be used as an indicator of gonadal maturity. After spawning, the water is sampled for the presence of veliger larvae and these samples provide information pertaining to size, density and the distribution of larvae. If approximately 50% of the animals exceed 200 um, settlement may be expected to occur within a week (Cormier, unpublished data).

Within the Newfoundland context, if one is using gonadal indices as an indicator of spawning time, caution must be used. Gonadal indices indicate the ripeness of only the sample animals and not the spawning condition of animals within other populations. This is an important consideration when monitoring larvae in the water column, because the larvae can remain in the water column for up to 50 days and, therefore, could be from distant populations. The broodstock from which these animals were spawned may be several kilometers away and may have spawned a few weeks before or after those for which the gonadal indices were estimated (D. and J. Caines, personal communication).

For this reason, continual sampling of the water column gives a much better estimate of the appropriate time to set spat collectors. The problem with this method is that the larvae of P. magellanicus look very similar to the larvae of other shellfish species: the icelandic scallop (Chlamys islandica), the blue mussel (Mytilus edulis), the Arctic clam (Hiatella arctica) and the soft-shelled clam (Mya arenia) (P. Dabinett, personal communication).

As an alternative to setting spat collectors, young scallops can now be obtained from several sources (the Port au Port Development Association, or a scallop hatchery within the Ocean Sciences Center of the Memorial University of Newfoundland).

B.2.1.2.2 Intermediate Culture (Year 2)

During September and October of the second year, the young scallops are transferred to blue bags (pearl bags) for intermediate culture. Conical bags are usually preferred as they do not have corners in which the scallops may accumulate. A stocking density of 50 scallops per bag currently is considered to be appropriate, however, scallop producers are experimenting with various densities (D. and J. Caines, and R. Hoyles, personal communication). Scallops are sensitive to changes in temperature and salinity. Therefore, it is important that they be kept in cool seawater during the transfer.

A "main line" system is used as support for a series of secondary lines from which the intermediate cultures will hang. The main line is usually 2.5 cm polypropylene rope that is 100 m in length, set in water that is approximately 30 m in depth. Ten or 12, 100 cm, single-eye inflatable buoys are used to keep the main line afloat. Approximately 15 to 20 blue bags are strung vertically on each branch line that is attached to the main line. The uppermost blue bag should be placed at least 3 m from the water's surface to ensure that the animals are not exposed to low salinity water. In areas where there is danger of ice damage to the gear, the main lines are often sunk about 5 m below the surface. The gear is sunk by removing floats or by adding sand bags. Care is taken to ensure that the cultures do not touch the bottom where they would be susceptible to predation by starfish, crabs or lobsters.

The intermediate culture usually lasts for one year and by this time they should have achieved shell heights of between 30 and 50 mm (Cormier, unpublished data).

B.2.1.2.3 Final Growout (Years 3 to 5)

Final growout is carried out by one of three methods:

- broadcasting the scallops on the bottom;
- continuing with cage culture as used in the intermediate culture; or
- ear-hanging the juveniles.

Bottom culture is the least labour-intensive method. The animals are scattered on the bottom at estimated stocking densities of 5-6 per square meter (Cormier, unpublished data). The animals are left for at least two years until they are of harvestable size (10 cm shell height). Mortalities of approximately 50 % occur for bottom cultures. Harvesting is carried out using scallop dredges, or divers. Preferred growout sites for bottom culture are large coves or inlets with flat, sandy bottoms and high water exchange. If a freshwater stream runs into the cove, there will be increased primary productivity that should result in greater scallop growth rates. The depths should exceed 10 m to avoid the effects of wave action and the potential effects of low salinity. However, depths should not exceed 30 m as productivity is reduced, and the difficulty in harvesting by diving is increased at greater depths. It is important to avoid areas that have high densities of predators such as starfish, crabs (Cancer spp.) and lobsters (Homarus americanus). One reason that spat collection and intermediate culture greatly increase the success of the farm is that the scallops are kept away from these predators.

One alternative to bottom culture is to grow the scallops in cages (lantern nets) comprised of up to 20 mesh trays within mesh tubes. The lantern nets are 50 cm in diameter and when fully extended may be almost 2 m in height. Initially, 20 spat are placed into each compartment of lantern nets with 25 mm mesh. By the fall of that year, the scallops should have grown to the point that thinning is required. As a rule of thumb, the combined surface area of all of the scallops in each tray should be less than the area of the tray. At this time, the animals are probably large enough to transfer to 40 mm mesh lantern nets (Naidu and Cahill 1983).

A second alternative, ear-hanging, is to drill a hole in one of the lateral hinge ears by which the animal is hung on a branch line. The scallops are separated by 15 cm along each line (T. Mills, and D. and J. Caines, personal communication). This method is more labour-intensive during the early stages than cage culture, however, once the animals are ear-hung, they are not touched again until they are harvested. The animals are harvested in Years 4 and 5 after spat collection (Year 1).

B.2.2 Distribution of Stocks and Areas of Heavy Spatfall in Newfoundland/Labrador

Placopecten magellanicus is distributed from Cape Hatteras at 36°N to the Northern Peninsula of Newfoundland (Taguchi 1978). No wild giant scallop beds have been found in coastal areas off Labrador. The depth distribution of giant scallops is correlated with its latitudinal distribution. Near the northern limit, P. magellanicus may be found as shallow as 1 m below the low tide. However, as the southern limit is approached, the depth at which it normally occurs increases until it reaches the 46 m isobath off North Carolina (Culliney 1974).

Extensive surveys have been carried out to determine the distribution of giant scallops along the coasts of Newfoundland (Squires 1958, 1962; Suzuki 1970; Fowler and Fletcher 1975; and Murphy [no date]). The 1957 and 1958 surveys taken by Squires (1958 and 1962) covered broad coastal areas of insular Newfoundland. Subsequent scallop surveys have covered the following areas:

1. Salmonier Arm, Harricott Bay, North Harbour, Mussel Pond Cove, St. Mary's Harbour, Shoal Bay, Mal Bay, Baie Verte, Woodstock, Ming Bight, and White Bay (Suzuki 1970);

2. Bonavista Bay and Belle Bay, Fortune Bay (Fowler and Fletcher 1975); and

3. Conception Bay, Bay of Islands and Port au Port in 1975 (Murphy, no date).

Scallops have been found in each of these locations, on various substrates including mud, sand and rock.

Squires (1962) and Naidu (personal communication) suggest that larval distribution around Newfoundland may be due to currents from the Gulf of St. Lawrence. Water masses moving along the west coast of Newfoundland carry larvae through the Strait of Belle Isle. They are then moved southward along the east coast of Newfoundland by the strong southward moving Labrador current. Areas such as the Newfoundland northeast coast do not favour local restocking; however, scallop beds exist in these areas as a result of replenishment by stocks from the northern Gulf of St. Lawrence.

B.2.3 Siting Requirements for Culture Facilities

B.2.3.1 Biological Overview

B.2.3.1.1 Life Cycle

The life history of the giant scallop is summarized in Table B2.1. The giant scallop normally has separate male and female individuals. However, a study of the reproductive biology of scallops that was conducted in the Port au Port area revealed that 1.3 % of the natural population were hermaphrodites (Naidu 1970).

Timing of spawning varies due to local geographic conditions and genetic variability within as well as amongst populations. There is evidence that scallops residing

TABLE B2.1: LIFE HISTORY OF *PLACOPECTEN MAGELLANICUS* (AT BETWEEN 12 AND 15°C). (Sources: Culliney 1974; Manning 1986)

DEVELOPMENTAL STAGE	TIME AFTER FERTILIZATION
TROCHOPHORE LARVAE	30-40 Hours
STRAIGHT-HINGED VELIGER LARVAE	4 Days
APICAL FLAGELLUM IS LOST	8 Days
EYE-SPOTS AND FUNCTIONAL FOOT DEVELOP	23 Days
LARVAL SETTLEMENT	35 Days
METAMORPHOSIS	75-95 Days
ADULT	2 Years

within the shallow sandy bays of the Port au Port area may spawn twice each year. A minor spawn occurs during June while the major spawn occurs during September and October. Naidu (1970) hypothesized that since scallops are slow in acclimating to temperature changes, rapid temperature changes will stimulate a spawn. Corroborative evidence is given by Culliney (1974) who artifically induced spawning among ripe animals by raising the water temperature by 3 to 5°C. Similarly, there may be two spawns in Pool's Cove, Fortune Bay (D. Caines and J. Caines, personal communication). A healthy female scallop may produce between 80 and 100 million eggs each year (Naidu and Cahill 1983).

Little research has been carried out to determine the minimum or optimum growth conditions of Placopecten magellanicus. The following discussion is based largely upon the laboratory work of Dr. J. Culliney (1974) and a literature review carried out by Manning (1986). At temperatures between 12 and 15°C the first larval swimming stage (trochophore larva) develops at between 30 to 40 hours after fertilization (Table B2.1). The trochophore eventually take on the characteristics of veliger larvae, approximately 6.9 mm in length and 6.3 mm at their greatest width (Manning 1986).

On the 23rd day, the larvae begin to show an adhesive tendency, causing them to stick to each other and the various particles that they come into contact with. By the 28th day after spawning, the larvae begin to exhibit a prominent rudimentary gill and begin to swim near the substrate (Culliney 1974). By the 35th day, the animals begin to settle and are said to be mature larvae. These "spat" will settle on a variety of objects including shell fragments and pebbles. The substrate must be clean, as silt and mud will choke young scallops (Naidu and Cahill 1983). Larval scallops are able to delay metamorphosis until they find suitable substrate. Naidu (personal communication) indicates that larvae may be seen in the water column for up to 50 days after the spawn. Metamorphosis takes place within 40 to 60 days of attachment. The animals do not feed during metamorphosis. Once metamorphosis is complete, the gills (the adult feeding organ) and oral palps become functional and take over the function of feeding. The inner fold of the mantle secretes the juvenile shell (the dissoconch). The byssus is usually lost at this stage. The shell height is between 6 to 10 mm (Anonymous 1982).

B.2.3.1.2 Factors Affecting Growth and Development

As previously mentioned, there is a paucity of research pertaining to the biology and ecology of Placopecten magellanicus. The quality of environment necessary for optimum growth is not precisely known.

Researchers at the Memorial University of Newfoundland (Ocean Sciences Center) have been able to rear sea scallops from embryonic stages until they are juveniles. These juveniles are then delivered to local scallop farmers. Hatchery development takes place generally between 14 and 15°C. However, optimum growth, in nature, is felt to take place at between 10 and 15°C (Dr. P. Dabinett, personal communication). Juvenile and adult scallops are probably able to grow within a much broader temperature range.

MacDonald and Thompson (1985a, b) studied the influences of temperature and food availability upon the ecological energetics of P. magellanicus within natural populations at Dildo, Sunnyside, Terra Nova National Park and Colinet, Newfoundland and within a bay at St. Andrew's, New Brunswick. Their results indicated that scallop growth is positively correlated to the increased seston concentrations and higher temperatures that were evident within shallow water sites. However, it is noteworthy that at Colinet the shallow water sites exhibited maximum temperatures as high as 18°C. Scallops from these shallow water sites grew at slower rates than did those from deeper waters. MacDonald and Thompson (1985a) felt that the extreme high temperatures of the shallow water sites at Colinet may have caused increased metabolic expenditures which may have been a factor causing reduced growth. Currently, research is being conducted on the effects of various levels of feeding and temperatures upon growth of juvenile scallops (C. Gillis, personal communication).

