IMPLICATIONS OF THE INTRODUCTION AND TRANSFER OF NON-INDIGENOUS MARINE SPECIES WITH PARTICULAR REFERENCE TO CANADIAN MARINE AQUACULTURE

DANIELLE NICHOLS

Implications of the Introduction and Transfer of Non-indigenous Marine Species with Particular Reference to Canadian Marine Aquaculture

By

Danielle Nichols

Submitted to the School of Graduate Studies in partial fulfillment of the requirements for the Degree of Masters of Marine Studies

Memorial University of Newfoundland

October, 2001

St. John's Newfoundland

Abstract

A relatively new and emerging field relating to the world's oceans has been the identification of risks associated with the introduction of exotic or non-indigenous species. There are numerous pathways for the introduction, either accidentally or intentionally, of non-indigenous species to marine ecosystems. These pathways include aquaculture activities, ship's ballast water, aquarium trade, and individual release. The relative importance of specific dispersal methods varies both temporally and spatially, but each plays a significant role in the introduction and dispersal of marine species throughout coastal environments. Many studies have focused on the impacts of these invasions but relatively few have analyzed the biological, physical, and socioeconomic impacts of non-indigenous species on aquaculture operations. Therefore, the objective of this report is to analyze case studies that focus on the implications, either positive or negative, of non-indigenous marine species on specific ecosystems and how they affect marine aquaculture, particularly in Canada.

Aquaculture is a growing industry worldwide and will likely play a significant role in meeting the increasing demand for fish products in the near future. One of the biggest threats to aquaculture industries and local marine habitats is the transmission of diseases, parasites and nuisance organisms. There has also been growing concern about the use of genetically altered organisms in aquaculture operations, such as use of triploids, transgenics or any selectively bred fish and shellfish. Furthermore, exotic species can destroy the habitats of native marine populations as a result of competition, changing predator-prey dynamics, hybridization, colonization and ecological alterations.

Within Canada there have been a number of studies directed at the impacts of non-indigenous species on aquaculture production. These studies have illustrated that aquaculture businesses in British Columbia have been more affected by accidental or intentional introductions of aquatic species than the east coast. On the Atlantic coast, relatively few species have been introduced as a result of aquaculture activity, but recent studies have illustrated that many non-indigenous species have entered the region through ship's ballast water and have affected many local aquaculture operations.

Canada has numerous federal and provincial regulations regarding the introduction or transfer of non-indigenous species, either between provinces or internationally. These management principles are often confusing, operating through both levels of government, and fail to adequately address existing and potential introductions. In order for the country to effectively monitor and control non-indigenous species introduction, existing guidelines will need to be more transparent, flexible and incorporate sound scientific advice with aquaculture management and ballast water controls. Furthermore, Canada should develop appropriate baseline information and assessment methods, improve communication, and evaluate the procedures that have been successful in other countries and apply those measures that would be most suitable.

Acknowledgments

I would like to take this opportunity to express sincere thanks to my academic supervisor, Dr. Paul Snelgrove, Associate Chair in Fisheries Conservation, for his patience, guidance and understanding during the writing of this report. I would also like to extend my gratitude to all the individuals who assisted me in locating information on this topic. This includes individuals from the Department of Fisheries and Oceans, the Newfoundland and Labrador Department of Fisheries and Aquaculture, Prince Edward Island Department of Fisheries, Aquaculture and Environment, the Nova Scotia Department of Fisheries and Aquaculture, and the Fisheries and Marine Institute of Memorial University of Newfoundland. I would also like to express thanks and appreciation to the library staff of the Fisheries and Marine Institute, especially to Ruth, Brian, and Dianne. Their assistance has been indispensable in the completion of this report.

Finally, I would like to thank my husband, Jason, and my parents for their unconditional love, support, and encouragement.

Table of Contents

Abstract	ii
Acknowledgments	iii
Table of Contents	iv
List of Figures	vi
List of Tables	vii
1.0 Introduction	1
2.0 Pathways and Adaptive Characteristics of Non-indigenous Species	3
3.0 Species Introduced Through Aquaculture	7
3.1 Microbial Pathogens	8
3.1.1 Viral Diseases of Salmon	12
3.1.2 Oyster Diseases	14
3.1.3 Viral Diseases of Shrimp	16
3.1.4 Summary	17
3.2 Marine Parasites	19
3.2.1 Eel Nematodes	20
3.2.2 *Marteilia sydneyi* of Oysters	21
3.2.3 Myxosporeans	22
3.3 Associated Species	22
4.0 Genetic Alterations and Aquaculture	25
4.1 Transgenic Fish and Aquaculture	25
4.2 Potential Impacts of Triploid Fish	28
4.3 Selective Breeding	29
4.4 Reduced Heterozygosity	32
5.0 Environmental Changes as a Result of Non-indigenous Species	35
6.0 Specific Introductions into Canadian Waters and the Implications	38
6.1 British Columbia	38

6.2 Atlantic Canada 55

7.0 Prevention and Management 66

7.1 Canadian Regulations 66
7.2 International Regulations 73
7.3 Foreign Approaches 79
7.3.1 Australia 79
7.3.2 New Zealand 81
7.3.3 United States 83

8.0 Conclusion 87

9.0 Recommendations 89

References 93

List of Figures

Figure 1. Effect of endemic pathogens on introduced stock 10

Figure 2. Effect of introduced pathogens on native stocks 11

Figure 3. Annual value of clam aquaculture harvest in British Columbia 97-99 51

Figure 4. Annual clam harvest by weight in British Columbia 1997-99 51

Figure 5. Annual oyster harvest by weight in British Columbia 1997-99 53

Figure 6. Annual value of oyster harvest in British Columbia 1997-99 53

List of Tables

Table 1. British Columbia's salmon aquaculture production value 1999 41

Table 2. British Columbia's salmon aquaculture export volume and value 1999 41

1.0 Introduction

One increasingly prevalent and ecologically damaging affect of human activities on the marine environment is the global movement of organisms beyond their natural range (Ricciardi & Rasmussen, 1998). These organisms are referred to as non-indigenous or exotic species and include those species that have been genetically altered. Non-indigenous species have become increasingly noticeable in marine and estuarine habitats throughout the world (Ruiz et al., 1997), particularly as their number and impacts continue to accumulate (Ruiz et al., 1999). The accidental or intentional introduction of marine organisms around the world's oceans is not a new trend, rather it has been occurring since humans first crossed the oceans for exploration, colonization, and commerce (Carlton, 1999). Today, most of the world's coastal marine ecosystems are affected to some extent by the introduction of non-indigenous species. Some of these introductions have occurred recently as a result of expanding aquaculture industries, particularly in North America (Sindermann, 1986).

There are three main concerns related to the introduction of marine organisms through aquaculture. First there are problems related to the introduction of exotic species through aquaculture activities, such as the accidental introduction of microbial pathogens, parasites, and marine pests. Second, there are concerns associated with the accidental release of genetically modified individuals and potential genetic influences on native species. Third, the release of non-native species has the potential to cause significant ecological changes, especially to local species and habitats.

As a result of these growing concerns, marine biologists, ecologists, and environmentalists have written numerous papers and books speculating about the impacts of non-indigenous species on oceanic habitats. A synthesis of the main points from these studies will provide a better understanding of the implications that non-indigenous species have had on marine ecosystems and how this can affect the aquaculture industry. The first section of the report examines the relative importance of different dispersal mechanisms, which vary both temporally and spatially, and the adaptive traits associated with successful invaders. The second section addresses population level changes as a result of species introduced through aquaculture activities, such as the transfer of potentially damaging diseases and parasites, and the global movement of marine pests. The third section deals with problems associated with genetic alterations focusing on the use of triploids for rearing purposes, genetic selection processes, reduction in heterozygosity, and transgenic studies. The fourth section investigates ecosystem level issues related to ecological impacts as a result of exotic species introductions, such as competition, predation, hybridization, and habitat modification. This report specifically assesses the Canadian experience with the introduction of non-indigenous species and their impacts, both positive and negative, on Canadian marine aquaculture. The final section of the report will investigate the types of regulations established by Canada to govern the importation of marine organisms, and evaluate how these solutions compare with international regulations/agreements and foreign approaches.

2.0 Pathways and Adaptive Characteristics of Non-indigenous Species.

Marine biological invasions have influenced, to some extent, all reaches of the Earth's coastal environments and will undoubtedly continue, particularly since expanding world markets and global trade accelerate the movement of organisms among continents (Ricciardi and Rasmussen, 1998). There are many pathways for the introduction of non-indigenous marine species, but the major vectors include aquarium trade, individual release, scientific research, and through ship hulls and ballast water (Elston, 1997; Ruiz et al., 1997). Aquaculture activities are also an important instrument for non-indigenous species introduction but will be discussed separately in the following section of this report. The ability of an organism to actually colonize an ecosystem to which they are not endemic requires particular biological characteristics. This section of the report will therefore outline the modes of introduction of exotic marine species and the traits that allow them to be successful in a new environment.

One pathway for non-indigenous species introduction is through the aquarium trade. Tropical fish, plants, and shellfish are often imported for the retail market from warmer countries to more northern latitudes, especially for sale in North America (Welcomme, 1984). Many of the plants, fish, and invertebrates that are sold in various pet and fish outlets are saltwater species or have some degree of saltwater tolerance. Importing organisms for such purposes could result in their escape or release into the local environment (Elston, 1997). Although it is a freshwater organism, the gold fish, *Carassius auratus*, is a primary example of aquarium release since it has achieved an extensive distribution throughout the world due to escape, either accidental or intentional, from ornamental ponds (Welcomme, 1992).

A second pathway for non-indigenous species introduction is by individual people who carelessly or accidentally release organisms into the wild. These types of introductions can include the discarding of live seafood products, aquarium plants and animals, or through marine species collected from various locations and transferred to the local ecosystem (Elston, 1997). By way of illustration, marine divers in British Columbia frequently report the appearances of Atlantic lobsters around Vancouver Island. It has been suggested that these introductions were either the result of unintentional release of live seafood products or from the intentional release by local Buddhists, who purchase and release live fish and shellfish as part of a monthly ceremony (Canadian Press Newswire, 1999). Assessing the risks from individual releases of exotic species is extremely difficult because the risks can vary; thus increasing public education on prevention measures might be a more effective means of reducing future introductions (Elston, 1997).

Non-indigenous species can also be introduced to a region by academic, government, and private research facilities, which import the organisms for experimental and educational purposes. A diversity of marine fish, plants, and invertebrates are typically used for research and teaching purposes. Many of these organisms are supplied by biological institutions that market and distribute live marine species to a variety of facilities throughout the world, such as the Marine Biological Laboratory in Massachusetts or the Carolina Biological Supply Company. Although many of the laboratories have precise protocols to handle non-indigenous species, research establishments do pose a minor risk for the possible introductions to native ecosystems (Elston, 1997).

The final and often most widespread pathway by which non-indigenous species are introduced is through ship ballast water (Carlton, 1985; Ruiz et al., 1997). Each year, more then 16 billion tonnes of ballast water is transported around the globe (Orr, 1999). Scientists and environmentalists have long acknowledged that organisms and pathogens are dispersed throughout the world by the water carried on transport or recreational vessels. Nevertheless, it took the outbreak of harmful algal blooms in Australia and the introduction of zebra mussels to the Great Lakes during the late 1980's before governments and the shipping industry took action to reduce the possible risk associated with introducing exotic marine species (DFO, 1995; Wiley, 1997). Ships take on ballast water to add stability and for navigational purposes, especially when the vessels have little or no cargo (Elston, 1997). Because ballast water is most often taken from bays and estuaries, it is not surprising that ships carry with them a diverse assemblage of organisms (Ruiz et al., 1997). Therefore, non-native marine organisms are transported to the next port of call and have the potential to colonize the new environment. The general pattern of shipping has changed dramatically over the last several decades with increases in cargo, tonnage, and speed, as well as new routes for vessels (DFO, 1995). These changes have unquestionably increased the frequency of transfers of marine organisms

(Elston, 1997). Marine organisms can also become attached to the hulls of vessels and there is evidence that some fish species actually accompany heavily fouled vessels in transoceanic voyages (AQIS, 1995). The fouling organisms themselves may colonize new environments and may have been more important as a mechanism than ballast water during the 19th century and earlier, when solid ballast was commonly employed and hull antifouling paints were unavailable. However, establishment and expansion of marine organisms by vessel hulls may in fact be relatively rare and further research is required to determine the actual risks associated with transoceanic voyages (Elston, 1997).