A laboratory study carried out by Culliney (1974) indicates that P. magellanicus larvae require salinities of at least 26 ppt. if they are to exhibit normal mobility. Dr. P. Dabinett (personal communication) rears hatchery stock in filtered seawater with salinities of between 31 ppt. and 32 ppt. and feels that this is probably within the range for optimum growth. In Japan, the genera of commercial scallops exhibit growth optima under slightly hypersaline conditions (Taguchi 1978 and Anonymous 1982).

B.2.3.2 Physical Siting Requirements

Physical siting requirements are summarized in Table 2.7 and are outlined below. Requirements for suspended scallop culture are similar to those described for Blue Mussels (Section B.1).

B.2.3.2.1 Exposure to Wind, Waves and Swells

Exposure to rough water and excessive winds can damage suspended culture equipment (in particular intermediate, pearl net, and lantern net gear) and, as described in Section B.1, can cause anchoring problems and create dangerous conditions for work and water travel. Ideally, wave heights should be less than 0.6 m and no more than approximately 1.2 m. These problems are largely avoided for spat collection gear placed just above the bottom in deep (15 to 20 m) water and for bottom culture techniques.

B.2.3.2.2 Ice Conditions

Ideally, sites should be ice-free where longline suspended culture is used. If the longlines are submerged (e.g., 3 to 5 m below the surface) during the winter months to avoid ice conditions, care must be taken to prevent the scallops from touching the sea bed, so as to avoid predation and reduced growth rate problems (Naidu and Cahill 1986).

B.2.3.2.3 Currents and Water Exchange

As with mussels, current velocities should be adequate to supply and circulate food particles and to dissipate waste products from the animals. Low current velocities may be advantageous for spat collection purposes. However, the pelagic scallop larvae may be accumulated in a localized area by currents (Sanders 1973). An advantage of currents on the high side, is good growth. As described for blue mussels, suspended culture systems can be designed for different current velocities within a limited range. Longlines with strong anchoring systems can utilize currents up to 4 kn (200 cm/s).

B.2.3.2.4 Water Depth

Giant scallops naturally occur from 1 m below low tide level to well over 100 m (Mottet 1979). Generally, scallops grow faster in shallow water, due to more abundant planktonic food. Water depth at a scallop culture site must consider both equipment and rearing strategy. For spat collection and intermediate culture, depths are approximately 15 to 30 m. Similar depths are used for final growout using suspended culture. Rearing nets are typically 2 m to 8 m long, but longlines may be suspended at depths of about 5 m. This strategy helps to avoid wave action, excessive fouling, conflicts with boat traffic and ice. Therefore, a minimum depth would be about 15 m (Mottet 1979). Longline systems in Japan are typically moored in waters 23 m to 35 m (and even up to 75 m in extreme cases; Taguchi 1978). Again, care must be exercised to maintain scallops off the sea bed, to avoid predation and suffocation in sediments.

Bottom culture should take place in depths greater than 10 m (to avoid surface wave action and low salinities), but less than 30 m (to avoid low productivity in deeper water and harvesting difficulties). Biological considerations of bottom type are important to bottom culture of scallops, in that silt and high levels of suspended sediments cause mortalities (especially with small animals; Larson and Lee 1978). Flat, sandy bottoms are preferred.

B.2.3.3 Biological Siting Requirements

B.2.3.3.1 Temperature

Giant scallops have a wide range of tolerance to temperature, but problems mainly occur at high rather than low temperatures. Mass mortalities of wild scallops are common, usually in July and August in depths less than 12 to 20 m (Dickie and Medcof 1963). High temperatures can either be lethal or simply weaken the animal, increasing susceptibility to predation. Dickie (1958) has cultured sea scallops as low as -1.5°C with no mortalities. Commercial fishing captures scallops from waters at 0°C (Squires 1962).

The optimum temperature for rearing giant scallops is 10-15°C (Young-Lai and Aiken 1986), while the upper lethal temperature is 20°-23.5°C (Bourne 1964). Freezing temperatures can be tolerated if the scallops are not handled roughly (Medcof and Bourne 1964). Below 8°C, growth slows and below 4°C, growth ceases (Young-Lai and Aiken 1986).

B.2.3.3.2 Salinity

Giant scallops are an open ocean species, and therefore exist in salinities of 33-35 ppt. Young-Lai and Aiken (1986) state that this is a stenohaline species that requires at least 30 ppt. salinity. However, larvae have remained viable for 42 hours at 10.5 ppt. (Culliney 1974). In any case, situations with wide salinity fluctuation should be avoided as this stress can cause mortalities (Young-Lai and Aiken 1986). Therefore, sites close to large river run-off and melting ice where a brackish layer (freshwater lens) can overlie the denser seawater, should be avoided.

B.2.3.3.3 Water Quality

Pollutants (as described in Section B 1, Blue Mussels) may affect growth and survival of scallops as well as affect human consumers. For example, oil pollution can cause a tainted taste in scallops (Motohiro and Iseya 1976). Heavy metals such as copper, zinc, cadmium and lead, concentrate in scallop tissue (mainly in the viscera). The muscle portion (consumed by most North Americans) remains essentially clear (Ray and Jerome 1987). Clearly, scallop (or other shellfish) culture operations must not be located near known or anticipated future pollution sources.

B.2.3.3.4 Phytoplankton

1. Beneficial Plankton

As filter feeders, scallops utilize phytoplankton (especially diatoms) as well as some organic detritus, for food (Posgay 1963; and Borden undated). Food supply is apparently more important to growth than is water temperature (Posgay 1979). A good food supply is most important in the larval lifestage, as larvae must undergo a non-feeding metamorphosis period for which they must be in good health (Young-Lai and Aiken 1986).

Kirby-Smith and Barber (1974) have suggested that normal variations in phytoplankton concentration do not affect the growth rate of bay scallops (Argopecten irradians). They found that growth rates do not rise when phytoplankton levels are increased above natural levels. It appears that the maximum growth rate of bivalves is temperature controlled, and independent of variations in phytoplankton concentration, unless the concentration falls below 1.2 micrograms/litre chlorphyll a at 22°C.

Other estimates of the nutrient requirements of scallops have been made by measuring total suspended particle concentrations. Bernard (1983) suggests that for culture of Patinopecten caurinus (a scallop species of similar size to Placopecten magellanicus), an optimum concentration of total suspended particles is 35 mg/L, and an acceptable range of 5-95 mg/L, for mariculture purposes. Beyond this range, the animals would not feed.

2. Harmful Plankton

Although high concentrations of paralytic shellfish poison (described in Section B.1, Blue Mussels) toxin have been found in giant scallop viscera, especially in fall and winter, the levels in adductor muscles are generally negligible (Jamieson and Chandler 1983). This is the scallop body part normally eaten by North Americans, though elsewhere, whole scallops are consumed.

B.2.3.4 Predators and Fouling

B.2.3.4.1 Predators

In early lifestages, scallops (and other bivalves) are planktonic, and are preyed upon by numerous large zooplankters (Young-Lai and Aiken 1986). Heavy predation mortalities can also occur during the juvenile benthic stage. They are consumed by numerous animals. Of particular concern are starfish (Asterias and Astropecten spp.), rock crabs (Cancer irroratus), cod (Gadus morhua), flatfish species (e.g., winter flounder, Pseudopleuronectes americanus and smooth flounder, Liopsetta putmani), wolffish (Anarhichas lupus) and lobster (Homarus americanus). Carnivorous snails, such as the moonsnail (Lunatia heros) drill through scallop shells to eat the scallop. Adult sea scallops are eaten mainly by starfish, cod, plaice, and wolffish (Bourne 1964; and Young-Lai and Aiken 1986).

Suspended culture methods avoid many of these predators, except those with planktonic larvae such as starfish and crabs. In Japanese bottom culture, juvenile scallops are not released from suspended nursery equipment until about 40 mm shell height, to better withstand benthic predation (Sanders 1973).

B.2.3.4.2 Fouling

Fouling of scallops and culture equipment has several adverse effects. The increased weight requires more buoyancy to be installed and/or increased labour to clean the fouling off and change nets. Water flow to the scallops is reduced, as is available food, thereby affecting growth and survival. The main fouling organisms are algae, mussels, starfish, barnacles and hydroids. Types of fouling, as well as intensities are very specific to site, season and depth, with wide variations common, even within relatively small geographical areas (Young-Lai and Aiken 1986). Certain fouling organisms, such as barnacles and tube worms, affect the appearance and hence market value of scallops.

B.2.3.5 Logistic and Other Requirements

Other site requirements such as access and proximity to a support community are basically the same as those described for blue mussels (Section B.1.3.5).

B.3 LITERATURE CITED IN APPENDIX B

B.3.1 Blue Mussels

Bayne, B.L. 1965.
Growth and the delay of metamorphosis of the larvae of Mytilus edulis (L.). Ophelia 2 (1):1-47 pp.

Bayne, B.L. and C.M. Worrall. 1980.
Growth and production of mussels Mytilus edulis from two populations. Marine Ecology Progress Series. 3:317-328 pp.

Bernard, F.R. 1983.
Physiology and the mariculture of some Northern Pacific bivalve molluscs. Can. Spec. Publ. Fish. Aqua. Sci. 63:24 pp.

Beveridge, M.C. 1987.
Cage aquaculture. Fishing News Books Ltd. Farnham, Surrey England. 352 pp.

Brenko, M.H. and A. Calabrese. 1969.
The combined effects of salinity and temperature on larvae of the mussel Mytilus edulis. Marine Biology 4:224-226 pp.

Burford, I. 1988.
Industry status report for blue mussel culture. Newfoundland Department of Fisheries. 12 pp.

Burford, I. 1989.
Technical Advisor, Shellfish Aquaculture, with the Newfoundland Department of Fisheries. Personal communication.

Cook, R.H., F. Sander and R.E. Drinnan (no date).
Atlantic marine water resources: their utilization and potential for aquaculture. Fisheries and Environmental Sciences, Biological Sciences Branch, Scotia-Fundy Region. Internal Report. 59 pp.

Fletcher, G.L. and L.C. Haggerty. 1975.
The distribution of Iceland scallops, mussels, clams and cockles and sea urchins in St. Lewis Bay, Alexis Bay, St. Michaels Bay and Sandwich Bay, Labrador. MSRL. Memorial University of Newfoundland. St. John's, Newfoundland. 35 pp.

Gilkinson, K. 1989.
Marine Biologist, S. Fudge and Associates. St. John's. Personal communication.

Green, L. 1989.
Mussel farmer. Gambo. Personal communication.

Hemming, J.E. 1988.
Mussel aquaculture in Alaska. Alaska Sea Grant Rep. 88-4:95-97 pp.