Although there are a variety of ways marine organisms can be transferred to a new environment, not all organisms have the ability to become established, reproduce and spread throughout the region. The characteristics of the receiving environment and the potential invader both play a significant role in determining if the organism is able to colonize the new habitat. According to Ricciardi and Rasmussen (1998), the initial step in predicting potential invaders is to identify a potential source population: environments that are known to provide source populations often share several characteristics. First, geographic regions with similar climate and oceanographic conditions have a greater potential for species exchange. Second, many potential donor habitats are often associated with large-scale shipping ports and hence a region with a developing economy should be considered a future donor site (Ricciardi and Rasmussen, 1998). Third, estuaries are often more vulnerable to transfers than open or coastal environments (Ruiz et al., 1997), particularly since they are often centers of human activity (Ruiz et al., 1999). Fourth, initial invasions may reduce an estuary's resistance to future invasions (Ruiz et al., 1997; Orr, 1999). Finally, heavily invaded habitats are more likely to continue to be invaded at accelerated rates (Orr, 1999).

From a possible donor environment, potential invaders could be selected based on particular biological characteristics (Ricciardi & Rasmussen 1998; Whoriskey, 2001). Successful invaders tend to be abundant and widely distributed in their original range. They usually have a wide tolerance to a range of environmental conditions. High reproductive rates or continuous spawners are usually observed with mass production of propagules and/or mechanisms to ensure juvenile survival. They generally possess a mechanism for rapid dispersal in the wild resulting in the effective establishment of juveniles into regions where they can flourish. Potential intruders are typically opportunistic feeders, with a capacity to feed on a wide variety of food sources. Invasive species are also often associated with high genetic variability, short generation time, rapid growth, and often form communities in large densities or schools (Ricciardi and Rasmussen, 1998;Whoriskey, 2001).

3.0 Species Introduced through Aquaculture

As previously mentioned, marine aquaculture also plays a role in the introduction of non-indigenous species. Over the last several decades, aquaculture (inland and marine) has emerged as an important and economically viable industry, particularly given the global decline in wild commercial fish stocks (Boghen, 1995). As with terrestrial agriculture, markets and technology drive the production of aquatic organisms. Consequently, the greater the market demand for exotic species, the greater the chance that introductions of non-indigenous organisms will occur. Traditionally, the introduction of exotic marine species for aquaculture was aided by government agencies and now many of those species have become well established in the aquaculture industry (Elston, 1997). An obvious example in Canada is the importation of Atlantic salmon eggs into British Columbia (Natural Resource Consultants Ltd., 1997). Although many countries are aware of the problems that can arise with the introduction of non-indigenous species for aquaculture purposes, introductions of species for cultivation are likely to continue as world consumption increases and market niches develop (Elston, 1997).

The deliberate introduction of non-native species for aquaculture purposes is unquestionably a primary mechanism of species movement, and detailed examples are described below with examples specific to Canada. Additional concerns associated with aquaculture introductions are accidental introductions of microbial pathogens, parasites, and associated species. Therefore, this section of the report will examine a few case studies on auxiliary introductions and their impact on aquaculture species and the surrounding ecosystem.

3.1 Microbial Pathogens

As more and more knowledge has been obtained about the oceanic environment, it has become evident that the transmission of diseases from non-indigenous species to indigenous populations can drastically affect abundance of native species (Sindermann, 1993). This concern is an important area of study for aquaculture investors since the spread of disease could be detrimental to their operations, affecting harvests and sales or closing the business entirely.

Because disease networks are vital to the spread of disease, it is important to understand the events that occur when pathogens are introduced to a marine population (Figs. 1 and 2). In one scenario (Fig. 1) a new pathogen is not introduced to a body of water but there is an introduction of a non-indigenous fish species. The native fish species is resistant to many local pathogens but harbours them in a latent state. When a non-native fish species is introduced, it may be susceptible to the pathogen, resulting in an increase of pathogen levels. Consequently, there are mortalities in both the non-indigenous and native stocks of fish. The native stocks can no longer tolerate the increasing pathogen load and high levels can eventually lead to massive outbreaks of disease (Sindermann, 1993).

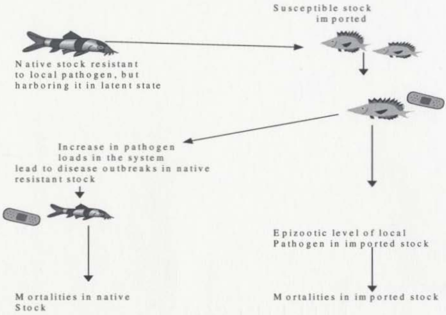

Figure 1: Effect of endemic pathogen on introduced stock.
Modified from Sindermann (1993).

The second scenario (Fig. 2) is potentially more damaging for the native stocks, yet, the introduced stocks are also affected. In this case, a fish species with resistance to pathogens that it carries is introduced, resulting in an outbreak of the pathogen in the native fish. As in the first scenario, this new outbreak leads to a pathogen overload in the system but in this instance it is the introduced fish that die from a pathogen they are normally resistant to (Sindermann, 1993).

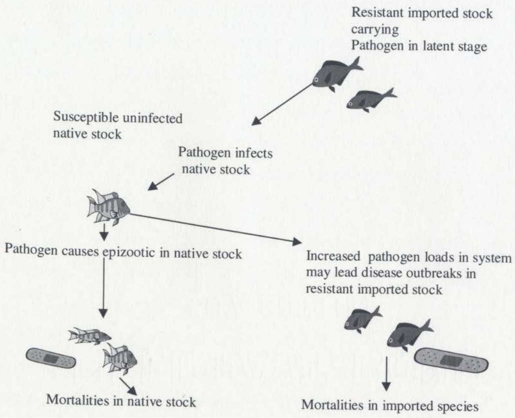

Figure 2: Effects of introduced pathogens on native stocks.
Modified from Sindermann (1993).

The two scenarios are similar in that both the native and introduced species suffer mortality. The difference is that the pathogen enters the system from different origins. Under either scenario the end result is devastation of a fish population, illustrating a very important implication of introducing non-indigenous species through aquaculture ventures (Sindermann, 1993).

The following section of the report will provide specific examples of the impacts of disease transmission for a few economically significant cultivated species, particularly salmon, oyster, and shrimp. These case studies focus on diseases identified in species that are cultured in areas of the world other than Canada, but which are either important to Canadian marine aquaculture, represent a potential threat to Canadian waters, or provide a particularly good illustration of non-indigenous disease transfer. Understanding these case studies is vital to aquaculture operations in Canada because improved understanding may prevent outbreak within this country, provide the basis for potential solutions to epidemics, and help prevent future introductions of pathogens.

3.1.1. Viral Diseases of Salmon

Over the last century, there have been several attempts to introduce Pacific salmon to Atlantic waters. Long-term establishment of spawning runs and reproductive populations have largely been unsuccessful, given that sustained runs were totally dependent on the repeated importation of eggs from the Pacific region. Regardless of the obstacles faced, attempts still continue, including approaches such as cage culture of coho salmon (*Oncorhynchus kisutch*) in coastal waters and private ocean ranching of pink salmon (*O. gorbuscha*) and chum salmon (*O. keta*). All of these approaches are dependent on the successful production of young fish (Sindermann, 1993).

The former Soviet Union had several large-scale introductions of Pacific salmon in Atlantic waters, which spread to Norwegian waters and other areas. In New Hampshire, USA, a long-term program involving the importation of coho salmon eggs has resulted in some natural spawning with low survival rates, but permanent runs have yet to be established. Many other programs with the same objective have been attempted but the results have been varied. In each of these examples, a primary concern has been competition with native salmon species and the importation of disease (Sindermann, 1993).

The diseases of greatest concerns are Infectious Hematopoietic Necrosis (IHN) and Viral Hemorrhagic Septicemia (VHS), which are both lethal viral diseases. IHN now occurs in Italy and France and was apparently introduced with rainbow trout (*O. mykiss*) from the west coast of the United States (Sindermann, 1993). IHNV was also introduced into Japan, most likely with the transfer of sockeye salmon (*O. nerka*) eggs from Alaska in 1968 (Sindermann, 1993). The virus spread rapidly to Honshu Island and since then has been linked to rainbow trout mortalities in Taiwan, Korea, and the People's Republic of China, probably as a result of the importation of rainbow trout eggs from Japan (Chen et al., 1985).

The second viral disease, VHS, is extremely common in Europe and is especially problematic in rainbow trout, but it was also identified in salmonids from the Pacific coast of North America in 1988 (Brunson, 1989). Initial concerns were that the virus had been imported from Europe as a result of aquaculture activities. However, recent studies have shown genetic and virulence differences in VHS virus isolated from Pacific salmon compared with those isolated from European salmon (Bernard et al., 1991). In this situation there may not have been an introduction of the viral pathogen but precautions must be in place because introductions of the different strains of VHS could still occur and result in high mortalities.

A number of salmonid species, including coho salmon, have been introduced to the coastal waters of Chile during the past few decades. In 1989 mass mortalities of up to 90% of stocks occurred at some aquaculture sites. After lengthy investigations it was discovered that the mortalities were the result of the importation of two deadly diseases, Rickettsial disease and *Renibacterium salmoninarum* (Fryer et al., 1990).

Renibacterium salmoninarum, is a bacterium that causes kidney disease in salmonids. Evidence suggests that the disease was introduced to the region from coho imports from the Northern Hemisphere and resulted in mortalities of native salmonid populations. By contrast, Rickettsial disease is found in local native aquatic species and this is believed to be the source of the disease found in the imported coho salmon (Fryer et al., 1990). In either case it is apparent that the introduction of a non-indigenous species resulted in disease outbreaks in both native and introduced species.

3.1.2 Oyster Diseases

Oysters are highly susceptible to mass mortalities, but during the last several decades there have been dramatic increases in stock losses. Of all marine organisms, oysters, particularly *Crassostrea gigas*, have been introduced most frequently to new areas, typically as a result of aquaculture activities. This has resulted in the development of an effective transfer network of pathogens and parasites. Oyster populations in the United States, Europe, and Japan have been hardest hit by these pathogens, which are often viruses and protozoans (Sindermann, 1993).

The Pacific oyster (*Crassostrea gigas*) was introduced to the coast of France between 1966 and 1977. The oysters were introduced to the region as both seed and adults from Japan and British Columbia. The Pacific oyster eventually replaced the indigenous Portuguese oyster (*C. angulata*) population, and prospered well in the region, resulting in major aquaculture expansion (Sindermann, 1993).

Although the massive introduction of Pacific oyster was successful for commercial aquaculture, a dramatic series of epizootics developed in two native species of oysters around the same time. In 1966, the native oyster, *C. angulata* suffered considerable losses resulting from a viral gill disease. Once the epizootic subsided, most of the *C. angulata* population was depleted and replaced with the Pacific oyster in most grow out areas. Another native species of oyster affected severely by epizootic disease was the European oyster (*Ostrea edulis*). In 1968, the protistan parasite *Marteilia refringens* harshly affected oyster-growing sites in the region (Elston et al., 1986a). The disease eventually subsided during the mid-1970s but was quickly replaced by another protistan parasite, *Bonamia ostreae*. This parasite developed quickly into epizootic proportions and dramatically reduced the oyster population. This disease is still present today, resulting in little to no culture of *O. edulis* in France. Evidence suggests that the pathogen *Bonamia ostreae* entered France in *O. edulis* seed imported from a California hatchery. This stock had originated decades before in the Netherlands and first entered the United States in the 1950's (Elston et al., 1986a). Given that *O. edulis* has the potential to be an important aquaculture species in Atlantic Canada, and particularly for Nova Scotia, it is essential for aquaculture facilities to identify potentially deadly diseases and the pathways of introduction that have occurred in other regions of the world.

3.1.3 Viral Diseases of Shrimp

Shellfish, and shrimp in particular, have become important products on world seafood markets in recent years. The increase in the demand for shrimp has led to growing interest in shrimp culture. The culture of shrimp occasionally requires the movement of seed populations and the introductions of species that present the most desirable rearing characteristics. This activity has led to the introduction of several lethal viral pathogens. The most serious of these pathogens is a disease termed IHHNV, which stands for infectious hypodermal and hematopoietic necrosis virus (Sindermann, 1993).

IHHNV is found in several shrimp brood stocks in Southeast Asia and has been introduced to aquaculture facilities in Florida, Hawaii, Texas, Philippines, Guam, and Tahiti. The disease was initially detected in shrimp farms in Mexico in 1981. Evidence suggests that the disease was transferred to the region from Panama and was detected in juveniles and adult shrimp weeks after their arrival. The biggest concern relates to the possibility of infecting the native population. However, there has been little evidence that this has become a problem (Sindermann, 1993).

It has been suggested that the transfer of viral diseases of shrimp can be linked to the movement of stocks during the past two decades. This movement of marine organisms has resulted in a transfer network and in the majority of cases the pathogen is never detected and travels rapidly throughout the network. A solution to the spread of diseases through this network requires establishing stricter quarantines on imports and carefully selecting brood stock to ensure that they present no sign of disease (Sindermann, 1993).