Incze, L.S., R.A. Lutz, and L. Watling. 1980.
Relationships between effects of environmental temperature and seston on growth and mortality of Mytilus edulis in a temperate northern estuary. Marine Biology 57:147-156 pp.

Jenkins, R.J. 1985.
Mussel cultivation in the Marlborough Sounds (New Zealand). N.Z. Fish. Ind. Bd. 77 pp.

Lutz, R.A. 1985.
Chapter 8. Mussel aquaculture in the United States. 331-364p. [IN]: Huner, J.V. and E.E. Brown (Eds.). Crustacean and mollusk aquaculture in the United States. AVI Publishing Company Inc. Westport, Connecticut.

Mason, J. 1972.
The cultivation of the European mussel, Mytilis edulis (Linnaeus). Oceanogr. Mar. Biol. Ann. Rev. 10:437-460 pp.

Mills, T. 1989.
Mussel and scallop farmer. Botwood. Personal communication.

Quayle, D.B. 1969.
Pacific oyster culture in British Columbia. Fish. Res. Bd. Can. Bull. 169:192 pp.

Scaplen, R.P. 1970.
Survey of shellfish (Mytilus edulis Linnaeus), the blue mussel in Bonavista Bay and the potential mussel fishery. Marine Sciences Research Laboratory, Memorial University of Newfoundland. Contribution No. 55.

Seed, R. 1980.
Shell growth and form in Bivalvia. 23-67p. [IN]: Rhoads, D.C. and R.A. Lutz (Eds.). Skeletal growth of aquatic organisms. Biological records of environmental change. Plenum Press. New York.

Smith, B. and S. Goddard. 1988.
A guide to longline mussel culture in Newfoundland. Aquaculture in Newfoundland. Publication No. 1. Fisheries Development Division. Fisheries and Habitat Management Branch. Department of Fisheries and Oceans. St. John's, Newfoundland. 17p.

Smith, B.S. 1988.
An examination of the Newfoundland mussel farming "industry". Faculty of Business Administration. Memorial University of Newfoundland. 73p.

Somers, W. 1988.
Technical details on culture methods in P.E.I. [IN]: Emmett, B. (ed). B.C. mussel culture workshop. Prov. B.C. Min. Agr. Fish. 63-72p.

Sutterlin, A., D. Aggett, C. Couturier, R. Scalpen, and D. Idler. 1981.
Mussel culture in Newfoundland waters. Mar. Sci. Res. Lab. Tech. Rep. Technical Report Number 23. Memorial University of Newfoundland. St. John's, Newfoundland. 82p.

Thompson, R.J. 1979.
Fecundity and reproductive effort in the blue mussel (Mytilus edulis), the sea urchin (Strongylocentrotus droebachiensis), and the snow crab (Chionoecetes opilio) from populations in Nova Scotia and Newfoundland. Journal of the Fisheries Board of Canada. 36:955-964p.

Walsh, D. 1989.
Mussel farmer. Fortune Harbour. Personal communication.

White, D.R.L. and A.W. White. 1985.
First report of paralytic shellfish poisoning in Newfoundland. Proceedings of the Third International Meeting of Toxic Dinoflagellates. 511-516p.

B.3.2 Giant Scallops

Aggett, D. 1981.
Provincial involvement in aquaculture in Newfoundland 1970-1980 and proposed activities for fiscal year 1981-1982. Newfoundland Department of Fisheries, St. John's. 12 pp.

Anonymous. 1982.
Culture of scallops. Canadian translation of Fisheries and Aquatic Sciences. No. 4885. Translated by the Translation Bureau (JM/PS) Multilingual Services Division, Department of the Secretary of State of Canada. Department of Fisheries and Oceans, Pacific Biological Station. Nanaimo, British Columbia. 65pp.

Bernard, F.R. 1983.
Physiology and the mariculture of some Northern Pacific bivalve molluscs. Can. Spec. Publ. Fish. Aqua. Sci. 63:24 pp.

Borden, M.A. (no date)
A contribution to the study of the great scallop, Placopecten grandis (S.). Biol. Bd. Can. MS. Rep. Biol. Sta. 350:27 pp.

Bourne, N. 1964.
Scallops and the offshore fishery of the Maritimes. Fish. Res. Bd. Can. Bull. 145:60 pp.

Caines, D. and J. Caines. 1989.
Shellfish farmers, St. John's, Newfoundland. Personal communication.

Cormier, J.G. 1989.
National Research Council, Project Coordinator. Personal communication.

Culliney, J.L. 1984.
Larval development of the giant scallop Placopecten magellanicus (Gmellin). Bio. Bull. 147:321-332 pp.

Dabinett, P. 1989.
Memorial University, Scientist. Personal communication.

Dickie, L.M. 1958.
Effects of high temperature on survival of the giant scallop. J. Fish. Res. Bd. Can. 15(6):1189-1211 pp.

Dickie, L.M., and J.C. Medcof. 1963.
Causes of mass mortalities of scallops (Placopecten magellanicus) in the southwestern Gulf of St. Lawrence. J. Fish. Res. Bd. Can. 20(2):451-482 pp.

Evans, J.W., R. Scaplen and D.R. Idler. 1973.
Scallop aquaculture report for 1972-1973. Marine Sciences Research Laboratory, Memorial University of Newfoundland. St. John's, Newfoundland. 29 pp.

Fowler, B.M. and G.L. Fletcher. 1975.
The distribution of giant scallops, clams, sea urchins and seaweed in Bonavista Bay and Belle Bay, Fortune Bay, Newfoundland. Marine Sciences Research Laboratory, Memorial University of Newfoundland. St. John's, Newfoundland. 27 pp.

Gillis, C. 1989.
Memorial University, Graduate Student. Personal communication.

Hoyles, R. 1989.
Newfoundland Department of Fisheries, Aquaculture Coordinator. Personal communication.

Jamieson, G.S., and R.A. Chandler. 1983
Paralytic shellfish poison in sea scallops (Placopecten magellanicus) in the West Atlantic. Can. J. Fish. Aqua. Sci. 40:313-318 pp.

Kirby-Smith, W.W., and R.T. Barber. 1974.
Suspension - feed aquaculture systems: Effects of phytoplankton concentration and temperature on growth of the bay scallop. Aquaculture 3:135-145 pp.

Larsen, P.F., and R.M. Lee, 1978.
Observations on the abundance, distribution, and growth of post-larval sea scallops, Placopecten magellanicus, on Georges Bank. Nautilus. 92(3):112-116 pp.

MacDonald, B.A., and R.J. Thompson. 1985a.
Influence of temperature and food availability on the ecological energetics of the giant scallop Placopecten magellanicus. I. Growth rates of shell and somatic tissue. Marine Ecology-Progress Series. 25:279-294 pp.

MacDonald, B.A., and R.J. Thompson. 1985b.
Influence of temperature and food availability on the ecological energetics of the giant scallop Placopecten magellanicus. II. Reproductive output and total production. Marine Ecology-Progress Series. 25:295-303 pp.

Manning, D.A. 1986.
Aquaculture of the giant scallop Placopecten magellanicus (Gmelin): Conditioning of the broodstock and energy requirements of the larvae and juveniles. MSc. Thesis. Biology Department, Memorial University of Newfoundland. St. John's, Newfoundland. 208 pp.

Medcof, J.C., and N. Bourne. 1964.
Causes of mortality of the sea scallop, Placopecten magellanicus. Proc. Nat. Shellf. Assoc. 53:33-50 pp.

Mills, T. 1989.
Mussel and scallop farmer. Botwood. Personal communication.

Motohiro, T., and A. Iseya. 1976.
Effects of water polluted by oil on aquatic animals. II n-paraffins, aromatic hydrocarbons, and crude oil concentration on taint in scallop (Patinopecten yessoensis). Hokkaido Daigaku Suisangakubu Kenkyu Iho 26(4):367-371 pp.

Mottet, M.G. 1979.
A review of the fishery biology and culture of scallops. Wash. Dept. Fish. Tech. Rep. 39:99/pp.

Murphy, T.C. (no date given)
M.V. Straight Shore May 8 - October 10, 1975. Scallop surveys. Scallop survey I - Conception Bay; scallop survey II - Bay of Islands; scallop survey III - Port au Port. Department of Fisheries and Oceans. St. John's, Newfoundland. 21 pp.

Naidu, K.S. 1970.
Reproduction and breeding cycle of the giant scallop Placopecten magellanicus (Gmelin) in Port au Port Bay, Newfoundland. Canadian Journal of Zoology. 48:1003-1012 pp.

Naidu, K.S. 1989.
Shellfish Scientist, Department of Fisheries and Oceans. St. John's. Personal communication.

Naidu, K.S., and F.M. Cahill. 1983.
Culturing giant scallops in Newfoundland waters. Can. MS. Rep. Fish Aqua. Sci. 1876:23 pp.

Posgay, J.A. 1963.
Tagging as a technique in population studies of the sea scallop. Int. Comm. N. Atl. Fish Spec. Publ. 4:268-271 pp.

Posgay, J.A. 1979.
Depth as a factor affecting the growth rate of the sea scallop. Int. Counc. Expl. Sea. Doc. C.M. 1979/K:27:5 pp.

Ray, S., and V. Jerome, 1987.
Copper, zinc cadmium, and lead in scallops (Placopecten magellanicus) from the Maritimes. Can. Tech. Rep. Fish Aqua. Sci. 1519:29 pp.

Sanders, M.J. 1973.
Culture of the scallop, Patinopecten yessoensis (Jay) in Japan. Aus. Dept. Fish. Wildl. Fish. Contr. (Victoria). 29:24 pp.

Squires, H.J. 1958.
Exploratory fisheries for giant scallop, west and southwest coasts of Newfoundland. Fisheries Research Board of Canada. Manuscript Report Series No. 648, 34 pp.

Squires, H.J. 1962.
Giant scallops in Newfoundland coastal waters. Fisheries Research Board of Canada. Bulletin No. 135, 29 pp.

Suzuki, N. 1970.
Report on scallop fishing project May 11 to October 22, 1970. Industrial Development Branch, Department of Fisheries and Forestry. St. John's, Newfoundland. 46 pp.

Taguchi, K. 1978.
A manual of scallop culture methodology and management. Fisheries and Marine Service Translation Series No. 4198. Department of Fisheries and the Environment, Fisheries and Marine Service, Pacific Biological Station. Nanaimo, B.C. 146 pp.

Young-Lai, W.W., and D.E. Aiken. 1986.
Biology and culture of the giant scallop, Placopecten magellanicus: A review. Can. Tech. Rep. Fish Aqua. Sci. 1478:21p.

APPENDIX C

AMERICAN EEL

APPENDIX C - AMERICAN EEL

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C.0 AMERICAN EEL (*Anguilla rostrata*)

C.1 STATE OF CULTURE TECHNOLOGY

C.1.1 Culture Status

Eel culture in North America has been limited, compared to culture activities in Europe and Japan (Brown 1983). In 1981, studies were undertaken to assess the potential for establishing an eel fishery and rearing operations in Bay D'Espoir (Button 1982). The study concluded that these activities would be feasible, but operating constraints required further examination. Biological data from a small test holding pond were limited. In the mid-1970's, commercial eel farming was attempted in New Bunswick but failed due to low winter temperatures and market-supply problems (Aiken 1984). A limited amount of research has also been undertaken in Ontario (Vladykov and Lieuw 1982). Eel culture was undertaken in the late 1970's in the eastern United States, to supply the Japanese market, but was largely discontinued in the eary 1980's (Brown 1983). Wild harvest still takes place in both Canada and the United States. A fishery for eels exists in Newfoundland, concentrated mainly along the west coast and northeast coast (Bruce 1982).