3.1.4 Summary

Only a few cases of disease and bacteria introductions via non-indigenous species were discussed, however, these examples were selected because they illustrate disease transfers in species that are either important to Canadian marine aquaculture, such as *O. edulis*, or provide a good example of disease transfer in culture systems. It is also important to note that the majority of the organisms that are intentionally introduced to a new region enter for aquaculture purposes (Sindermann, 1993). From the case studies that were evaluated in this section, a number of points can be made. First, pathogens may move along transfer networks. Second, introductions of aquatic pathogens have been accidental, even when the introductions of host species were intentional (i.e., aquaculture). Third, countries need to identify pathogens quickly and develop programs to study these organisms in their new habitat. Moreover, it is important to realize that although some countries have strict regulations regarding the introduction of non-indigenous species, it is almost impossible to prevent the spread of disease. For example, preventing the spread of disease is very difficult in adjacent geographic regions and there is often no required treatment of ballast water on vessels entering foreign ports. Fourth, there is a potential disease risk associated with introductions of new species. Fifth, once a disease enters a population it is almost impossible to control its expansion, especially in regions where cage culture occurs. A final point is that the movement of organisms throughout the world, in ballast water, for aquaculture application, or scientific research, is steadily increasing and it is therefore anticipated that many parasites and diseases will emerge in new environments (Sindermann, 1993).

In addition to addressing the pathways of disease, Sindermann (1984) proposed a disease control program. Disease control in intensive culture systems is clearly necessary and feasible, particularly if the program is designed around four main elements. First, any aquaculture operation will require some form of physiological stress management. In other words, it is necessary to maintain appropriate water quality, reduce overcrowding, provide a proper diet, and prevent abnormal temperatures and salinities. Stressful situations can cause serious behavioral and physiological changes that will eventually reduce resistance to pathogens. Second, vaccinations (prophylactic immunization) should be a standard practice in aquaculture facilities. There are three important components of an immunization program for marine aquaculture; government supported research and development, commercial production of vaccines, and a non-traumatic procedure of mass application. A third requirement in a disease control program is the utilization of chemotherapy techniques. This type of treatment is applied only when other measures fail because it can result in drug resistance after continuous use and can have detrimental affects on algal food and nitrifying bacteria. The final element of a disease control program for marine aquaculture is the prevention or careful introduction of non-indigenous species with appropriate screening, which requires both a national and international management agenda.

3.2 Marine Parasites

All living organisms have parasites, including fish and shellfish species. Many of these parasites are not actually harmful to the host organisms but they may affect the texture, appearance, or behaviour of the species. The identification of parasites in aquaculture operations is an important source of concern because parasites can impact the sale of the product as a result of lesions, discolouration, poor meat quality, or even high mortality in highly infected systems. More importantly, parasites can be transferred to a new region with the introduction of a non-indigenous marine species for aquaculture purposes. The new environment offers the parasite the opportunity to reproduce, disperse, and invade additional host species, which may include both aquaculture and wild organisms. The following section will examine a few case studies of parasites, particularly eel nematodes, *Marteilia sydneyi* in oysters, and myxosporeans, as well as their impact on aquaculture facilities. Although these case studies focus on parasites found in aquaculture operations throughout the world, there are either similar parasites already identified in Canadian marine aquaculture or these parasites have the potential to invade Canadian waters.

3.2.1 Eel Nematodes

In Europe there has been recent emergence and massive expansion of nematode worms, *Anguillicola crassus*, among native European eel populations (*Anguilla anguilla*). The worms entered Europe through the introduction of live Japanese eels. The worms are large bloodsucking organisms that attack the swimbladder, resulting in high mortalities in holding pens; there are also negative implications for spawning migrations (Sindermann, 1993).

The infection of native eel populations was first documented in Germany in 1982. The origin of the infection was traced back to the release of infected eels that were shipped from Taiwan in 1980. Today, the parasites are found in most European countries, including Netherlands, Denmark, Poland, England, Spain, and Greece. The infection is acquired in the early elver stage, where an acute inflammation develops in the swimbladder. Small crustaceans usually act as an intermediate host (Sindermann, 1993).

An active network of eel introductions has undoubtedly aided in the rapid spread of nematode populations throughout many European countries. The majority of eel farms have been dramatically affected, with massive reductions in growth rates and mortalities of up to 65% in culture populations. *Anguillicola crassus* will likely continue to expand as a result of human transport of eels for the stocking of aquaculture ponds and for markets within and across national boundaries (Sindermann, 1993).

3.2.2 *Marteilia sydneyi* of Oysters

Marteilia sydneyi is a protoctisian parasite that invades the digestive gland epithelial cells of host species. The most commonly affected organisms are the oyster *Saccostrea commercialis* and *Crassostrea echinata*. These two species are native to the east coast of Australia but have been introduced to other areas of Australia for production in aquaculture facilities. *Marteilia sydneyi* accompanied these introductions and was able to establish itself in many coastal areas throughout the country (Bower, 1996).

The greatest concern with *Marteilia sydneyi* in cultured oyster populations is that it is responsible for QX disease (Bower, 1996), which is similar to MSX disease identified in oyster culture on the east coast of North America (Gorman, 1995) and will be discussed in a subsequent section of the report. Generally, infected oysters are in weakened condition with completely resorbed gonads. Massive invasion by *Marteilia sydneyi* results in the discolouration of the infected tissue, severe shrinkage of the body, and tissues become transparent as a result of gonad resorption. Infected oysters usually die within 60 days as a result of starvation (Bower, 1996). Therefore, infected regions pose a serious threat to aquaculture operations because death of the organism is usually unavoidable. This parasite seems to be confined to the waters of Australia and limited to the species discussed above. However, further research is required to determine its impact on other oyster species and whether or not it can colonize marine habitats outside its natural range.

3.2.3 Myxosporeans

Myxosporeans have always been a serious pathogen of both wild and cultured fish populations. The best known of these parasites is *Myxosoma* (Myxobolus) *cerebralis*, which is responsible for 'whirling disease' in many hatchery facilities throughout the world. *M. cerebralis* has been identified in cultivated salmonids in Europe, Asia, and in North America. In the United State this parasite has caused extensive losses to aquaculture operations since its introduction, and it has spread throughout many regions as a result of transports of salmonids for culture and stocking purposes. Generally, mortality occurs in heavily infected fish, whereas moderately infected fish exhibit skeletal disfigurement and growth retardation (Sindermann, 1990). Although this is only one example of a myxosporean infection in cultured marine fish, there are several others that have been identified. *Kudoa thrysites*, which causes fatalities in year-old Atlantic salmon on the Pacific Coast of North America, will be discussed later in the report.

3.3 Associated Species

In addition to the introduction of microbial pathogens and parasitic organisms by aquaculture introductions, the introduction of associated aquatic species has also occurred. The majority of these introductions are the result of accidental introduction of adult or larval benthos in transport mediums of aquaculture species, such as in seaweed or saltwater. The impacts of these introductions on the native ecosystem can sometimes be dramatic, causing serious damage to indigenous populations and altering characteristics of the surrounding environment.

The introduction of oyster populations for aquaculture purposes, for example, has been identified as the pathway of introduction for non-indigenous snail species (Lafferty and Kuris, 1996). The oyster drill, *Urosalpinx cinerea*, is a highly invasive species that is able to colonize a non-native ecosystem even when the introduced oyster culture has failed (Carlton, 1975). On the Pacific coast of North America, oyster drill introduction has become a serious threat to commercial oyster culture (Elston, 1997). *Ilynassa obsoleta*, which was introduced from the east coast of North America, and the Japanese snail, *Battilaria attramentaria*, are known to compete with the native mud snail, *Cerithidea californica*, by preying on its egg masses (Whitlatch and Obrebski, 1980; Race, 1982).

A second example of introductions of associated species has been transfers of the organisms responsible for red and brown tides. These introductions have been linked to imports of shellfish species for mariculture (Shumway, 1989) and through ship ballast water (Hallegraeff, 1993). Red and brown tides form as a result of marine dinoflagellate blooms (Lafferty and Kuris, 1996) and have serious implications for the affected region. Red tides can kill large numbers of fish in an area, which causes pollution of nearby shoreline and severe losses to local commercial fisheries and aquaculturalists. More commonly, red tides cause paralytic shellfish poisoning, which can result in human illness and possible mortality after consuming highly toxic shellfish species. Affected areas must then be closed to commercial harvesting, often for extended periods of time. By contrast, brown tides, which are caused by chrysophytes, can cause serious damage to invertebrates populations and eelgrass beds and have been know to severely affect local scallop fisheries (Lafferty and Kuris, 1996). This type of associated aquatic species introduction is effectively illustrated by the recent outbreak of algal blooms in aquaculture sites on the east coast of New Zealand as a result of transfers of wild Pacific oysters spat from the west coast of the country (Haworth, 2001). These associated introductions have the potential to cause major changes to local species abundance, impact economically important fish and shellfish fisheries as well as aquaculture operations, and alter the physical ecosystem.

A final illustration of an associated introduction is that of the Asian clam, *Corbicula fluminea*. The Asian clam is native to southern Asia, east coast of Africa, eastern Mediterranean, and central and eastern Australia (Morton, 1986). *C. fluminea* was first identified along the banks of the Columbia River near Knappton, Washington, USA in 1938. Chinese immigrants, who use the species as part of their diet, most likely introduced the clam to the region. Today, the Asian clam has become widespread through the Pacific Northwest as a result of introductions of aquaculture species to new regions and by bait bucket introductions in sport fisheries (Counts, 1986). Since its introduction, the Asian clam has caused serious modifications to local ecosystems, including the displacement of indigenous suspension and filter feeders, altering the feeding cycles of many native fish and bird species, reducing phytoplankton blooms, and modifying the stability of surrounding substrates (Lafferty and Kuris, 1996).

4.0 Genetic Alterations and Aquaculture

The need to preserve aquatic biodiversity has become increasingly evident over the last several decades, particularly since growing public and academic comprehension regarding the complexity of aquatic interactions has resulted in conservation biology becoming a major discipline in the life sciences (Ryman et al., 1995). The three most important threats to aquatic biodiversity include loss of species, introduction of exotic species, and loss of genetic variability (Philipp et al., 1995). This section will examine the concerns and impacts of genetic alteration on aquatic biodiversity as a result of aquaculture activities.

4.1 Transgenic Fish and Aquaculture

Over the last several decades, the understanding of molecular genetics has increased substantially (Hallermann and Kapuscinski, 1992), particularly in the development of transgenic fish. Transgenic fish are organisms that have been genetically altered through the introduction of DNA sequences from other organisms, accompanied by the integration of one or more of the novel sequences into their chromosomal DNA (Maclean and Laight, 2000). As a result of these modifications, fish are typically able to grow faster to marketable size, are considered safe for human consumption, and will pass modified genes on to successive generations (Hallermann and Kapuscinski, 1992) if reproductively viable. Transgenic species can also be modified to have greater resistance to lethal pathogens through altered immune systems (Hew and Fletcher, 1997), thereby reducing the need for vaccines and chemotherapy in cultured systems. Furthermore, studies have been conducted on the possibility of developing strains of fish, such as Atlantic salmon, that can tolerate extremely low temperatures as a result of introducing an antifreeze protein gene obtained from higher latitude species (Fletcher and Davies, 1991; Maclean and Laight, 2000). Some more recent studies have focused on developing fish that are able to expand their geographical range with modified genes for salinity tolerances (Iyengar et al., 1996) and improving the carbohydrate metabolism of fish to reduce feed costs (Pitkanen et al., 1999).

It has been suggested (Hew and Fletcher, 1997) that aquaculture will play a significant role in meeting the increasing demand for fish products in the near future, and that transgenic applications will increase yields because they produce fast growing fish with more efficient feed conversion ratios. Furthermore, it has been argued that in order for a country like Canada to remain competitive in international markets, it will need to continue research on transgenic applications and maintain support in this area from both government and regulatory agencies (Blewett and MacDonald, 1998).