C.1.2 Culture Methods

In general, eel culture methods vary from open, extensive methods often in association with species such as carp, to intensive, controlled methods such as those practiced for eel culture in Japan (Usui 1974; Bardach *et al*. 1972). Slow, well oxygenated waters and temperatures higher than 15.0°C are generally required for good growth.

Culture normally begins by capturing elvers migrating into freshwater during winter. In Japan, elvers (*A. japonicus*) are placed initially in shallow (50/cm deep), concrete or rock-sided ponds (Brown and Nishimura 1983). As the eels grow, they are placed in successively deeper ponds (to 90/cm deep). Heated water is usually used (25.0°C). Other methods incorporating water recirculation, greenhouse covered production units and flow-through raceways are also used, but less commonly. Eel culture has been attempted in several locations in Europe (Italy, France and West Germany) during the late 1960's and 1970's (Huet 1986; and Brown 1983). In Italy, elvers are captured for placement in brackish water lagoons or freshwater concrete tanks. Elvers placed in concrete tanks are moved to grow-out ponds after they reach approximately 2.0 g. The freshwater faciltities generally use recirculating water.

American eel elvers were reared in an artificial pond in southern Ontario during the late 1960's and early 1970's (Vladykov and Liew 1982). These fish were exposed to natural temperature conditions (20 to 30°C during summer) and natural pond food was supplemented with a small amount of artificial diet. These eels reached approximately 20 to 60 gm after one year in the pond.

C.1.3 Siting Requirements for Culture Facilities

C.1.3.1 Biological Overview

C.1.3.1.1 Distribution and Habitat

American eel occur along the eastern seaboard of North America as far north as Hamilton Inlet in Labrador (Scott and Scott 1988). Juvenile eels are found in freshwater through most of their life. Mature adults move downstream in autumn to spawn in the sea. Young eels move into streams in the spring after one year in saltwater. In freshwater, the eels occupy stream, river and lake bottoms, often in muddy or silty habitat.

C.1.3.1.2 Life History Considerations

1. Spawning and Early Larval Stages

Spawning appears to take place in the Sargasso Sea, to the east of the Bahamas, between February and July (Scott and Crossman 1973; and Scott and Scott 1988). The eels remain in the sea as larvae for approximately one year, when they transform to adult form and, shortly afterwards, enter freshwater (length 40-90 mm; Scott and Scott 1988; Vladykov and Lieuw 1982). Spawning of eels in captivity has proven difficult which means genetic control over stock characteristics is not yet possible (Deelder 1984). A dependable supply of elvers is critical (Matsui 1979).

2. Freshwater Rearing

Canadian elvers normally enter coastal waters in April and enter streams in May and June (Scott and Scott 1988). In Newfoundland, the greatest growth rates have been from the Hamilton Sound area. Eels reportedly grow better in freshwater compared to brackish water, although in the southern United States, eels appear to grow more rapidly in estuaries but achieve a lower overall size (Helfman 1982). In freshwater, in Newfoundland, weights of 6-8 kg have been reported (Scott and Scott 1988). Vladykov and Liew (1982) suggest large differences exist amongst strains (i.e., Quebec stocks versus New Brunswick stocks) and sexes. Fish generally reach 20-60 g after one year in a semi-natural pond and one specimen reached 150 g. Large size differences can occur amongst smaller individuals leading to feed competition and cannabalism (Matsui 1979).

Eels tend to enter a form of hibernation during winter and cease feeding when temperatures drop below 5-10°C (Matsui 1979). Usui (1974) indicates growth effectively ceases for all species below approximately 12°C. Suitable temperatures are 23-30°C.

3. Maturation

After remaining a number of years in freshwater, eels migrate seaward then move to the marine spawning grounds. Eels can remain in freshwater for many years (e.g. up to 18 years before migration). Females grow to a larger size (e.g. 75-120cm) than males (e.g. 60 cm). Vladykov and Liew (1982) indicate that, in fact, male growth can be more rapid during the first year, but afterwards females appear to grow more rapidly.

C.1.3.2 Biological and Physical Siting Requirements

Culture can involve capture and temporary rearing of elvers to supply growout operations elsewhere (Europe and Japan) or can involve growing out the elvers to market size. Since culture experience with American eel is limited, the following descriptions of siting requirements are mainly for experiences with other eel species (Usui 1974; Matsui 1979; Bardach *et al.* 1972).

C.1.3.2.1 Water Supply Quantity

Usui (1974) indicates a general flow requirement of 430 m^3 per day to produce 20 tons of eel. This means a loading density of approximately 64 kg/LPM which is much higher than those normally used for salmonids.

C.1.3.2.2 Temperature

Eels require relatively high temperatures (20-30°C) for optimum growth. Growth appears to cease at approximately 8-12°C. Eels enter a form of hibernation at temperatures of 5-10°C. Therefore, eels intended for commercial market size would have to be maintained over the winter. This likely would require some form of supplemental heating.

C.1.3.2.3 Oxygen

As with salmonids, eels require relatively well oxygenated water; fully saturated water would be ideal. Asphyxiation occurs at oxygen levels between 0.5 and 1.0 mg/L (Usui 1974). In Japan, phytoplankton growth is considered a positive feature for oxygen production in ponds (unless oxygen eliminating blooms develop), while oxygen-consuming zooplankton and rotifers are discouraged (Usui 1974).

C.1.3.2.4 Water Quality

Usui (1974) indicates either surface or groundwater can be used and turbid conditions are acceptable. However, acidic conditions are generally not suitable; neutral or slightly alkaline waters are better. As discussed earlier, culture in brackish water is possible.

C.1.3.2.5 Land Area

Land area requirements will vary according to the type of production involved. For example, the production yields from open pond culture are substantially lower than for the more intensive running water facilities. To achieve the same production four to eight times as much land is required for pond culture (Bardach et al. 1972).

C.1.4 Logistic and Other Requirements

Proximity to a support community, accessibility, power and communications are similar to those described for freshwater salmonid species (Appendix A).

C.2 LITERATURE CITED IN APPENDIX C

Aiken, D.E. 1984.
Aquaculture in Atlantic Canada. [IN]: G.I. Pritchard (Ed.). Proceedings of the national aquaculture conference strategies for aquaculture development in Canada. Department of Fisheries and Oceans, Ottawa. Canadian Special Publications of Fisheries and Aquatic Sciences 75. 6-15 pp.

Bardach, J.E., J.H. Ryther and W.O. McLarney. 1972.
Aquaculture: the farming and husbandry of freshwater and marine organisms. Wiley-Interscience (John Wiley and Sons, Inc.). Toronto. 868 pp.

Brown, E.E., S. Nishimura. 1983.
Japan. [IN]: E.E. Brown. World Fish Farming: Cultivation and economics. Second edition. AVI Publishing Company Inc., Westport Connecticut. 323-388 pp.

Bruce, W.J. 1982.
American eel, Anguilla rostrata - Newfoundland region. [IN]: K.H. Loftus (Ed.). Proceedings of the 1980 North American eel conference. Ontario Ministry of Natural Resources. Ontario Fisheries Technical Report Series No. 4. 36-38 pp.

Button, C.E. 1982.
The feasibility of establishing a commercial eel fishery/aquaculture operation in Bay D'Espoir. A report to the Bay D'Espoir Development Association.

Deelder, C.L. 1978.
A short note on the intensive culture of eel (Anguilla anguilla L.). Aquaculture 13: (1978):289-290 pp.

Deelder, C.L. 1984.
Synopsis of biological data on the eel Anguilla anguilla (Linnaeus 1758). Food and Agriculture Organization of the United Nations. FAO Synopsis No. 80, Revision 1.

Helfman, G.S. 1982.
Development of the fishery for American eels (Anguilla rostrata) in Georgia. [IN]: K.H. Loftus (Ed.). Proceedings of the 1980 North American eel conference. Ontario Ministry of Natural Resources. Ontario Fisheries Technical Report Series No. 4. 53 pp.

Matsui, I. 1979.
Theory and practice of eel culture. Nihon Suisan Shigen Hokaku Kyokai Publishers, Aquaculture Series 4. Translated from Japanese.

Scott, W.B. and E.J. Crossman. 1973.
Freshwater fishes of Canada. Canada Department of the Environment. Fisheries Research Board. Bulletin 184, 966p.

Scott, W.B. and M.G. Scott. 1988.
Atlantic fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219. 731p.

Usui, A. 1974.
Eel culture. Translated by Ichiro Hayashi. Fishing News (Books) Ltd., Surrey, England.

Vladykov, F.D., and P.K.L. Liew. 1982.
Sex of adult American eels (Anguilla rostrata) collected as elvers in two different streams along the eastern shore of Canada, and raised in the same freshwater pond in Ontario. [IN]: K.H. Loftus (Ed.). Proceedings of the 1980 North American Eel Conference. 1982. Ontario Ministry of Natural Resources, Fisheries Technical Report Series No. 4. 97 pp.

APPENDIX D

MARINE FINFISH SPECIES

APPENDIX D - MARINE FINFISH SPECIES

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D.0 MARINE FINFISH SPECIES

D.1 ATLANTIC COD (Gadus morhua)

D.1.1 State of Culture Technology

D.1.1.1 Culture Status in Newfoundland

Atlantic cod hatchery culture was first undertaken late in the last century in both nothern Europe and Newfoundland (Driscoll 1981). Juvenile cod are caught and raised to commercial size in several Newfoundland bays (Williams and Kiceniuk 1986; Fisher 1988; Waiwood et al. 1988). Previously, culture beyond the initial larval stages was prevented by larval feeding problems. These problems have been overcome and culture from the egg stage to harvest is technically possible though the commercial potential could be limited (Jones 1984).

D.1.1.2 Culture Methods

Based on recent studies and commercial applications in Scotland, Norway and Newfoundland, a number of culture options are evident (Kvensteth and Oiestad 1984; Oiestad et al. 1985; Svasand and Godo 1987; Howell 1984; Waiwood et al. 1988):

- hatchery culture;
- larvae to fry growout in tanks;
- larvae to fry growout in large natural ponds;
- wild juvenile capture for growout to harvest;
- juvenile to harvest growout in netpens;
- release of cultured fry for ranching; and
- juvenile to harvest growout culture in tanks.

The economic viability of culture to harvest is uncertain given analyses that estimate production costs could exceed prices (Jones 1984). Consequently, capital intensive culture methods, in particular, landbased culture, are not expected unless cod is grown as a supplement to other species cultured in such facilities.

Ranching has involved release of juveniles for population enhancement (Svasand and Godo 1987; Svasand et al. 1987) and release of juveniles conditioned to return to an artificial feeding location (Midling et al. 1987).

D.1.2 Siting Requirements for a Culture Facility

D.1.2.1 Biological Review

D.1.2.1.1 Natural Distribution and Habitat

Atlantic cod are found throughout the marine waters of Atlantic Canada (divided into 12 to 14 recognized stocks; Scott and Scott 1988). In the wild, cod tend to occupy depths having relatively cool temperatures (-0.5 to 10°C). Under netpen culture conditions in Newfoundland, temperatures are between 7-15°C (Waiwood et al. 1988). In some areas, cod move offshore in winter and onshore during summer. The fish appear to occupy depths having preferred temperatures but move into other depths for feeding (Scott and Scott 1988). Both eggs and early young are pelagic.

D.1.2.1.2 Life History Considerations

1. Spawning

Atlantic cod can be spawned in captivity without handling (Huse et al. 1983). In one case, spawning took place over an eight to nine week period (Howell 1984). Atlantic cod spawn during winter and spring off Newfoundland, as early as February off northern Labrador, and as late as June off the Grand Banks (Scott and Scott 1988).

2. Egg/Larvae Development

Eggs are small (1.2-1.6 mm diameter) and, given the spawn timing, generally incubate under cold water conditions. Incubation times are (Scott and Scott 1988):

- 50 to 60 days at temperatures of -1.5 to 0°C;
- 40 days at temperatures of -1 to 1°C; and
- 14 days at 6°C.

Howell (1984) incubated eggs at 8°C and raised larvae at 10°C. Feed trials undertaken in those experiments indicated that techniques for larval feeding of turbot (Scophthalmus maximus) are applicable to cod.

Larvae can be fed small size live feed such as rotifers and Artemia nauplii (Howell 1984) though the nutritional quality of feed batches can drastically affect survival. Cannibalism can be a problem as can skeletal deformities and non-filling of swim bladders. Larvae have been grown to a small fry size (0.7 gm) in seawater pond systems using only natural feeds (32 ppt.) (Oiestad et al. 1984). Growth rates can vary amongst stocks and location.

3. Growth of Post-Larval Fish

The average size of cod caught commercially in the inshore waters of Newfoundland is between 1.0 kg and 2.5 kg. These fish are five to six years old. Culture operations in Newfoundland capture young cod in traps at appoximately 1.0 kg in June and grow them in netpens (in water temperatures of 7-15°C) in which they double their weight by October (Waiwood et al. 1988). Growth rates are greatly reduced between October and December (Fisher 1988). Maximum growth rates appear to occur at 10-13°C for fish between 18 g and 475 g (Howell 1984). At these temperatures, fish grow approximately 2.6 cm per month. Cod appear to grow well in salinities between 25 and 35 ppt. (Braaten 1984).

4. Maturation

Growth studies indicate a decline in growth rate four to five months before spawning and a loss of weight for the three months just prior to spawning (Braaten 1984). In this case, spawning occurred in March and spawners reached a maximum average weight of 2 kg just prior to spawning.

D.1.2.2 Physical Siting Requirements

As described in Section D.1.1, production can involve a combination of facilities: hatchery and larval rearing, fry production, adult growout in netpens or shore tanks and fry release for ranching. The physical site requirements will clearly vary greatly depending on the type of production method chosen. A hatchery or adult landbased tank facility will require similar site features to the landbased systems described for salmonids (Appendix A). An important difference for site selection is the temperature and salinity requirements of cod (discussed below in Section D.1.2.3). Adult growout in cage systems will also have the same physical site requirements as the salmonids. Cod fry production (from larvae) or growout to harvest size might involve utilizing natural saltwater ponds or drained, nearshore lake basins (Oiestad et al. 1985; Anonymous 1985). Important considerations for such a facility would be maintenance of high salinities and sufficient water exchange for oxygen and waste removal, which could mean having to pump in seawater from deep areas outside the pond.

D.1.2.3 Biological Siting Requirements

D.1.2.3.1 Temperature

Egg and larval stages appear to have an optimum temperature of approximately 5-6°C. Extreme temperatures that can be tolerated might range from less than -1.5°C to 10°C.

Optimum temperature for growout appears to be 10-13°C (Howell 1984). Much lower temperatures are likely tolerated under natural conditions (e.g., 0-1°C), though growth rates would be reduced, and higher temperatures (e.g., 15-16°C) appear acceptable.

D.1.2.3.2 Salinity

Studies comparing growth and survival at different salinities were not obtained during this review. Culture experiments have tended to utilize higher salinities (e.g., greater than 30 ppt; Howell 1984), given the marine characteristics of the species (described in Subsection D.1.2.1). Fish raised in netpens for which salinities fluctuated between 25 and 31 ppt. appear to have satisfactory growth compared to fish raised in tanks for which salinities were 34 ppt. (Braaten 1984). Similar salinities can be expected along the eastern shore of the Avalon Peninsula (see Section 2.0 of this report) where good growth rates are apparent for cod raised in cages (Waiwood et al. 1988). Low and greatly fluctuating salinities (i.e., less than 25 ppt.) likely would produce increased stress.

D.1.2.3.3 Other Factors

Oxygen levels in closed circuit systems are normally kept above 90% saturation (Braaten 1984; Howell 1984) and similar saturation levels likely are required in open systems (ponds or cages). Areas having blooms of potentially harmful phytoplankton (such as those that affect salmon species as outlined in Appendix A), should be avoided. Similarly, areas having large concentrations of potential bird predators (e.g., cormorants), marine mammal predators (e.g., seals), or possible pollution sources, must also be avoided. Bird predators might be difficult to control if natural ponds are used.

D.1.2.4 Logistic and Other Requirements

Logistic and other siting requirements (e.g., access, power and communications) will be similar to those described in Appendix A for salmonids. However, ranching with recapture in nearshore coastal areas requires knowledge of stock migration patterns and susceptibility to capture by other fisheries (Gamble 1984; Svasand and Godo 1984).

D.2 ATLANTIC HALIBUT (HIPPOGLOSSUS HIPPOGLOSSUS)

D.2.1 State of Culture Technology

Atlantic halibut culture is being investigated in Great Britain, Norway and Atlantic Canada (i.e., the Ocean Sciences Centre in Newfoundland, and at sites operated through the federal DFO Biological Station in St. Andrews, New Brunswick). Culture problems have been related to maintenance of yolk sac fry and early fry feeding, which now appear to have been overcome (Anonymous 1988; Pittman 1988). Larger halibut are sensitive to abrasion. Therefore on-growing likely will require containment units with smooth, rigid bottoms (Huse 1988). These might include tanks, raceways, rigid-bottom netpens or nearshore cages affixed to the sea bottom (Huse 1988; Waiwood et al. 1988).

D.2.2 Siting Requirements for a Culture Facility

D.2.2.1 Biological Overview

D.2.2.1.1 Natural Distribution and Habitat

Atlantic halibut occur in Atlantic Canada coastal waters from northern Labrador to New Brunswick (Scott and Scott 1988). As a flatfish, they are typically a bottom fish with young occupying relatively shallow water (37-55 m) and adults occupying deeper water (165-229 m). They avoid temperatures less than 2.5°C (adults are usually captured in water temperatures of between 3 and 9°C) and tend to utilize shallow water in summer and deeper water in winter. However, the fish appears to tolerate temperatures less than -1°C for several weeks though they may be sensitive to handling at low temperatures (Waiwood et al. 1988).

D.2.2.1.2 Life History Considerations

1. Spawning

Spawning takes place mainly between January and April at depths greater than 180 m and at times possibly more than 1,000 m (Huse 1988; and Scott and

Scott 1988). Females have a short ovulatory rhythm and for culture, care must be taken to observe the correct timing for egg stripping (Huse 1988).

2. Egg and Larvae Development

Hatching time is short (e.g., 18 days at 5°C; Lonning et al. 1982), but the yolk sac stage is long (e.g., 50 days at 4.7°C; Blaxter et al. 1983). Eggs in nature are usually found in dense waters where salinities are between 33.8 ppt. to 35 ppt. (Haugg et al. 1984 [IN]: Scott and Scott 1988). Lonning et al. (1982) found the eggs to be buoyant only at salinities above 37 ppt. during laboratory studies. They found mortalities to be lower at 39 ppt. than at 33 ppt. and speculated that, since dead material tended to sink, it would mix with the non-buoyant eggs at 33 ppt.. Antibiotic treatment of eggs greatly improves survival at temperatures of 5°C and 7°C (Blaxter et al. 1983).

The yolk sac stage is critical since the larvae are highly susceptible to mechanical, developmental and bacterial problems at this stage (Huse 1988). Generally, temperatures must be kept low (approximately 3-4°C) to optimize development. Lonning et al. (1982) observed lower mortalities at 5°C than at 2.5°C. Mouth deformities occur at 10°C compared with lower temperatures, 6°C and 2°C (Bolla and Holmefjord 1988). A number of containment devices have been used for egg and larvae development; silos are felt to offer the best opportunity for commercial development (Huse 1988).

The larvae begin feeding before the yolk sac is absorbed. The period of initial feeding has been a time of high mortality (Waiwood et al. 1988). Development of nutritionally enriched artemia and rotifer diets, the collection of zooplankton, or use of controlled ecosystems, are felt likely to overcome problems at first feeding (Huse 1988; Waiwood et al. 1988).

3. Growth of Post-Larval Fish

At approximately 2 cm, the larvae metamorphase and after approximately 100 days move to the bottom (Huse 1988). After four to five weeks, they can be fed moist or dry prepared diets.

Larger individuals grow well under culture conditions; some experiments indicate 1.6 times more rapidly than fish under wild conditions (Waiwood et al. 1988). Fish weighing 480 g in June, weighed approximately 1.7 kg after 14 months using fresh or frozen fish diets and ambient temperatures. Rabben and Huse (1986) indicate growth from 1.8 kg to 5.3 kg after 14 months at mean monthly temperatures ranging from 5°C to 11.5°C. The fish were fed commercial semi-moist pellets formulated for Atlantic salmon. Under natural conditions, fish can reach sizes of 250-300 kg. A likely target size for culture is 5-20 kg to avoid maturation (Huse 1988).

4. Maturation

Female halibut mature at approximately 20 kg and male halibut mature at approximately 5 kg (Huse 1988). These sizes are reached in approximately six to seven years in the wild and are expected to be reached in approximately four to five years in captivity. However, data in Scott and Scott (1988) suggest that in Atlantic Canada, as a result of heavy fishing directed at larger size fish, both males and females are maturing at approximately 3 kg. Seasonal steroid levels are being studied at the Ocean Sciences Centre (Memorial University) to develop techniques for determining the sex of halibut and to relate reproductive hormone levels to fish maturation and the onset of spawning (L. Crim, personal communication).

D.2.2.2 Physical Siting Requirements

Commercial production systems are still being investigated so appropriate physical siting requirements for commercial facilities cannot be defined. At this point in time, egg and larval production appears likely to involve a landbased silo system to manage the relatively long larvae life history stage (Rabben et al. 1987). Commercial growout is most likely to occur in nearshore impoundments, such as coastal lagoons or landbased systems because the halibut does not adapt well to conventional cages (J. Brown, personal communication; K. Waiwood, personal communication). Studies of halibut performance in nearshore impoundments are being investigated by researchers at the Federal Biological Station in St. Andrews, New Brunswick; and growth trials in laboratory tanks are underway at the Ocean Sciences Center of Memorial University in Newfoundland. The choice of substrate could affect biological performance (Rabben and Huse 1986).