Although there have been many successful developments in molecular genetics, there are several issues regarding the application of transgenic fish in aquaculture operations. First, there is concern about the possible release of transgenic organisms into the ecosystem, where they could survive, reproduce, either with other transgenic individuals or with indigenous populations, and scatter into nearby habitats (Hallermann and Kapuscinski, 1992). However, Hew and Fletcher (1997) argued that there is no evidence to suggest that transgenic organisms will disrupt the ecological balance of an ecosystem. Moreover, they recommended that sterile fish can be used to reduce any potential impacts. Second, there is a fear that transgenes might cause defective characteristics in modified fish, which might be harmful to humans. This is a serious concern for the industry; however, all genes presently used in fish transgenic studies are thought to be safe for humans and are strictly regulated for future complications (Maclean and Laight, 2000). Third, there is a concern that transgenic incorporation could cause genetic problems through position effects or other genetic interactions, but this possibility seems to be fairly rare in practice (Maclean and Laight, 2000). Fourth, religious groups, particularly in the United States, have questioned the morality of genetic engineering and opposition to future development is therefore likely (Blewett and MacDonald, 1998). Fifth, some groups, such as the Humane Society of America, are concerned that gene transfers will result in animal suffering (Blewett and MacDonald, 1998). Finally, there has been enormous concern by the general public regarding the safety of consuming genetically altered plants, animals and aquatic species (Blewett and MacDonald, 1998) and that the process used to produce transgenic fish is 'unnatural' (Maclean and Laight, 2000). Research has shown that it is hard to determine natural and unnatural breeding methods and many of the products consumed today have been created artificially, such as certain crops and cattle species (Maclean and Laight, 2000).

4.2 Potential Impacts of Triploid Fish

A relatively recent development in the aquaculture industry has been the manipulation of numbers of sets of chromosomes. The studies are based on rearing triploid fish and motivated by the notion that triploid fish, which do not invest a large amount of energy in gonad development, will grow more efficiently than diploid fish (Lincoln and Bye, 1984). Moreover, because triploid fish are sterile, there is reduced concern about them reproducing if released into the environment.

Although triploid females generally have poorly developed ovaries, triploid males (especially in some salmonids) exhibit signs of partially developed testes with normal levels of reproductive hormones (Benfey and Sutterin, 1984, Lincoln and Scott, 1984). In the case of masu salmon, the testes of triploid males are less developed then diploid males and have no spermatozoa, even in spawning season. However, the males do exhibit external secondary sexual characteristics with similar level of steroid hormones and gonadotrophic hormone as diploid males (Nakamura et al., 1987). Therefore, although triploid males may lack functional sperm, they could exhibit sexual behavior towards diploid females and influence reproductive behavior in diploid populations.

Studies were conducted on masu salmon to determine the impacts of triploid males on diploid females during spawning season in modified aquarium environments. In these experiments, triploid males displayed a frequency of quivering similar to diploid males and all females tested spawned within 12 hours after the start of the experiment. These quivering movements can be accredited to natural activities of steroid hormone production within fish (Nakamura et al., 1987).

In summary, triploid male musa salmon, even without sperm, exhibit typical courtship behavior and have the ability to induce spawning of ovulated females. Inada and Taniquchi (1991) have also observed that triploid ayu (*Plecoglossus altivelis*), which have poorly developed testes, will chase after diploid females and are often involved in spawning activities with females. These reports suggest that a diploid female will spawn with a triploid male, even in the natural environment. Therefore the release or escape of triploid males into marine ecosystems may affect the productivity of natural populations (Kitamura et al., 1993). This is an important area for continued research, because it could have serious effects on natural fish populations and even threaten natural fisheries.

4.3 Selective Breeding

Genetic modification of aquatic species in order to improve production, range and quality is a relatively recent development in the aquaculture industry. This timing is remarkable given that the business of aquaculture has many elements similar to that of agriculture and draws heavily upon the experience and knowledge developed in animal husbandry. Scientists have suggested that fish may respond more effectively to genetic selection than terrestrial animals and that aquaculture breeding programs could help meet the increasing demand for aquaculture products (Gjedrem, 1997).

Until recently, selective breeding programs have been relatively rare in aquaculture operations throughout the world. One of the earliest reported selection experiments was carried out on rainbow trout populations by researchers at a California Fish and Game facility (Hot Creek State hatchery). Scientists at this facility were able to modify spawning periods, alter the spawning age to two years, and create a two-fold increase in average fecundity (Parsons, 1998). In 1971, a Norwegian company, AKVAFORSK, initiated an extensive breeding analysis with Atlantic salmon and rainbow trout. Within a few years, the study developed into a major breeding program that focused on growth rate selection. The program eventually advanced into a national breeding agenda and currently sets standards for cultured salmon and trout population in terms of body weight at marketing, early maturation, disease resistance, and flesh quality (Gjedrem, 1997). In 1993, the Philippine Tilapia breeding programme (PNTBP) was launched, and it presently focuses on growth rate selection, delayed sexual maturation and disease resistance. Although the program is relatively new to the Philippines, genetic improvements will unquestionably play a large role in meeting the demands for *Tilapia* products in the region (Gjedrem, 1997).

Breeding programs are most often directed at selecting for characteristics that produce faster growth rates, more effective disease resistance, and delayed sexual maturity. Fast-growing fish generally have a much lower production cost than that of a slower growing fish because they have a rapid turnover rate and more efficient feed utilization. Moreover, faster growing fish and shellfish are considered lower risk because they need shorter time to reach marketable size. Selecting characteristics that improve disease resistance can have many economic benefits for the industry, such as more fish to harvest, decreased feed wastage, reduced need for antibiotics, and less infection strain in the environment. The final characteristic that aquaculture operations often select for is delayed sexual maturity. Postponing the age of sexual maturity is more profitable to the industry since the optimal market size is reached sooner and production control is more effective. In addition, delaying sexual maturity can improve flesh quality, which can increase the demand and price received for the product and prevent loss of product during processing operations (Gjedrem, 1997).

Although selective breeding can offer many positive elements to aquaculture business, there are concerns over the potential negative implications that may arise if the organisms are released into the wild. Genetic threats are usually cited as the most serious concern to wild populations, because farmed populations are occasionally inbred with reduced genetic variability. Although this concern is often restricted to a single stock or species, ecological threats may extend to many classes of plants and animals, such as birds, insects, mammals, fishes, amphibians, invertebrates, and seagrass (Pearsons and Hopley, 1999). For example, anadromous salmonids play a significant role in both freshwater and marine environments; therefore, the release of modified salmonid species into native systems can have serious consequences for other components of the ecosystem. Genetically selected fish are generally larger and behave differently than their wild counterparts, which can result in different ecological interactions between similar species and other organisms (Nielsen, 1994; White et al., 1995; Pearsons and Hopley, 1999). The accidental release of genetically altered species can impact native species through various ecological mechanisms, including competition, displacement and transmission of diseases (Pearsons and Hopley, 1999). Furthermore, they can alter predator-prey dynamics, either resulting in an increase or decrease in native species abundance (Collis et al., 1995; Pearsons and Hopley, 1999). Further research is needed to determine the impacts of selectively bred organisms on native ecosystems and to create a risk assessment program and additional prevention measures.

4.4 Reduced Heterozygosity

The existence of genetic variation, either between populations or among individuals within populations, is imperative for their survival and ability to respond to short or long-term environmental changes. Three primary threats to intraspecific genetic diversity of aquatic species are local extinctions, hybridization, and loss of genetic variation. Reduction in genetic diversity between populations, which can occur between genes, individuals, populations or geographic regions, occurs any time a genetically distinct population ceases to exist or when its integrity is compromised through hybridization or selection (Ryman et al., 1995).

Extinction is a process that occurs when there is a total loss of genes or gene combinations from a particular region. Disappearance of species or native populations is most often the result of losses or modification of the surrounding habitat, such as the blocking of migratory routes of anadromous fish populations, pollution of estuaries and bays, and human construction in wetland environments. In addition to physical habitat modifications, the introductions of non-indigenous species and associated diseases and parasites have also played a significant role in the extinction of aquatic organisms (Ryman et al., 1995). For example, Nile perch (*Lates niloticus*), which were introduced into Lake Victoria during the 1950s, threaten many indigenous cichlid populations through both competition and disease (Achieng, 1990).

The second threat to genetic diversity, either between or within species, is hybridization (Ryman et al., 1995). This process may not result in the loss of individual genes, but in the rearrangement of gene combinations, which usually cannot be recreated and may result in failure to adapt to changing environmental conditions (Hinder et al., 1991). Hybridization between species is often associated with human activities, such as intentional or accidental transfers of exotic species through ship ballast water or canal construction (Campton, 1990), and it has clear and immediate effects on biodiversity (Waples, 1995). For instance, there has been extensive flow of genes from introduced rainbow trout (*Oncorhynchus mykiss*) and cutthroat trout (*Oncorhynchus clarki*) to endemic populations of related species in the United States interior (Allendorf and Leary, 1988). These introductions have resulted in the loss of genes and the development of several hybrid populations. Intraspecific hybridization is also a major threat to the genetic diversity of local population. For example, many wild salmonid populations are threatened as a result of stocking programs, ocean ranching and escapes from net-pen culture (Ryman et al., 1995). Although the exact impact of hybridization on the genetic diversity of local populations is unknown, it must be considered a potential problem and future guidelines need to be established.

The third threat to genetic diversity is the loss of genetic variation within populations, which usually occurs through selection, either deliberate or accidental, genetic drift, and inbreeding as a result of restricted population size. Selection is a process that results when certain genotypes produce more offspring than others, which causes only a limited number of genes and genotypes to be preferred. Consequently, there is a reduction in the in the number of alleles, which ultimately results in loss of genetic diversity within the population. Although the process of selection is known as an important element in the reduction of genetic diversity, it is difficult to determine the characteristics, intensity and direction of the selective forces. Nevertheless, the most obvious examples are those caused by human activities, such as differential harvesting techniques, cultivation practices, and selective breeding programs (Ryman et al., 1995).

Loss of genetic variability due to restricted population size is generally referred to as reduction of heterozygosity within populations. Populations need a minimum number of individuals in order to maintain genetic variability (Ryman et al., 1995). The largest threats to population heterozygosity are the numerous breeding-release programs aimed at supporting particular native populations (Ryman and Laikre, 1991) that have become threatened by over-fishing or habitat destruction (Waples, 1995). Although stocking of fish into natural waters has occurred for more than a hundred years, most programs have failed to adequately anticipate or understand the potential threats to local ecosystems (Pearsons and Hopley, 1999). Transfers of relatively low numbers of cultured fish to a region have been used as a means of maintaining genetic diversity in many isolated salmonid populations. However, in many instances these transfers actually undermine genetic variation within populations (Luiz, 1999). In addition, many of these programs have increased the number of fish in the wild, but threaten genetic diversity of the total population by reducing its effective genetic size (Ryman et al., 1995).

5.0 Environmental Changes as a Result of Non-indigenous Species

The ecological ramifications resulting from the introduction of non-indigenous marine species into a particular ecosystem are potentially numerous, extremely complex, and often misunderstood. However, scientists have been identifying and analyzing two principal issues to address these impacts. The first issue is to understand the interactions of introduced organisms with species endemic to the ecosystem; these interactions include competition, predator-prey relationships, disturbances, and co-introductions. The second issue is the interaction of non-indigenous species with their new environment (ICES, 1994).

Non-indigenous species may compete with native species for physical space, such as the direct or indirect competition for spawning or juvenile feeding grounds, for food supply, and for other essential resources. These forms of competition could potentially cause a change in local species abundance or possible extinction of the native species from a specific ecosystem. Furthermore, the alteration of native species abundance may have an indirect effect on other elements within the ecosystem, especially relationships with and among other species (ICES, 1994). Environmentalists, scientists, and the general public are concerned about competition issues that could potentially arise if exotic cultured species are accidentally released into the wild.

The introduction of non-indigenous marine species may also have a major impact on predator-prey dynamics within the ecosystem, in that the introduced species could consume native species or vice versa. These interactions can change native and introduced species abundance and/or alter their diets and feeding strategies (ICES, 1994). This is a serious issue for aquaculture operations and commercial fisheries. For example, Atlantic salmon aquaculture in British Columbia has been a topic of considerable debate in recent years because Atlantic salmon are not endemic to the region. Commercial salmon fishers have been concerned that if Atlantic salmon escape from aquaculture sites, they will be more aggressive feeders than local populations, causing a change in the feeding behavior and location of local salmon (Thornton, 2000). There is no scientific evidence, however, to demonstrate that this situation will occur.

A non-indigenous species can also modify a habitat by altering the distribution and abundance of other species within the ecosystem through indirect effects of disturbances. For example, polychaete worms, clams, or crustaceans, which instinctively burrow into soft substrates, can significantly reform surface sediments and boundary layers (ICES, 1994), which in turn can affect the feeding behavior of many marine organisms, including those which are economically important to the aquaculture industry. For example, the euryhaline bivalve *Potamocorbula amurensis*, which was first observed in San Francisco Bay in 1986, is a non-native shallow burrowing organism that intensifies sediment resuspension by destabilizing surface sediments and increasing bed roughness (Carlton et al., 1990).

The final issue relating to the interaction between introduced and native species has been the co-introduction of associated species, such as the numerous species found on oyster shells or planktonic organisms located in fish transport water (ICES, 1994). This type of interaction can lead to serious impacts on the local ecosystem, such as the spreading of harmful algal blooms as a result of dinoflagellate cysts in sediments affiliated with the transport of fish or shellfish (Sindermann, 1993).

The second major scientific issue is the interaction of non-indigenous species with their new environment, particularly in terms of ecological and geological impacts. Introduced species may inhabit an area where few or no ecologically similar species have existed, thereby altering the natural functioning of the ecosystem. Furthermore, introduced species can change the physical landscape of a region. For instance, the substrate burrowing New Zealand sphaeromatid isopod crustacean (*Spaeroma quoyanum*) was accidentally introduced into San Francisco Bay during the early 20^{th} century, causing massive shoreline erosion that continues to be a problem to the present day (ICES. 1994). Altering the physical environment of a particular ecosystem can have serious implications for fish and shellfish populations; for example, shoreline erosion may destroy vital rearing grounds for juvenile finfish populations (Elston. 1997) and/or destroy potential aquaculture sites.

6.0 Specific Introductions into Canadian Waters and the Implications

This section of the report will deal briefly with the introduction of non-indigenous marine species into Canada's east and west coast provinces, which include British Columbia, Newfoundland, Nova Scotia, New Brunswick, and Prince Edward Island. This section will also address the implications of the introduction of exotic species to each province, focusing on pathways of introductions, microbial and parasitic transfers, genetic alterations, environmental changes, and the documented impact of these introductions, if any, on aquaculture businesses.

6.1 British Columbia

Of all the Canadian provinces, British Columbia has been the most influenced by the introduction of non-indigenous marine species. These introductions have been both intentional, for aquaculture or live seafood markets, and unintentional, through transport media, ballast water, and migration between shared waters (British Columbia and Washington State). Therefore an analysis of several species, including Atlantic salmon, brown algae (*Sargassum muticum*), cordgrass, Japanese oyster drill, Asian copepod, green crab, mahogany clam, Manila clam, Japanese scallop, and the Pacific oyster, along with their positive and negative impacts on the aquaculture industry, would be extremely beneficial.

Atlantic salmon (*Salmo salar*)

Although British Columbia has participated in the farming of salmon for several decades, it was not until the early 1980's that the industry moved towards more advanced culture techniques and husbandry practices (Natural Resource Consultants Ltd., 1997). In the mid-1980s the Federal/Provincial Fish Transport Committee (FTC) was responsible for evaluating the proposed introduction of Atlantic salmon into Pacific coast waters. The committee recommended against the introduction because of strong opposition from steelhead (*Oncorhynchus mykiss*) advocates and concerns over possible environmental impacts. However, the Federal government disregarded the recommendations made by the FTC, and allowed the importation of Atlantic salmon eggs from 1985 to 1991, arguing that upgrading of fish farming was required and that Atlantic salmon represented an important economic opportunity for the aquaculture industry (Elston, 1997).

Today, British Columbia is the fourth largest producer of farmed salmon in the world, after Norway, Chile, and the United Kingdom. In 1999, the province harvested 49,100 tonnes, which contributed 329 million dollars to the economy (BC Fisheries statistics, 1999). Atlantic salmon is the dominant salmon species farmed in British Columbia, producing 38,700 tonnes in 1999, at a farmgate value (income received by the harvester) of 224 million dollars (Table 1). Salmon farming is regionally based, primarily near North Vancouver Island, Clayoquot Sound, and Campbell River. In 1999, for the first time, farmed salmon production exceeded the wild sector in harvesting quantity and value, as well as the wholesale value of processed products. This change can be partly attributed to declines in native commercial stocks around that time. Greater then 70 percent of British Columbia's farmed salmon are exported, with 90 percent designated for U.S markets, followed by Japan, Taiwan, and the European Union (Table 2). In 1999, the exports of frozen and processed Atlantic salmon equaled 122 million dollars, which was 39% of the total export value of fish and seafood products within the province (BC Fisheries Statistics, 1999).

The majority of salmon farming companies in British Columbia are vertically integrated. This means that owners/operators run the farms and hatcheries, raise brood stock to produce the next generation for harvest, transport and process mature fish, conduct research, and market the product locally and internationally. In addition, these companies often operate fish waste composting operations. Unlike many commercial fisheries, the salmon aquaculture industry is free of government subsidies (BC Salmon Farmers Association, 2000).

Table 1: British Columbia's salmon aquaculture production and value, 1999.

Species	*Production (tonnes)*	*Farmgate Value ($ million)*	*Wholesale Value ($million)*
Atlantic	38,700	224.6	N/A
Chinook	8,800	55.6	N/A
Coho	1,600	12.0	N/A
Total	49,100	292.2	329.0

Source: BC Fisheries Statistics, 1999

Table 2: BC salmon aquaculture export volume and value, 1999.

Exports of B.C Salmon Products	*U.S Markets*	*Japan Markets*	*Taiwan Markets*
Tonnes (Thousand '000) Exported	34,382	833	603
Value of Exports ($millions)	295	5	8
Percent of total BC farmed salmon export value	95%	3%	2%

Source: (BC Salmon Farmers Association, 2000)

In addition to the value it contributes directly to the regional economy, the salmon industry employs roughly 2,700 people, either directly or indirectly, with salaries and benefits totaling over 62 million dollars a year. Greater than 92% of the direct jobs are based in coastal communities outside of the greater Victoria and Vancouver regions, which helps to diversify and stabilize local economies. At a time when many coastal communities are losing their traditional jobs, salmon aquaculture has created stable, long-term employment (BC Salmon Farmers Association, 2000).

Most of the money made from the salmon aquaculture industry is reinvested into the local economy, as well as into service and manufacturing businesses throughout the province. There are more then 250 companies that currently sell directly to the industry, which means that the industry makes roughly 90% of its purchases locally. The total value of these goods and services contribute over 130 million dollars annually. All levels of government benefit from salmon aquaculture, through increased employment opportunities, self-sufficiency of workers, and increased tax returns. Furthermore, because the majority of these products are exported, they generate valuable export incomes, which strengthens both the provincial and Canadian economies (BC Salmon Farmers Association, 2000).

Despite the fact that the introduction of Atlantic salmon has been extremely beneficial to the local economies, many feel that it can have serious implications for the local ecosystem. These concerns are associated with issues such as competition, hybridization, colonization, modification of predator-prey relations, transgenic alterations, and disease transmission (Elston, 1997). The level of competition between Pacific and Atlantic salmon will depend on the number of cage escapees and whether or not colonization occurs (Natural Resource Consultants Ltd., 1997). Currently, the level of competition between Atlantic and native salmon in Pacific waters is not considered a serious threat to wild stocks (Ginetz, 1996; Natural Resource Consultants Ltd., 1997), nevertheless studies are being carried out on the potential impact on native spawning grounds (Amos and Appleby, 1999) and other essential resources (Volpe et al., 2001).

The second concern relates to possible hybridization, which occurs when two individuals either of the same species but different race or of related but distinct species mate and produce young with genetic traits of both parents (Amos and Appleby, 1999). However, this outcome was determined to be a highly improbable event between Atlantic and Pacific salmon (Ginetz, 1996; Natural Resource Consultants Ltd., 1997). There are three main explanations for this failure. First, the Pacific salmon male selection process tends to ostracize Atlantic salmon (Amos and Appleby, 1999). Second, results show that while it is possible to generate hybrid progeny in laboratory situations, the survival of crosses is extremely low and those that did survive are unable to mature sexually (Ginetz, 1996; Natural Resource Consultants Ltd., 1997; Amos and Appleby, 1999). Finally, even if reproduction between Atlantic and Pacific salmon was possible in the wild, the offspring would be sterile and thus unable to reproduce themselves (Amos and Appleby, 1999).

The third concern is the possible establishment of wild Atlantic salmon populations in British Columbia. Several studies have been conducted and conclude that this outcome is unlikely to occur, but cannot be ruled out entirely (Natural Resource Consultants Ltd., 1997; Amos & Appleby, 1999). Furthermore, these studies suggest that Atlantic salmon are more likely to colonize land-locked lakes than their typical anadromous behaviour (Natural Resource Consultants Ltd., 1997).

Another concern relates to predator-prey dynamics. According to the studies conducted to date, there is no evidence that Atlantic salmon have any impact on native stocks or their feeding cycles (Natural Resource Consultants Ltd., 1997). In fact, most of the Atlantic salmon that were recaptured on the Pacific coast showed no signs of feeding on fish or fish eggs. This evidence suggests that the escaped fish are unsuccessful in feeding on fish outside their caged environments (Amos and Appleby, 1999).

An additional concern relates to the potential introduction of trangentic Atlantic salmon. Although there is no current commercial transgenic salmon production, more research needs to be conducted in this area. However, it has been shown that the use of triploid transgenic females will not affect local Pacific salmon populations and will result in more efficient growth rate for the cultured species (Natural Resource Consultants Ltd., 1997).

The final issue of concern is the possible spread of disease. This is an area of considerable debate because it is difficult to prevent the spread of disease, especially in aquaculture conditions (Natural Resource Consultants Ltd., 1997). However, all Atlantic salmon in British Columbia were introduced from either the east coast of North America or Europe and entered as eggs from a pathogen-regulated broodstock. If there was any detection of a pathogen during the screening process, the eggs were not allowed to enter British Columbia or any west coast state (Amos and Appleby, 1999).

Although there is always a possibility of disease transfers between native and introduced species, a greater concern in some instances is an outbreak within the introduced population. Scientists have recently identified several new parasitic diseases associated with netpen culture in British Columbia. These diseases have developed as a result of Atlantic salmon being reared outside their natural environment (Kent, 2000). The following examples will illustrate the pathway of disease associated with netpen culture of Atlantic salmon in Pacific waters.

Because Atlantic salmon in British Columbia are an important element of both the provincial and national economies, there has been great concern associated with the identification of the myxozoan parasite *Kudoa thrysites* in Atlantic salmon netpen culture on the Pacific coast of North America (Whitaker and Kent, 1991). *Kudoa thrysites* is a complex parasite that causes an infection in the muscles of many marine fish. Although mortality is rare, serious infection can cause unsightly white cysts or soft spots in fillets, which in turn lowers the market value of the product. Little is know about the early development and transmission of the disease and therefore further studies are required in order to prevent and treat the infection (Kent, 2000).

A second concern to Atlantic salmon production in British Columbia has been the identification of a gill disease caused by the parasitic copepod *Haemobaphes disphaerocephalus* (Family Pennellidea) (Kent et al., 1997). The genus *Haemobaphes* contains nine species, four of which are found in British Columbia. Although *Haemobaphe* spp. occurs in a number of marine fish species, the discovery of this disease in B.C. Atlantic salmon is the first appearance in either captive or wild salmon. The materialization of this disease in Atlantic salmon suggests that the accidental infection was the result of a native host being reared outside its natural environment (Kent, 2000).

Brown Alga (*Sargassum muticum*)

The brown alga, *Sargassum muticum*, was initially discovered in the Pacific Northwest during the 1950's and its introduction was linked to shipments of either Pacific oyster to California during the late 1800's (Elston, 1997) or with oyster spat transplanted to Washington State (Abbott and Hollenberg, 1976). After its introduction, the alga expanded rapidly northward and can now be found in most coastal areas of Washington State and British Columbia. At present there are no known beneficial uses of this species. However, there are a few potential serious implications resulting from this introduction. *S. muticum is* an extremely invasive seaweed, characterized by fast growth (up to 4 cm per day) and the ability to tolerate a wide range of environmental conditions. This means that it can permanently displace native algae and suppress the natural recovery of kelp beds. The species has also colonized an ecological niche that does not appear to have been utilized by a native species (Hume, 1998). The greatest concern, especially for oyster growers throughout the Pacific Northwest, is its ability to invade commercial shellfish beds and its potential to inhibit shellfish growth (Elston, 1997).

Cordgrass (*Spartina alterniflora*)

Spartina alterniflora was intentionally introduced to Puget Sound, Washington, during the 1940's in an attempt to prevent erosion of nearby islands. Eventually it spread into

British Columbia. However, there have been some indications that it has existed in Pacific Northwest waters since the late 1800's, when it was used as packing material for eastern oysters (Elston, 1997). Since its introduction, cordgrass has caused major modifications to tideland areas. This species forms large dense vegetative growth, which results in increased silt deposition, displacement of tidal flat organisms, alteration of tidal exchange, and a reduction in the capacity of estuaries to buffer freshwater inputs during flood periods. This loss can have a detrimental effect on rearing habitats for salmon species, clams, and oysters, which in turn has the potential to destroy commercially valuable areas for aquaculture. Although there is no real economic benefit associated with *Spartina alterniflora*, it has been suggested that it can be used as a cage rearing ground for juvenile chinook salmon, which are known to have an affinity for salt marsh habitat (Elston, 1997).