D.2.2.3 Biological Siting Requirements

D.2.2.3.1 Temperature

Optimum temperatures for eggs and larvae are low (3-4°C) and acceptable extreme temperatures appear to occur between 2°C and 9°C (Anonymous 1988; Bolla and Holmefjord 1988; Huse 1988). Larger fish appear to do well in temperatures of 4-12°C (J. Brown, personal communication). Lower temperatures to 2°C are possible but the fish are stressed during handling. Growth rates appear to be highest at average temperatures of 8-10°C (Rabben and Huse 1986), though comparative growth rate studies using different temperatures and different fish sizes appear necessary.

D.2.2.3.2 Salinity

High salinities appear necessary for egg and larvae production (e.g., greater than 37 ppt.), with acceptable salinities generally greater than 33°C (Lonning et al. 1982; Anonymous 1988). As with other marine species, salinities during studies with larger fish are normally maintained at high seawater levels (greater than 33 ppt; e.g., Rabben and Huse 1986). A lower acceptable level was not identified in papers examined during the present review, but presumably as a marine species, halibut would not tolerate low (less than 20-25 ppt.) or rapidly fluctuating salinities.

D.2.2.3.3 Other Factors

Requirements for oxygen, water quality, phytoplankton blooms, potential predators and fouling described for Atlantic cod (Section D.1) would also apply to halibut, except that cage culture of halibut, at this time, does not appear likely. The use of nearshore lagoons or impoundments, for which trials are currently underway, are more probable.

D.2.2.3.4 Logistics and Other Requirements

The logistic and other requirements (access, power and communications) will likely be similar to those outlined for other species (e.g., Atlantic salmon and Atlantic cod).

D.3 LUMPFISH (Cyclopterus lumpus)

D.3.1 State of Culture Technology

Lumpfish have been caught in Europe for their roe and flesh, possibly for several centuries (Davenport 1985). The potential for culturing lumpfish, given good market conditions for roe, has been investigated under laboratory conditions in Newfoundland since the mid-1980's and in 1988 was extended to field pilot testing (Waiwood et al. 1988). The test project is being undertaken by the Cape Freels Development Association and Beothic Processors Ltd. with technical guidance from the Ocean Sciences Center (Memorial University of Newfoundland). Culture options could include growout in captivity or release of juveniles for ranching (Waiwood et al. 1988). In either case, the market objective might be for roe production (the traditional market) or meat. Larger individuals are relatively docile in captivity, at least under laboratory conditions (J. Brown, personal communication).

D.3.2 Siting Requirements for Culture Facilities

D.3.2.1 Biological Overview

D.3.2.1.1 Natural Distribution and Habitat

Lumpfish are found in cold, temperate waters on both sides of the Atlantic Ocean. In Canadian waters, they extend from Hudsons Bay to the Bay of Fundy (Scott and Scott 1988). The fish generally occupy rocky or firm bottoms in relatively deep water (e.g., 180 - 330 m). Young fish are semipelagic occupying surface water layers often, apparently, amongst floating seaweed. They occupy surface water for approximately one year before settling to the bottom.

D.3.2.1.2 Life History Considerations

1. Spawning

Spawning usually occurs during spring or early summer. In Canadian waters, the spawners often move into shallower inshore areas. Spawning could be temperature-dependent, requiring rising temperatures — above 4°C (Collins 1976). In the wild, adults spawn at age five (Davenport 1985), but in captivity this might be reduced to two to three years (J. Brown, personal communication). In the wild, egg masses are guarded by the male parents (Davenport 1985). Egg and sperm stripping is not currently possible. This is an important area of potential research (Davenport 1985; J. Brown, personal communication).

2. Egg and Larval Development

In the wild, egg incubation takes six weeks to two months and as indicated above (Scott and Scott 1988), likely has an optimum temperature above 4°C. Temperatures to 6°C appear suitable (Collins 1976). Good hatching rates might not occur below 4°C (Davenport 1985). Larvae are relatively large when they hatch (5-6 mm) and are able to feed on artemia nauplii (Waiwood et al. 1988). Larval survival is good and juveniles can be weaned onto alternate diets by the late fall. Salinities between 20 and 34 ppt. were required for normal development in some studies but strong differences amongst different stocks are expected (Davenport 1985)

3. Growth of Post-Larval Stages

Growth rates in captivity are very good and production of market size fish appears to be possible within two years (J. Brown, personal communication). Growth and survival in a pilot production facility (Valley Field, Newfoundland) will be monitored over 1989 (Waiwood et al. 1988). This will include the release of juveniles and monitoring their movements in the wild. In the wild, sizes of 46-60 cm and up to 9.5 kg have been reported (Scott and Scott 1988). In the laboratory, lumpfish have been exceptionally easy to maintain (J. Brown, personal communication). Davenport (1985) describes the lumpsucker as eurythermal, based on 0-20°C surface temperatures throughout its range and a tendency to occur in shallow waters in some areas. Temperature, salinity and oxygen requirements might vary amongst stocks.

4. Maturation

The onset of maturation in the wild is between age three and age five (Scott and Scott 1988; Davenport 1985). This likely can be reduced to two years during culture (J. Brown, personal communication).

D.3.3 Physical Siting Requirements

The production options and culture methods for this species are currently being investigated so that specific siting requirements cannot be defined.

As discussed above, production might involve growout in captivity (shorebased tanks or netpens) or ranching. The general physical siting requirements are likely the same as those described for other marine species described in this Appendix (such as Atlantic cod and Atlantic halibut).

Uncertainties relating to the viability of ranching operations are being examined as part of the Cape Freels project. Lumpfish are known to spawn in the same area, but little is known about their marine survivals, homing mechanisms and migration patterns (J. Brown, personal communication). Similarly, nothing is known about the homing ability of these fish if the early life history stages occur in a culture facility before release.

D.3.4 Biological Siting Requirements

D.3.4.1 Temperature

Egg and larval development appears to be good at moderate temperatures (4-10°C; Davenport 1985; Collins 1976). Temperatures should be greater than 4°C; and can be at least as high as 10°C. The upper acceptable temperature is not known, but for some stocks could be as high as 15-20°C since the fish spawn in shallow waters over spring and early summer.

During juvenile to adult growout, optimum temperatures appear to be 8-10°C, though lower temperatures (e.g., -1 - 0°C) can be tolerated. Upper lethal temperatures are not known, but might be as high as 20°C, again, given the tendency of fish to occupy shallow water over early summer.

D.3.4.2 Salinity

Marine species normally spawn in areas having relatively high salinities (i.e., greater than 32 ppt.). Thirty-two to 35 ppt. is likely close to optimum for lumpfish development and lower salinities (e.g., below 30 ppt.) should be avoided, though it appears that lumpsuckers can tolerate salinities as low as 20 ppt. (J. Brown, personal communication).

D.3.4.3 Other Factors

Other requirements (such as oxygen, water quality, phytoplankton blooms, predators and fouling) are likely the same as those described for other marine species, in preceding sections (e.g., Atlantic cod, Section D.1).

Netpen growout might not be possible given the relatively high surface water temperatures and low fluctuating salinities that might occur in summer. The ability of the lumpsucker to grow well under these conditions must yet be investigated.

Also lumpfish are prone to a more sedentary way of life. They are not well designed for continuous swimming.

D.3.5 **Logistics and Other Requirements**

The logistics and other requirements (access, power and communications) will likely be similar to those outlined for other species (e.g., Atlantic salmon and Atlantic cod).

D.4 WOLFFISH (Anarhichas lupus)

D.4.1 State of Culture Technology

Culture potential is being investigated in the U.S.S.R. and Norway (Pavlov and Novikov 1986; Myrseth 1988). It is considered a potential species for culture in Newfoundland (J. Brown, personal communication). Development is still at the research level and pilot commercial production has not begun.

D.4.2 Siting Requirements for Culture Facilities

Given the state of culture development for this species, definitions of siting requirements for commercial purposes are not possible. Therefore, this review is restricted to a biological overview of culture factors and an outline of possible production options.

D.4.2.1 Biological Overview

D.4.2.1.1 Natural Distribution and Habitat

The wolffish is normally found in deeper waters (70 - 350 m) in eastern Canada (Scott and Scott 1988). The wolffish is found in north, temperate waters on both sides of the Atlantic and, in Canada, is found throughout coastal waters from southern Labrador to New Brunswick.

D.4.2.1.2 Life History Considerations

1. Spawning

Spawning appears to take place between late summer and mid-winter, depending on the location (Scott and Scott 1988). In Newfoundland, adults appear to move into shallower, nearshore water (5 -15 m) in the spring in anticipation of spawning during the following August-September (Keats et al. 1985). Spawning takes place around boulders and rocks. The males guard egg deposits.

2. Egg and Larvae Development

Eggs are large (up to 6 mm) and are deposited in a cohesive mass (Scott and Scott 1988). In nearshore waters of eastern Newfoundland, wolffish hatch by mid-December (Keats et al. 1985). Elsewhere in Canadian waters, eggs have been collected in February and March. The eggs are demersal and have been found at depths of 150 - 200 m. Larvae are pelagic, but usually stay close to the bottom until the yolk sac is absorbed.

Pavlov and Novikov (1986) indicate that under laboratory conditions, few egg mortalities occur at approximately 5°C. They indicate that mortality takes place earlier at progressively higher temperatures (within an experimental range of 4-9°C). At temperatures above 12°C, problems with coagulated yolks develop rapidly. They suggest that under natural conditions, egg incubation occurs at temperatures close to 0°C so that the period of incubation lasts eight to nine months. At 4.9°C, the incubation period is 116 to 163 days, which is also relatively long. However, one result is that the larvae hatch at a relatively large size (approximately 2 cm) and the following yolk sac stage is very short (10-15 days). Furthermore, the pelagic larval stage is short (one to two months in nature and 20 days in the laboratory). The salinity during these experiments was 26-27 ppt.

Pavlov (1986) indicates that the larvae will easily accept relatively large feed sizes (i.e., Artemia nauplii of 1-2 mm length). Within several days, the larvae move to the bottom of the rearing containers.

3. Post-Larval Stages

At 25-30 mm, juveniles begin defending territories in the bottom of the rearing units (Pavlov 1986). At this time, they will feed on Artemia (5-6 mm in length), frozen fish and earthworms. Optimal growing temperatures are not known, but likely are in the 8-12°C range based on holding larger adults in captivitiy (Pavlov and Novikov 1986). Gjosaetor and Moksness (1987) report a decrease in growth rates above 11°C.

Growth rates in captivity, consequently, are expected to be much greater than in the wild. For example, Pavlov and Novikov (1986) report cultured juveniles were 34-45 mm in March, a size that wild juveniles would have in August or September.

Juvenile fish raised by Gjosaetor and Moskness (1987) were held in salinities the same as those at the location were captured (33 ppt.). Fish held in captivity display aggressive behaviour during early life history stages and later near spawning (Pavlov and Novikov 1986; Gjosaetor and Moskness 1987).

4. Maturation

Pavlov and Novikov (1986) found captive males to mature in mid-July when rising water temperatures reached 10-14°C. Females mature towards the end of July and early in August when temperatures are 12-14°C. They note that under natural conditions, females move to deeper, cool water areas prior to spawning. Also, Pavlov and Novikov (1986) found maturing fish, particularly males, to be aggressive when kept in small holding containers. Separating panels were required to avoid fish damage and mortality.

In shallow waters off eastern Newfoundland (5-15 m), Keats et al. (1985) estimate spawning occurred during the autumn. Feeding is reduced or stops during the breeding season. Captured males were approximately 78 cm in length and captured females 83 cm in length.

D.4.3 Possible Production Options

The production options for growing lumpfish likely apply also to wolffish (e.g., growout in landbased tanks or netpens and ranching). Opportunities are possibly greatest for landbased culture or use of coastal lagoons given their tendency to use bottom areas. Suitability for cage culture is less likely but can be investigated. Substantial research is required, especially with Newfoundland stocks since life history characteristics appear to differ between Europe (where culture research has been undertaken) and Newfoundland.

D.5 LITERATURE CITED IN APPENDIX D

D.5.1 Atlantic Cod

Anonymous. 1985.
On-shore basins put cod fry on a commercial scale. Fish Farmer 8(5).

Braaten, B. 1984.
Growth of cod in relation to fish size and ration level. Flodevigen rapportser 1(1984):677-710 pp.

Driscoll, J. 1981.
Aquaculture methods in Newfoundland (an introduction). Government of Newfoundland and Labrador, Department of Fisheries, Development Branch, St. John's, Newfoundland. 32 pp.

Fisher, R. 1988.
Assessment and observations of a cod farming operation in Newfoundland. Canada Department of Fisheries and Oceans, St. John's, Newfoundland. Canadian Industry Report of Fisheries and Aquatic Sciences No. 194.

Gamble, J.C. 1984.
The future of cod farming and the possibility of restocking local coastal cod populations. Flodevigen rapportser 1(1984):857-883 pp.

Howell, B.R. 1984.
The intensive rearing of juvenile cod, Gadus morhua L. Flodevigen rapportser 1(1984):657-675 pp.

Huse, I., I. Opstad and P. Jensen. 1983.
Intensive production of cod fry systems and results so far. International Council for the Exploration of the Sea. C.M. 1983/F:24. 9 pp.

Jones, A. 1984.
Does cod farming have a commercial future? A technical and economic assessment. Flodevigen rapportser 1(1984):773-785 pp.

Kvensteth, P.G. and V. Oiestad. 1984.
Large-scale rearing of cod fry on the natural food production in an enclosed pond. Lodevigen Rapportser 1(1984). The propagation of cod Gadus morhua L.:645-655 pp.

Midling, K.O., T.S. Kristiansen, E. Ona and V. Oiestad. 1987.
Fjord ranching with conditioned cod. International Council for the Exploration of the Sea. C.M. 1987/F-29. 11 pp.

Oiestad, V., P.G. Kvenseth and A. Folkvord. 1985.
Mass production of Atlantic cod juveniles Gadus morhua in a Norweigian saltwater pond. Transactions of the American Fisheries Society. 114:590-595 pp.

Oiestad, V., P.G. Kvenseth and T. Pedersen. 1984.
Mass-production of cod fry (Gadus morhua L.) in a large basin in western Norway - a new approach. International Council for the Exploration of the Sea. C.M. 1984/F-16. 9 pp.

Scott, W.B. and M.G. Scott. 1988.
Atlantic fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219. 731 pp.

Svasand, T., and O.R. Godo. 1987.
Results of investigations of migration pattern of artifically reared coastal cod (Gadus morhua L.) in western Norway. International Council for the Exploration of the Sea. C.M. 1987/F-26.

Svasand, T., T.S. Kristiansen and H. Naess. 1987.
Tagging experiments on artificially reared O-group coastal cod (Gadus morhua L.) in western Norway - results from the releases in 1984. International Council for the Exploration of the Sea. CM 1987/F-25.

Waiwood, K., G. Goff and J. Brown. 1988.
Marine finfish culture in Atlantic Canada: Status and potential. Aquaculture International Congress and Exposition, Vancouver, September 6-9, 1988. Congress Proceedings. Aquaculture International Congress, British Columbia Pavilion Corporation, Vancouver, B.C. 491-496p.

Williams, V.P. and J.W. Kiceniuk. 1986.
Feeding and growth rates in Atlantic cod (Gadus morhua) held in captivity during the summer-autumn months. Canada Department of Fisheries and Oceans. Canadian Tech. Rept. Aquat. Sci. 1466.

D.5.2 Atlantic Halibut

Anonymous. 1988.
First glimmers of success with halibut. Fish Farmer January/February 1988.

Blaxter, J.H.S., D. Danielssen, E. Moksness, and V. Oiestad. 1983.
Description of the early development of the halibut (Hippoglossus hippoglossus) and attemps to rear the larvae past first feeding. Marine Biology 73:99-107 pp.

Bolla, S and I. Holmefjord. 1988.
Effect of temperature and light on development of Atlantic halibut larvae. Aquaculture 74:355-358 pp.

Brown, J. 1989.
Research Scientist. Marine Sciences Research Laboratory, Memorial University of Newfoundland. Personal communication.

Crim, L. 1989.
Scientist, Fish Reproduction and Aquaculture Broodstock Management, Marine Sciencies Research Laboratory. Personal communication.

Huse, I. 1988.
Culture of halibut. Aquaculture International Congress and Exposition. Vancouver, September 6-9, 1988. Congress Proceedings. Aquaculture International Congress, British Columbia Pavilion Corporation, Vancouver, B.C. 481-484 pp.

Lonning, S., E. Kjorsvik, T. Haug and B. Gulliksen., 1982.
The early development of the halibut Hippoglossus hippoglossus (L.), compared with other marine teleosts. Sarsia 67:85-91 pp.

Pittman, K. 1988.
Progress in raising halibut larvae to viable fry. Aquaculture Association of Canada Bulletin 88-4. 40-42 pp.

Rabben, H. and I. Huse. 1986.
Growth of juvenile halibut (Hippoglossus hippoglossus L.) in captivity. International Council for the Exploration of the Sea. C.M. 1986/F-20. 7p plus figures.

Rabben, H., A. Jelmert and I. Huse. 1987.
Production experiment of halibut fry (Hippoglossus hippoglossus) in silos. International Council for Exploration of the Sea. C.M. 1987/F-42.

Waiwood, K., G. Goff and J. Brown. 1988.
Marine finfish culture in Atlantic Canada: Status and potential. Aquaculture International Congress and Exposition, Vancouver, September 6-9, 1988. Congress Proceedings. Aquaculture International Congress, British Columbia Pavilion Corporation, Vancouver, B.C. 491-496p.

Waiwood, K. 1989.
Research Scientist, Department of Fisheries and Oceans, Biological Station, St. Andrews, New Brunswick. Personal communication.

D.5.3 Lumpfish

Brown, J. 1989.
Research Scientist. Marine Sciences Research Laboratory, Memorial University of Newfoundland. Personal communication.

Collins, M.A. 1976.
The lumpfish (*Cyclopterus lumpus* L.) in Newfoundland waters. The Canadian Field - Naturalist (90):64-67 pp.

Davenport, J. 1985.
Synopsis of biological data on the lumpsucker *Cyclopterus lumpus* (Linnaeus, 1758). Food and Agriculture Organization of the United Nations, Rome. FAO Fisheries Synopsis No. 147. 31 pp.

Scott, W.B. and M.G. Scott. 1988.
Atlantic fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219. 731 pp.

Waiwood, K., G. Goff and J. Brown. 1988.
Marine finfish culture in Atlantic Canada: Status and potential. Aquaculture International Congress and Exposition, Vancouver, September 6-9, 1988. Congress Proceedings. Aquaculture International Congress, British Columbia Pavilion Corporation, Vancouver, B.C. 491-496p.

D.5.4 Wolffish

Gjosaeter, J. and E. Moksness. 1987.
Some preliminary observations on catfish (Anarhichas lupus and A. minor Olafsen) in captivity. ICES. C.M. 1987/F-32. 12 pp.

Keats, D.W., G.R. South, and D.H. Steele. 1985.
Reproduction and egg guarding by Atlantic wolffish (Anarhichas lupus: Anarhichidae) and ocean pout (Macrozoarces americanus: Zoarcidae) in Newfoundland waters. Can. J. Zool. 63(11):2565-2568 pp.

Myrseth, B. 1988.
New species development and technological advances in aquaculture in Europe. [IN]: Aquaculture International Congress and Exposition, Vancouver, September 6-9, 1988. Congress Proceedings. Aquaculture International Congress and British Columbia Pavilion Corporation. 29-39 pp.

Pavlov, D.A. 1986.
Developing the biotechnology of culturing White Sea wolffish, Anarhichas lupus marisalbi. II Ecomorphological peculiarities of early ontogeny. J. Ichthyology. 26(6):156-169.

Pavlov, D.A. and G.G. Novikov. 1986.
On the development of biotechnology for rearing of White Sea wolffish, Anarhichas lupus marisalbi. I Experience on obtaining mature sex products, incubation of eggs and rearing of the young fish. J. Ichthyology. 26(4):95-106.

Scott, W.B. and M.G. Scott. 1988.
Atlantic fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219. 731 pp.

APPENDIX E

SUMMARY OF FISH PROCESSING FACILITIES IN EACH AQUACULTURE DEVELOPMENT ZONE

E.0 SUMMARY OF FISH PROCESSING FACILITIES IN EACH AQUACULTURE DEVELOPMENT ZONE

The number, location and operating features of fish plants in each Aquaculture Development Zone are summarized in Table 3.1 and this appendix.

E.1 ZONE 1

All three plants in Zone 1 (Cape Charles to Nain) are provincially owned facilities operated by the Torngat Fish Producers Co-op Society based in Happy Valley. Torngat also has a plant in Rigolet (Zone 2). The three plants in Zone 1 handle primarily salmon, char and cod (and trout) but turbot is also an important species. Torngat will likely take over full operation of these plants; it has good connections with local communities in which most of the fishermen are co-op members.

The plants in Zone 1 are seasonal, operating from July to September. Makkovik operates from June to November and in the latter part of the season buys cod/turbot from a mobile longliner fleet based in insular Newfoundland ports.

Makkovik has both freezing capacity and cold storage capabilities.

E.2 ZONE 2

Fourteen fish plants are located in Zone 2, between Smokey (in the north) to Battle Harbour (in the south). All operate on a seasonal basis from the start of the salmon season in late May or June (when ice retreats) to October/November, when most fishermen sell their wet-bulk salted cod to a number of Labrador and Island-based firms.