Japanese Oyster Drill (*Ceratostoma inornatum*)

The Japanese oyster drill was accidentally introduced into Pacific Northwest waters during the early 1900's when Pacific oysters were imported from Japan. This species is one of the most damaging pests found in oyster beds, causing up to 25 percent mortality in cultured areas, an increase in production costs of up to 20 percent, and losses in net profit as high as 55 percent (Elston, 1997). Given the serious ramifications to aquaculture operations resulting from this introduction, both Canada and the U.S are investigating possible solutions to the problem and one possible approach is future restriction on the movement of shellfish from one area to another (i.e. transfers) (Elston, 1997).

Asian Copepod (*Pseudodiaptomus inopinus*)

There have been at least six different species of Asian copepods that have been introduced to the Pacific coast of North America. Of those introduced, *Pseudodiaptomus inopinus* has colonized and spread throughout the Columbia River estuary between the years 1980 and 1990 (Cordell and Morrison, 1996). Copepods are small crustaceans that are found in marine, estuarine, and freshwater systems. Because these organisms are found in almost any aquatic environment, including ocean trenches, aquatic plants, and bottom sediments, they play a significant role in the aquatic food chain as prey for a variety of small fish and invertebrates (Elston, 1997). Nevertheless, it has been observed that *Pseudodiaptomus inopinus* will compete with native copepod species, displacing them from their native habitat (Cordell and Morrison, 1996). *Pseudodiaptomus inopinus* also inhabits estuaries that are important feeding grounds for juvenile salmon and smelt. Given the recent decline in many commercial fish species in the Pacific Northwest, it is not surprising that fisheries scientists, managers, and aquaculturists want to determine the actual impact of this copepod on important fish species and their planktonic prey (Cordell and Morrison, 1996).

European Green Crab (*Carcinus maenus*)

The natural distribution of *Carcinus maenus* extends from Mauritania to Norway in the eastern Atlantic and to the temperate waters of the Mediterranean Sea (Jamieson et al., 1998). This species was first identified on the Pacific coast of North America in 1989 when scientists recognized the crab species in San Francisco Bay (Hume, 1998; Jamieson et al., 1998). There are two proposed mechanisms for the introduction of *Carcinus maenus* on the Pacific Coast. First, ship ballast water may have contained sufficient numbers of larvae to establish a viable population (Hume, 1998). Second, it may have been associated with seaweed that was used as packing material to ship lobsters and bait worms from the east coast (Elston, 1997). Although some regions of the world harvest green crab for consumption, it is relatively small in size compared to other larger and more desirable crab species in the region (Elston, 1997). Hence, it is unlikely that there will be any commercial use for the green crab in British Columbia.

Green crabs have no natural predators in this new environment and thus have the potential for a massive population explosion (Hume, 1998). Scientists and environmentalists are tracking the rapid spread of this crab species along the Pacific coast (Jamieson et al., 1998), particularly because it preys on a number of bivalves (Juanes, 1992; Cohen et al., 1995) and other crab species (Ropes, 1968; Elner, 1981). In addition, the green crab is a fierce competitor with native Dungeness crab for food resources and space in intertidal environments (Elston, 1997; Hume, 1998). Given the diversity of intertidal species on the Pacific coast relative to the Atlantic, the green crab may have a greater impact in British Columbia than on the Atlantic seaboard (Jamieson et al., 1998). The gravity of this introduction is a major concern for the commercially valuable shellfish industry in British Columbia (Hume, 1998) and future management will have to address possible reduction measures.

Mahogany Clam (*Nuttalia obscurata*)

Mahogany clam, also referred to as the varnish clam, is native to Korea and Japan, and was first identified in the Pacific Northwest in 1994. Although, it is not actually known how the species colonized the region, it has been suggested that it had arrived a few years earlier as a result of ballast water from transport vessels. After its initial introduction, the mahogany clam was able to disperse rapidly and colonize a vast area around Vancouver Island and the Strait of Georgia. Currently, there are no significant economic benefits resulting from the introduction, however, there are studies being conducted on the use of the species for aquaculture purposes and commercial harvest (Elston, 1997). The only negative implication resulting from this introduction that has been identified thus far is that the mahogany clam has the potential to compete with other bivalves for food and space, which could eventually cause a serious problem for commercial and cultured species (Elston, 1997).

Manila Clam (*Venerupis philippinarum*)

The Manila clam was accidentally introduced into British Columbia's waters with shipments of Japanese oysters in the early 1930's. Since its introduction, the Manila clam has become one of the most important aquaculture and fishery species in British Columbia, producing a higher value than native species, such as the littleneck clam (Elston, 1997). The Manila clam is the primary clam species farmed in the province. In 1999, 900 tonnes of clams were harvested, with a wholesale value of 6.6 million dollars (Figs. 3 & 4) (BC Fisheries Statistics, 1999). There has been no documented negative impact resulting from this introduction, except for possible limited competition with native clam species (Elston, 1997).

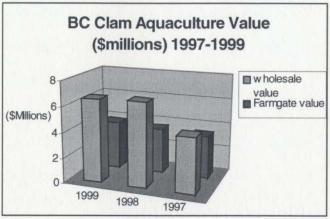

Figure 3: Annual value of clam aquaculture harvest in British Columbia 1997-99.
Source: BC Fisheries Statistics1999

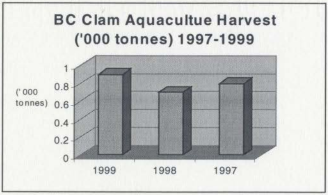

Figure 4: Annual clam aquaculture harvest by weight in British Columbia 1997-99.
Source: BC Fisheries Statistic, 1999

Japanese Scallop (*Patinopecten yessoensis*)

The Japanese scallop was introduced to British Columbia between 1987 and 1990 for experimental purposes. During hatchery trials at the Pacific Biological Station (Nanaimo

BC) the Japanese scallop was compared to native scallop species, particularly the weathervane (*Patinopecten caurinus*) and the rock scallop (*Crassadoma gigantea*) (Saunders and Heath, 1994). Studies concluded that the Japanese scallop would be the preferable species for further culture methods because of its favorable hatchery characteristics, fast growth rates, and strong market potential (Bourne et al., 1989). Since its repeated introductions in the late 1980s, the Japanese scallop has suffered significant mortalities from a native protistan parasite called *Perkinsus quqwadi* or SPX. The parasite produces infections in the gonads, digestive glands, and mantle, usually causing up to 100 percent mortality in one-year-olds. However, there is no evidence to suggest that the parasite affects native scallops and none of the local scallops examined histologically were infected with *P. quqwadi*. Thus some species of scallops are resistant to infection by *P. quqwadi* and therefore, selective breeding programs could reduce the impacts of the parasite on the developing scallop industry (Bower et al., 1999). The Japanese scallop provides an excellent illustration of disease transfer from a native ecosystem to a non-resistant exotic species.

Pacific or Japanese Oyster (*Crassostrea gigas*)

The Pacific oyster was initially introduced into Washington State during the early 1900's as a replacement for decreasing native populations of *Ostrea conchaphila*, which was an economically important fishery. Introductions continued throughout the century until regulations were introduced to prevent transfers. However, the species is now found in all coastal regions of the Pacific Northwest, including British Columbia. Although the

Pacific oyster has colonized the area, it has also developed into a major aquaculture industry, accounting for 75 percent of farmed shellfish production in the Province of British Columbia (Elston, 1997). Oyster production in British Columbia produced 5,800 tonnes in 1999, for a wholesale value of 11 million dollars (Figs. 5 and 6). Like the Pacific salmon, most of the Pacific Oysters are exported out of the province, primarily to Japanese and U.S markets (BC Fisheries Statistics, 1999).

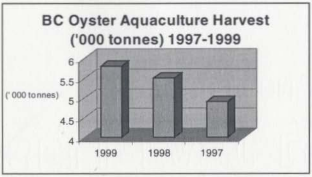

Figure 5: Annual oyster aquaculture harvest by weight in British Columbia 1997-99.
Source: BC Fisheries Statistics, 1999

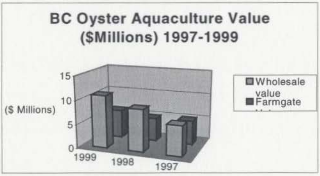

Figure 6: Annual value of oyster aquaculture harvest in British Columbia 1997-99.
Source: BC Fisheries Statistics, 1999

Summary of British Columbia's Shellfish Farming Industry

Shellfish farming has primarily been a small-scale industry in British Columbia. However, this pattern is rapidly changing as a result of technological and management improvements, expanding markets, and a general awareness that shellfish farming is a profitable business opportunity. As previously mentioned, the two main shellfish species grown in British Columbia are the Pacific oyster and Manila clam, both of which are not indigenous to the region but have contributed substantially to the local and national economy. Currently there are 258 licensed shellfish companies, which control 423 cultured sites. While production has been increasing over the last several years, it pales in comparison to Washington State. Even though British Columbia has a much larger marine resource potential, Washington State shellfish culture industry is estimated to be greater than 60 million dollars annually, which is six times the current level of production in British Columbia. Therefore, shellfish culture in the province has the potential to expand substantially and compete with U.S growers (BC Shellfish Growers Association, 2001).

Current employment in the province's shellfish aquaculture industry is estimated to be approximately 1,000 people. Because shellfish production occurs in many rural coastal areas, shellfish farmers are able to generate sustainable economic opportunities. The industry has become increasingly technology driven and has high labour demands, which provide year round employment opportunities. In many regions of the province, shellfish aquaculture is portrayed as a source of local pride and is a prime example of economically and environmentally sustainable development (BC Shellfish Growers Association, 2001).

The long-term economic potential for shellfish farming in the province is extremely promising. Some of the main reasons to expect expansion in this area are strong global markets, environmental sustainability, and ample space to support growth of the industry (BC Shellfish Growers Association, 2001).

6.2 Atlantic Canada

In contrast to British Columbia, there has been relatively little scientific research on non-indigenous species and their impact on aquaculture operations in the Atlantic Provinces. Many of the intentional introductions into Atlantic Canada have been the result of aquaculture activites and most unintentional introductions are the product of ships ballast water. However, it is likely that there are numerous introductions that have yet to be identified, such as associated organisms, diseases or parasites. Therefore, future assessment of the region is essential.

Aquaculture Introductions

Of the Atlantic Provinces, Newfoundland has been the most fortunate when considering the introduction of exotic species. Very few species have been introduced into inland waters, and it seems that most of the concern about species introduction centers on the aquaculture industry. *Oncorhynchus mykiss* (rainbow trout) has been introduced from

Ontario and Prince Edward Island into Newfoundland for the purpose of marine aquaculture, but because individuals have been triploid, escapees are generally thought to have minimal potential for ecological damage since they cannot reproduce (Crossman, 1991). Although Atlantic salmon and Arctic charr (*Salvelinus alpinus*) are native to Newfoundland, there have been transfers of these organisms from both Nova Scotia and New Brunswick for aquaculture purposes. Pink salmon, *Oncorhynchus gorbuscha* (from British Columbia) has also been introduced for aquaculture and as of yet there have been no conclusive studies to indicate that there are any negative implications associated with escapees (Crossman, 1991).

These deliberate introductions and transfers have brought clear economic benefits to Newfoundland in the form of revenue and labour opportunities. In 1999, the total harvested weight of steelhead (marine rainbow trout) was 2,078 tonnes, with a total value of 11.4 million dollars; steelhead was the largest and most profitable finfish grown in the province (DFO, 1999). Given that steelhead aquaculture is relatively new in the province and is often associated with other finfish culture, the statistics on employment, export value and biomass were difficult to determine and therefore will not be included as part of the evaluation.

Nova Scotia is much like Newfoundland in that relatively few known species have been introduced unintentionally. Some of the species that have been introduced and transferred for aquaculture purposes include *Oncorhynchus mykiss, Salmo salar, Salvelinus alpinus*

(Crossman, 1991), European oyster (*Ostrea edulis*), and bay scallop (*Argopecten irradians*) (Judson, 1992). In 1999, Nova Scotia produced 3,923 tonnes of rainbow trout (steelhead) at a value of 17.4 million dollars, representing 51.2% of the total value of aquaculture production in the province. Roughly 42 tonnes of all trout production was exported in 1999 for a total value of $218,000. Approximately 313 tonnes of European oysters were harvested in 1999 and contributed $285,000 to the economy (NS Department of Fisheries and Aquaculture, 1999).

As is illustrated by these statistics, modest revenue has been made through the introduction or transfer of non-indigenous species for aquaculture ventures in Nova Scotia, providing jobs for local and non-local Canadians. Total full-time employment in the aquaculture industry in Nova Scotia in 1999 was 444 workers: 504 positions were short- term (less then 6 months) and 165 positions were long-term, part-time (greater then 6 months). The majority of these positions are involved in finfish production, especially steelhead trout (NS Department of Fisheries and Aquaculture, 1999).