Fishermen process their own salt-bulk cod in numerous summer stations just off the coast where they live for most of the fishing season. Salmon is collected early in the season and taken to plants in the permanent communities (indicated by a (p) in Table 3.1). The Canadian Salt-Fish Corporation, and their designated agents operate their own plants, processing salt-cod in addition to buying the same product from local fishermen. Cod, salmon, trout, crab, lumpfish roe, mussels, scallops and whelks are processed at plants in Zone 2.

Black Tickle, Domino and Smokey have approximately 562,000 pounds of cold storage capacity among them. Chill storage capacity exists at five other locations (St. Lewis, Frenchman's Island, Rigolet, Battle Harbour and Williams Harbour). The only plate freezer capacity is at Pinsents Arm (1,250 lbs/hour).

Ice (in tons/day) is available at:

Black Tickle	10 t.p.d.
Cartwright	12 t.p.d.
St. Lewis	6 t.p.d.
Mary's Harbour	12 t.p.d.

Ice may also be available at other locations along the coast, but not indicated on DFO statistics. Smokey has 10 tons per day (a regional ice plant).

E.3 ZONE 3

There are 17 fish plants in this aquaculture zone ranging in size from large plants, such as those at St. Anthony (operated by Fisheries Products International) and at La Scie (operated by National Sea Products), to small independently operated seasonal processing operations. St. Anthony operates for about 10 months of the year; La Scie operates for about five months. Most plants in Zone 3 operate for six month. This is characteristic of this northern section of the northeast coast.

The whole zone has significant cold storage/chill storage and blast/plate freezer capacity. Key concentrations of this infrastructure are at St. Anthony, Jacksons Arm, Fleur de Lys, Roddickton and La Scie. Conche is the only location indicated on DOF ice making statistics (10 t.p.d.), but it is obvious that many of the major plants and fishing communities have ice making capacity.

For the most part, these plants are typical multi-species plants concentrating on a variety of groundfish (mainly cod) and pelagic species (herring, mackerel, capelin) or else are restricted to cod/salmon or a single species such as squid. Scallops are landed at Bide Arm, Englee and La Scie; shrimp and crab at Fleur de Lys and some eels are processed through the plant at Jacksons Arm.

E.4 ZONE 4

There are 34 plants operating in the area of the coast stretching between Cape John and Cape Freels, the majority of which are located in Notre Dame Bay. Though most of these processing operations are still considered seasonal facilities, the length of time they are open is generally several months longer than those in Zone 3. For most of the small plants, the usual season is from April/May to November/December; however, many plants operate up to 10 months of the year. Five work year-round (Botwood, Comfort Cove, Fortune Harbour, Lewisport and Campbellton).

For the most part, these plants are typically oriented to multi-species processing (groundfish and pelagics). Squid, when it is available, is harvested along the coast at many locations. Eels are processed at many locations (e.g., Cambellton, Comfort Cove, Middle Arm, Summerford and Little Bay Islands; and smelts at Cottlesville, and clams and mussels at Cambellton). Mussels are also harvested and processed at several locations near Fortune Harbour on the east side of Zone 4. (The plant in Fortune Harbour is leased and operated by Atlantic Ocean Farms.)

Zone 4 has a significant amount of processing capacity: cold storage capability on a zonal basis is 8.20 million pounds; blast freezer capacity is about 52,000 pounds/hour; and, plate freezer capacity is 20,467 pounds/hour. The largest cold storage facilities are found at Joe Batt's Arm, Seldom, Comfort Cove, Fogo, Twillingate, Triton, Little Bay Islands and Herring Neck. Most of the larger plants have ice making capability, but DOF statistics show a capacity of only 6 tonnes per day at Lumsden South and 30 tonnes per day at Durells.

E.5 ZONE 5

Fifteen processing facilities are located in Zone 5. Most plants process groundfish and pelagic species. Some eels are processed at Dover and Glovertown. Most plants operate from April/May to November/December, and only one plant appears to operate year-round (at Glovertown). The region has an enormous, vastly underutilized cold storage capacity (11.8 million pounds in total). Significant locations for cold storage and blast/plate freezer capacity are at Glovertown, Bonavista, Charleston, Greenspond, Valleyfield, Salvage and Dover.

E.6 ZONE 6

Zone 6 (Trinity Bay) has 21 licensed processing plants and the majority of plants have blast freezing or plate freezing capacity, or both. Plants claim to have a total of about 5.6 million pounds of chill storage capacity as well. Significant concentrations of cold storage exist at Old Perlican, Catalina, South Dildo, Clarenville, Hants Harbour, New Harbour and Winterton. Eight locations have chill storage capability (locations just noted plus Sibleys Cove).

There is a varied mixture of seasonal processing operations. Some operate only in the first five to six months of the year,some for just a two to three month period in mid-year, and others operate the usual April to November period. However, about nine plants operate 10 to 12 months.

The vast majority of plants (both seasonal and year-round) are concentrated on processing of groundfish (mainly cod) and pelagics (mainly capelin). Trout are processed at Hickman's Harbour, and some eels at Hants Harbour where P. Janes and Sons operate a very diversified processing plant (primary and secondary processing of nearly all species they buy). At South Dildo, Carino Company Ltd. has developed seal and capelin silage processing systems and more recently a fish protein concentrate (FPC) which it intends to use and sell for livestock and aquaculture feed. This area generates a vast quantity of unused male capelin which is a by-product of the market for females in Japan. Males are currently dumped, or sold into fish meal plants (e.g., at Catalina in Zone 6 and at Carbonear in Zone 7).

E.7 ZONE 7

This small zone has a total of 25 fish processing operations, nine of which operate on a year-round basis. The remainder follow the usual pattern of activity (April/May to October/November), and several operate for only three to four months. Most plants are similar to those in Zone 6, in that they are also highly concentrated on groundfish/pelagic processing. There is also a concentration of salt-fish processing operations in this zone; such plants obtain most of their annual supply of salt-bulk cod from Zone 2. Mussels and whelks are purchased at several locations (e.g., Foxtrap and Harbour Grace).

The zone has a total cold storage capacity of 17.08 million pounds, and 18 plants have cold storage, blast freezers, and plate freezers. Total chill storage capacity is said to be 5.2 million pounds.

E.8 ZONE 8

Nine fish processing operations are located in the short stretch of coast between Cape St. Francis and Cape Race. All but two or three are located in the area from St. John's down the Southern Shore as far as Renews. Most of the Southern Shore plants are small to mid-size groundfish/pelagic operations which process fish in the period April/May to November/December. Year-round plants are in St. John's and Witless Bay.

This zone has significant cold storage facilities (12.7 million pound capacity) and blast/plate freezer capacity in approximately 11 locations.

E.9 ZONE 9

The seven plants in Zone 9 are mainly concentrated in St. Mary's Bay; FPI's year-round operation at Trepassey is the only exception. Three of the seven are year-round operations; the others are typically seven to nine month operations. Processing concentrates on groundfish/pelagic species and capelin and salmon.

Four locations have blast freezers (Admirals Beach, St. Mary's, O'Donnels and St. Josephs). Total cold storage capacity is 4.35 million pounds. Trepassey also has tunnel freezing capacity of 1,200 pounds/hour.

E.10 ZONE 10

Zone 10 contains a mix of year-round offshore based plants and typical small to medium sized seasonal operations (active usually between April to October/November depending on raw material supplies). Most plants are concentrated on groundfish/pelagic species. Arnolds Cove and Southern Harbour, both on the northeast side of the bay, process scallops. There are extensive grounds for this species throughout the head of the bay.

St. Lawrence, formerly owned by FPI, also takes eels, scallops and clams. Burin is FPI's major secondary processing centre but only operates between June and December. FPI is planning to develop a new operation to produce fish protein hydrolysate (FPH) at Marystone. This operation will utilize available offal supplies of 70 million pounds from its own Burin Peninsula operations to produce FPH for worldwide and domestic aquaculture feedstock.

The zone has 2.9 million pounds of cold storage and six to seven locations with blast/plate freezer capacity.

E.11 ZONE 11

This zone of the south South Coast was, and still is for the most part, the heartland of the province's year-round processing sector. About seven plants operate year-round or for close to 11 months. Along this part of the province, the most active inshore/nearshore fishery occurs in the winter months; in summer, activity usually drops off. Offshore landings occur year-round.

The largest plants are concentrated on offshore groundfish processing; scallops are purchased in at least three locations along the coast (Burgeo, Frenchman's Cove and Harbour Breton). The deep fjord bays along the coast provide excellent grounds for this species.

Zonal cold storage capacity is 12.1 million pounds and seven plants have plate freezing capabilities. The three older offshore plants (Burgeo, Grand Bank and Gaultois) retain some blast freezer capability. DOF data indicate that Harbour Breton (FPI plant) also has tunnel freezers. This location is also slated for construction of a new fish meal plant (to produce a high quality, low temperature product suitable for fish feeds - likely with a view towards Bay d'Espoir salmon production).

E.12 ZONE 12

Six plants in this zone are concentrated in the short space of coast between Rose Blanche and Port aux Basques. For the most part, they are year-round operations. These plants concentrate on groundfish, pelagics and salmon and rely on local inshore/nearshore supplies, as well as landings by the mobile longliner fleet (from other provincial locations) during the early part of the winter. Total cold storage capacity is 6.58 million pounds and there is about 0.815 million pounds of chill storage available as well.

E.13 ZONE 13

The 12 plants in this area have a varied pattern of seasonal activity as indicated on Table 3.1. The tendency is towards a concentration on pelagic species, especially in the Stephenville to Corner Brook area, but most plants also purchase lobster and salmon. Scallops are purchased at Fox Island River, Piccadily and Stephenville. St. Georges Bay is a particularly good area for this species. Most of the fishery and fish processing in this zone occurs between the Port au Port Peninsula and Cape St. Gregory.

Cold storage capacity is concentrated at Stephenville (1.45 million pounds), Benoits Cove (88,000 pounds), Cox's Cove (330,000 pounds), Fox Island River (60,000 pounds), and Corner Brook (44,000 pounds). Blast/plate freezing capabilities exist in five locations/plants:

- Stephenville (2);
- Corner Brook (1);
- Benoits Cover (1); and
- Cox's Cove (1).

E.14 ZONE 14

There are 34 plants in this large zone and, given its size, it is to be expected that fish processing operations are of a very diversified nature.

In general, most plants are small-scale operations active in the period May/June to October. These plants process a combination of groundfish (mainly cod), pelagics (herring and salmon), and lobster. Twenty plants, all along the coast, deal in scallops and a significant number purchase eels, clams, smelt, whelks, and mussels as well. Plants along the Labrador Straits side of the zone are concentrated on salt-cod processing and scallops. All of the 11 plants between Lanse au Clair and Cape St. Charles operate between June to October. There are only two year-round operations in Zone 14 (Port au Choix and Rocky Harbour).

Cold storage capacity exists at only five locations (Sandy Harbour, Winterhouse Brook, Red Bay and Lanse au Loup), but likely (though DOF statistics do not show this), FPI's operation at Port au Choix has cold storage capacity as well. Total cold storage capacity in the zone is 1.37 million pounds. Blast or plate freezing only occurs at New Ferrole (blast and plate), Brig Bay (blast and plate), Lanse au Loup (plate), and Winterhouse Brook (blast and plate).