In comparison to the other Atlantic Provinces, a provincial agency in Prince Edward Island (PEI) reported that no new additional species have been intentionally released in public waters since 1981 (Crossman, 1991). Before that time, introductions and transfers of *Salvelinus alpinus*, *Oncorhynchus mykiss*, *Salmo salar*, *Argopecten irradians*, *Mercenaria mercenaria* (quahaugs) (Judson, 1992), and *Ostrea edulis* (Newkirk et al., 1995) had occurred for the purpose of aquaculture, most of which is either still in the developmental stage or no longer in production. Like Newfoundland and Nova Scotia, there have been very few documented ramifications from these introductions other than the positive implications of employment and revenue for the local economy, which is relatively small compared to the other provinces (Crossman, 1991).

New Brunswick, like the other East Coast provinces, has had very few introductions or transfers for aquaculture purposes. *Oncorhynchus mykiss*, *Salvelinus fontinalis*, and *S. alpinus* have all been introduced from other provinces, particularly Ontario, Manitoba, and Quebec, for recreational fishery and aquaculture ventures. Rainbow smelt, *Osmerus mordax*, was also introduced to this province; several studies have indicated a lack of forage fish for wild Atlantic salmon in New Brunswick and the introduction of the smelt remedied the problem without any known negative implications (Crossman, 1991). New Brunswick is the largest producer of marine aquaculture finfish species in Atlantic Canada, producing 22 thousand tonnes in 1999 at a value of 156 million dollars (DFO, 1999).

Whereas finfish species in each of the provinces were transferred from existing populations in Canada, *Ostrea edulis* and *Argopecten irradians* were introduced to the Atlantic region from other countries. There were several early attempts to introduce *Ostrea edulis* to North America (Newkirk et al., 1995). In 1957 and 1958, Medcof (1961) tried to establish populations of European oyster (from the United Kingdom) in St. Andrews, New Brunswick, and to Ellerslie, PEI. However, populations were unable to survive more then a few years because of cold ocean temperatures. Around the same time, *Ostrea edulis* was imported to Milford, Connecticut, USA, from native populations in Holland. Grow-out trials were more successful and the oysters were able to adapt to the local environment (Loosanoff, 1955). Oyster stocks from Holland are more winter-hardy than those from the United Kingdom (Drinnan, 1970). Therefore, in 1969, Drinnan transferred European oyster stocks from Milford to Ellerslie station to be held in quarantine and hatchery facilities. In the following years, the oysters were spawned in the hatchery and the offspring were tested in sites around the island. The initial growth trial was favorable and led the way for future *Ostrea edulis* production in Eastern Canada (Nova Scotia) (Newkirk et al., 1995).

The bay scallop, *Argopecten irradians*, was originally introduced into Canadian waters in 1979 (Judson, 1992; Couturier et al., 1995), when shipments from Connecticut (Judson, 1992) were transferred to the Ellerslie Fisheries Research Station in PEI (Couturier et al., 1995). The introduced scallops were held under strict quarantine for three generations before grow-out trials were tested in the open ocean (Townshend and Worms, 1983). Initial growth rates of the scallops were favorable during the summer months, but the organisms were unable to survive during the colder winter months and consequently field trials were terminated in 1983 (Couturier et al., 1995). In 1985, Nova Scotia acquired the remaining bay scallops from Ellerslie Station and was able to produce several thousand juveniles for grow-out trials (Mallet and Carver, 1987). By 1988, the first commercial bivalve hatchery in Canada, the Mountain Island facility (Blandford, N.S) began producing bay scallops for aquaculture facilities and by 1989 sold over 2 million scallop seed and greater then 7,000 kg of marketable scallops (Couturier, 1990). At present, there is still interest in bay scallop culture in Nova Scotia and PEI, but the industry faces many challenges, such as lack of seed producers, insufficient markets, slow growth, and concerns for over-wintering (Couturier et al., 1995).

Concerns for Aquaculture Business on the East Coast

The intentional introduction of non-indigenous marine species into Atlantic Canada has been limited to a few commercially important aquaculture species. However, there are issues of concern for scientists and environmentalists that relate specifically to aquaculture. These issues include the use of transgenic fish, the introduction of potentially damaging non-native species through vessel ballast water, and the identification of exotic parasites, diseases and pests. Although this section only briefly describes some of the major concerns for aquaculture operations, there are potentially many more that have yet to be identified and will likely be the focus of future scientific studies.

In 1988, a fish (eel pout) antifreeze protein gene was fused to a growth hormone from chinook salmon and injected into Atlantic salmon. These injections produced salmon that would grow ten times faster than non-transgenic salmon (Fletcher and Davies, 1991). Although there is no commercial transgenic salmon production in the province, debates regarding the use of transgenic fish is ongoing and has obvious ramifications for the aquaculture industry and fisheries managers. These concerns include possible impacts resulting from the escape of exotic or highly selected species, fish hybrids, and fish with manipulated chromosome sets. However, these concerns could be reduced if the farmed individuals are reproductively sterile (Devlin and Donaldson, 1992). In Bay D'Espoir Newfoundland, for example, salmon growers were required by government regulations to rear only female triploid steelhead in sea pens to prevent the possible introduction of non-indigenous species into Newfoundland waters. These triploids are a positive development because they usually grow faster than non-triploid fish and the detrimental effects of sexual maturation do not alter meat quality (Sutterlin and Collier, 1991).

The second issue relates to the introduction of exotic species from ships' ballast water; some of these taxa are clearly harmful to aquaculture operations. Recent studies have provided extensive evidence that ballast water from vessels has contributed significantly to the global spread of Diarrhetic Shellfish Poisoning (DSP) and Paralytic Shellfish Poisoning (PSP), which can have disastrous results for the aquaculture industry. This is a major concern for the aquaculture industry in Atlantic Canada because the number of ships entering coastal waters has been steadily increasing over the last several years. Presently, there is only a limited amount of research on ballast water impacts in Atlantic Canada. However, it is the long-term goal of the department of Fisheries and Oceans to study these impacts more closely (DFO, 1995).

A third major concern for the aquaculture industry has been the discovery of the parasitic protozoan, *Perkinsus*, in Canadian waters. The disease entered into the country through the introduction of its host species, *Argopecten irradians* (bay scallop). The imports, and therefore the parasites, came from the United States between 1979 and 1980 (Sindermann, 1993; Whyte et al., 1993). Because the parasites were detected early in the rearing process, the scallops were maintained in quarantine for three generations before release. Then in 1989, after open water culture began, the parasitic protozoan was once again found and identified as *P. karlassoni.* This example illustrates that even after careful monitoring, disease risks are never zero (Sindermann, 1993).

The pathogenicity of *P. karlssoni* has yet to be identified. However, there has been no evidence to suggest interspecies transmission to other molluscs (McGladdery et al., 1993; Sindermann, 1993). Further research into the potential impacts of this parasite is necessary given that shellfish culture plays a significant role throughout the Atlantic region and the threat of disease is a concern for all aquaculture operations.

The introduction of the nuisance green alga *Codium fragile* ssp. *tomentosoides* (Chlorophyta, Caulerpales) to Atlantic Canada is another major concern for aquaculture operations. The alga, also known as the oyster thief (Garbary and Jess, 2000), was first identified in the Atlantic region when a sample was collect from Graves Shoal in Mahone Bay, Nova Scotia, in December 1991 (Bird et al., 1993). It is believed that *C. fragile* entered Eastern North America with the transfers or introduction of aquaculture shellfish species to the United States from Europe during the 1950's (Bouck and Morgan, 1957). The species was able to spread northward through most of the New England States (Bouck and Morgan, 1957; Garbary et al., 1997) and was suspected to have migrated into Atlantic Canadian waters as early as 1989 (Bird et al., 1993). The spread of this species through the Northwest Atlantic has caused some serious concern for scientists, fishers and shellfish growers because it is an effective colonizer that can form dense strands in short periods of time. Where abundant, the species is able to compete with native flora and can have serious economic consequences for commercial fisheries and aquaculture operations by overgrowing valuable shellfish beds, attaching to oyster shells, and clogging dragnets (Fralick and Mathieson, 1972; Carlton and Scanlon, 1985). Since its initial introduction over ten years ago, *C. fragile* has expanded its range to northern Nova Scotia, southern New Brunswick and P.E.I., and has become the dominant alga in many subtidal areas (Garbary and Jess, 2000). The alga has yet to be identified in Newfoundland but protocols must be in place to prevent the possible spread to the province or other regions throughout the Atlantic.

A further concern for aquaculture operators in Atlantic Canada has been the identification of the clubbed tunicate (*Styela clava*) in P.E.I. waters. *Styela clava* was first described in Plymouth, Devon, in 1953 (Carlisle, 1954; Houghton and Millar, 1960) and was likely introduced to the North Atlantic from the Northwest Pacific on the hulls of warships following the end of the Korean War in 1951 (Millar, 1960). Today, *Styela clava* occupies many salt-water habitats throughout the world from Australia to many regions in the Northwest Atlantic. The introduction of this clubbed tunicate to the coast of P.E.I. is a serious concern for both aquaculture operations and fishers because it attaches to the casement of many shellfish species making them very difficult to clean during processing. Although *Styela clava* is presently limited to only a few areas around the island, it is likely to spread by natural dispersal to many other regions. However, to hamper rapid movement of the organism throughout the Atlantic region, measures must be established to prevent the accidental transportation by aquaculture operations, fishing gear and boats (DFO and PEIFAE, 2000).

As in British Columbia, the green crab, *Carcinus maenus*, is also a concern for aquaculture in Atlantic Canada. The green crab was first reported in the Western Atlantic in 1817 (Cohen et al., 1995), where it became established along the American coast from Cape Cod to New Jersey (Grosholz and Ruiz, 1996). Further expansion of the species did not occur until 1905 (Vermeij, 1982) when an increase in air and surface temperatures allowed the green crab to move northwards (Ropes, 1968). By 1951, *C. maenus*, had reached northeastern Maine and New Brunswick and in 1961 (Welch, 1969) was discovered on the outer coast of Cape Breton Island, Nova Scotia (Welch, 1969; Jamieson et al., 1998). Today *Carcinus maenus* is found in many areas throughout the Atlantic Provinces of Canada, including its most recent expansion to the shores of P.E.I. (DFO & PEIFAE, 2000). Although the green crab can occur on any shore type, it is most commonly found in sheltered shores where they out-compete other crab species (Elner, 1981). Their introduction has had serious consequences on soft-shell clam species, young oysters and crabs, as well as artificially created mollusc beds (Lafferty and Kuris, 1996). In coastal areas, *Carcinus maenus* feeds primarily on bivalves, with *Mytilus edulis* being the most common food item in gut analysis (Ropes, 1968). This is of particular concern for mussel growers throughout the Atlantic region given the economic importance of mussel production to P.E.I., Nova Scotia and Newfoundland's aquaculture operations.

A final concern for aquaculture operations is diseases associated with net pen culture. Rosette agent, which was initially identified as a lethal pathogen in cage culture of chinook salmon in Manchester, Washington, USA (Elston et al., 1986b), has been observed in net pen culture of Atlantic salmon on the Northeast coast of Canada (Cawthorn et al., 1991). The rosette agent infects the macrophages in the spleen, kidney, and other organs, resulting in mortality. The highest mortalities occur during the summer and autumn months and losses of greater then 90 percent have been documented (Kent, 2000). Given that the disease can cause devastating losses in net pen operations, it is a major concern for aquaculture businesses.

A second disease found in Atlantic Canada net pen culture, which affects rainbow trout populations, is the trematode, *Stephanostomum tunue*. Rainbow trout are native to western North America and have been introduced to the east coast of Canada for aquaculture. In net pen culture in Atlantic Canada, a serious heart infection by trematode metacercariae causes high mortalities in rainbow trout populations (McGladdery et al., 1990), and is unquestionably a problem for aquaculture operations.

Net pen culture is the preferred method of rearing salmonids because of low construction and maintenance costs. However, because water exchange is not controlled, there is an increased probability that various parasites will enter the system, thereby making net pen culture susceptible to parasitic diseases (Kent, 2000). In addition, many of the new diseases that have emerged in net pen culture arise as a result of transfers of non-indigenous species to new environments (Kent, 2000) and incidence of disease will need to be carefully monitored in the future.

7.0 Prevention and Management

7.1 Canadian Regulations- Provincial and Federal

Initially, aquaculture activities in Canada were linked with traditional fishery resources and were therefore under licensing regulations set by the federal government. However, as the industry diversified and expanded, it became clear that the activities associated with aquaculture were more closely tied to agriculture, because of the dependence on provincial land and waters resources. Aquaculture has therefore become the responsibility of the provincial governments (Blewett and MacDonald, 1998). Although aquaculture is provincially licensed (except for P.E.I.), the federal government remains responsible for the regulation, conservation, and protection of Canada's fishery resources, which include control over the introduction and transfers of fish, either internationally or between provinces (Cook and Simpson, 1995). Though the federal and provincial governments can not share legislative and governing responsibilities, they are able to delegate administrative and operational functions to each other by signing memoranda of understanding. Memoranda of this type have been signed between DFO and the east and west coast provinces for the development of aquaculture and the creation of a comprehensive licensing and leasing program for commercial aquaculture ventures (Cook and Simpson, 1995), although there are slight variations in some of the specific agreements.

Canada and British Columbia signed a memorandum of understanding in 1988, which recognized the provinces right to license aquaculture businesses (Blewett and MacDonald, 1998). Through this agreement, the federal and provincial governments are both responsible for the regulation and management of intentional introductions in British Columbia's waters. The federal government's influence regarding introductions is contained in the Fisheries Act Regulations section 55 and 56 and in the Pacific Fisheries Regulation (PFR), 1993, section 5. Within these regulations the federal government can control the release of live fish into any habitat or the transfer of any live fish into fish rearing facilities. However, the law only pertains to fish and invertebrates and does not cover the introduction of aquatic plants (Elston, 1997; Blewett and Macdonald, 1998). The Provincial Wildlife Act (BC Reg 261/83) and the Provincial Fisheries Act provide the Provincial government authority concerning introductions. These regulations address the transfer of live oysters, freshwater finfish, and lamprey eels, but do not include legislation regarding tropical fish, ornamental fish, or marine fish. Therefore, the combined federal and provincial authorities necessitated the creation of the federal/provincial Fish Transplant Committee (FTC), which is a governing body responsible for reviewing applications for exotic and native fish and invertebrate transfers into and within the province (Elston, 1997).

Although the above regulations cover the majority of concerns associated with the introduction and transfer of organisms, there are several areas that still need further assessment and are currently being discussed in a review of the PFR. These concerns include insufficient intraprovincial enforcement, the lack of provincial border staff, and inadequate training of Canadian custom officers (Elston, 1997).

Aquaculture activities are not the only pathway of non-indigenous introductions, as was illustrated in the first section of the report. Federal and British Columbia governments, applying many of the policies and enforcement procedures that are used for aquaculture, regulate aquaculture trade. The only areas of concern are the overlaps, discrepancies, and gaps found between the governing bodies, where the provincial regulations exclude all tropical and ornamental fish from permit request, but federal regulations only exclude specific species, such as tilapia (*Tilapia spp.*) and carp (*Cyprinus carpio*) (Elston, 1997). British Columbia's aquaculture regulations also apply to research and teaching institutions and live seafood trade (Elston, 1997). However, at present there are no policies, enforcement procedures, or voluntary programs for ballast water introductions in British Columbia (Gauthier and Steel, 1995). Given the discrepancies between federal and provincial jurisdictions, further reviews of the regulations are required, as are means to adapt to future changes. A national review board is presently establishing a national code on introductions and transfers of aquatic organisms for Canada (J. Parsons, Fisheries and Marine Institute of Memorial University of Newfoundland, Pers. Comm.)

As in British Columbia, aquaculture initiatives in the Atlantic Provinces are developed and controlled through licensing and leasing by the provincial Departments of Fisheries and Aquaculture. Under the administration of the provincial authority in each of the provinces, any individual practicing aquaculture is required to obtain a valid license and follow established regulations. Federal authority under the agreements requires consultation and approval by DFO for aquaculture operations. DFO also continues its support for scientific research and development of commercial aquaculture technology (Cook and Simpson, 1995). Furthermore, DFO regulates fish transfers and introductions under the federal Introduction and Transplant Committee (Blewett and MacDonald, 1998).

Although many of the agreements signed for each Atlantic Province are similar, a few important distinctions are notable. In Nova Scotia, the agreement states that there is to be no collection or capture of natural or wild stocks for seed, brood, or other aquaculture intentions and that any organism used in aquaculture facilities has to be obtained from authorized hatcheries (Cook and Simpson, 1995). Within the framework of the Canada-Newfoundland memorandum of understanding for aquaculture development, the province is responsible for granting licenses (Cook and Simpson, 1995) and governing the introduction of new fish into river systems within the province under the direction of the provincial Environmental Assessment. Newfoundland also maintains partial authority over fish transfers permits under the Newfoundland Transfers and Introductions Policy, which was created by DFO.

The Department of Fisheries and Oceans (DFO) monitors the introduction of exotic species in each province through the Fish Health Protection Regulations (FHRP) under the Fisheries Act of Canada. The FHPR, in collaboration with the Manual of Compliance, are continuously revised as new knowledge regarding fish diseases and their causative agents emerges (Cook and Simpson, 1995).

The main purpose of the FHPR is to reduce the risks of introducing or spreading potentially dangerous diseases within the Canadian aquatic environment. This objective is met through the establishment of strict regulations governing the transportation of fish or eggs from other countries as well as among provinces of Canada. Permits must be issued, by a DFO- appointed local fish health officer for any importation of fish or eggs (including any fertilized or unfertilized products) of culture or wild fish into Canada or between provinces. Fish health certificates are also required by all fish production facilities in Canada and these certificates are only issued after careful examination of the facilities (Cook and Simpson, 1995).

Another important point, although not under FHPR regulations, is that processors who export fish out of the province are required to obtain a certificate of registration, a shipping certificate, and have regular DFO inspections (Cook and Simpson, 1995).

In order to efficiently monitor all Canadian fish regulations a committee has been established in each DFO region. The committees evaluate requests to introduce or transfer fish in accordance with fishery regulations, under the Fisheries Act of Canada. These committees are concerned with issues related to both indigenous and non-indigenous species, including the transfer of potentially dangerous diseases and parasites and genetic or ecological harm that could develop from competition between species (Cook and Simpson, 1995).

These rules and regulations are vital to the health of marine ecosystems, given that every watershed has its own native fauna that could be easily affected by outside introductions. Therefore, any individual failing to comply with the regulations established by both the FHPR and DFO will automatically lose their shipment and additional penalties may also be imposed depending on the seriousness of the action.

In addition to regulating fish transfers and introductions in Canada, DFO has established a temporary policy on the application and transfer of transgenic aquatic organisms in order to regulate biotechnology initiatives, particularly for aquaculture research (DFO, 1994). This policy provides guidelines for research, rearing practices in natural ecosystems, and containment standards to reduce possible escapes. DFO regards the policy as essential because the potential benefits from the utilization of transgenic aquatic organisms are significant to the industry, regional economies, and consumers, yet transgenics are considered new organisms with little existing information on their behavior or performances in either artificial or natural environments (Blewett and MacDonald, 1998).

The draft policy on transgenic aquatic organisms incorporates seven statements:

- Research on genetic modification to produce transgenic aquatic organisms is to be conducted in laboratories or facilities that have been inspected by DFO, and where precautions have been taken to prevent escape into Canadian waters.

- Requests for authority to use transgenic organisms in or near natural aquatic ecosystems must be accompanied by a detailed risk assessment of the effects of use, including unintentional escapes, on the environment and natural populations of aquatic organisms.

- Written authorization to use transgenic organisms must be obtained from the appropriate Regional Director General, after review and approval of proposals by the Assistant Deputy Minister, Science, to ensure national consistency in assessment procedures.

- Such use of transgenic organisms must be made through an authorized step-by-step process, including interim stages of release into facilities designed to prevent the escape of transgenic organisms but enable exposures to the natural environment. Each stage must be assessed and reported on before the next stage can proceed.

- Initially, and until otherwise authorized, use of transgenic organisms outside contained facilities may be made only with reproductively sterile organisms. Following initial approved use, there will be a requirement for annual reporting.

- Public hearings may be required prior to use of transgenic organisms outside contained research facilities to assess the potential implications of proposed uses on fisheries resources.

Source: Meakin Consultants (Undated)

Although there are many policies and enforcement procedures dealing with potential aquatic transfers in Canada, they are often ineffective and confusing because they are the products of overlapping federal and provincial jurisdictions. Therefore, it is not surprising that many of the existing policies are under review in order to construct more transparent and practical guidelines. Furthermore, future initiatives to control introductions and transfers will need to be more flexible to incorporate national and international perspectives. The draft proposal that is presently being developed by the members of the task group on introduction and transfers may help to rectify this particular problem.

7.2 International Regulations/Agreements

A heightened awareness related to the conservation and protection of biological resources has grown and expanded rapidly over the last several decades (Ryman et al., 1995). This global environmental movement promotes the protection of terrestrial and aquatic habitats from the impacts of human activities. Since the 1970s, many international organizations have come to play a significant part in identifying, analyzing and regulating the introduction of non-indigenous species throughout the world. International action, which is supported by internationally agreed legal instruments, is vital in managing non-indigenous species because the impacts of biological invasions are not restricted by political boundaries, especially in the marine environment (Shine et al., 1999).

Currently, there are more then fifty international agreements, global and regional, and 'soft law' (non-binding) instruments relating to the introduction, control and elimination of exotic species. These agreements and regulations vary considerably in terms of type of conservation (nature or biodiversity), species analyzed, region of interest (freshwater, marine, or coastal), activities (fishing, aquaculture, or shipping), and procedures (quarantine or transport) (Shine et al., 1999). Although many international agreements or treaties are relatively general in structure (relating to all exotic species), they do provide appropriate international guidelines concerning introductions and transfers. The following section briefly reviews some of existing international instruments dealing with the introduction of non-indigenous marine species.

One of the most important developments over the last twenty years has been the enunciation and endorsement of an international policy concerning transfers and introductions by countries bordering the North Atlantic. Under the administration of the International Council for the Exploration of the Sea (ICES), a general "Code of Practice" was established, and approved by member countries, for regulations concerning non-indigenous species introductions (Sindermann, 1986).

The ICES "Code of Practice to Reduce the Risks of Adverse Effects Arising from Introductions of Non-indigenous Marine Species" (1973) is as follows:

1. Recommended procedure for species prior to reaching a decision regarding new introductions.

   (a) Member countries contemplating any new introduction should be requested to present to the Council at an early stage, information on the species, stage in the life cycle, area of origin, proposed place of introduction and objectives, with such information on its habitat, epifauna, associated organisms, potential competition to species in the new environment, etc., as available. The Council should then consider the possible outcome of the introduction, and offer advice on the acceptability of the choice.

(b) Appropriate authorities of the importing country should examine each "candidate for admission" in its natural environment, to assess the justification for the introduction, its relationship with other members of the ecosystem, and the role played by parasites and diseases.

(c) The probable effects of an introduction into the new area should be assessed carefully, including examination of the effects of any previous introductions of this or similar species in other areas.

(d) Results of b. and c. should be communicated to the council for evaluation and comment.

2. If the decision is taken to proceed with the introduction, the following action is recommended:

(a) A brood stock should be established in an approved quarantine situation. The first generation progeny of the introduced species can be transplanted to the natural environment if no disease or parasites become evident, *but not the original import*. The quarantine period will be used to provide opportunity for observation for disease and parasites. In the case of fish, brood stock should be developed from stocks imported as eggs or juveniles, to allow sufficient time for observation in quarantine.

(b) All effluents from hatcheries or establishments used for quarantine purposes should be sterilized in an approved manner (which should include the killing of all living organisms present in the effluents).

(c) A continuing study should be made of the introduced species in its new environment, and progress reports submitted to the International Council for the Exploration of the Sea.

3. Regulatory agencies of all member countries are encouraged to use the strongest possible measures to prevent unauthorized or unapproved introductions.

4. Recommended procedure for introductions or transfers which are a part of current commercial practice.

(a) Periodic inspection (including microscopic examination) by the receiving country of material prior to mass transportation to confirm freedom from introduced pests and disease. If inspection reveals any undesirable development, importation must be immediately discontinued. Findings and remedial actions should be reported to the International Council for the Exploration of the Sea.

(b) Inspection and control of each consignment on arrival.

(c) Quarantining or disinfection where appropriate.

(d) Establishment of brood stock certified free of specified pathogens.

(Source: Sindermann, 1986)

A second organization dealing with introductions in the aquatic environment is the United Nations (UN). In 1982, the UN Convention on the Law of the Sea requested its member countries to take all measures necessary to prevent, decrease and control the voluntary or accidental introductions of exotic species to any particular part of the marine environment (Shine et al., 1999). Around the same time, many other international agreements were also reached in order to prevent and control introductions into inland water systems.

A third organization dealing with potential introductions is the World Health Organization (WHO). In 1969, International Health Regulations (IHR) were established and adopted by the World Health Assembly of the WHO (Geneva, 1969 and revised in 1982). Because many non-indigenous species serve as hosts or vectors for diseases that are harmful to humans, the IHR was created to prevent the spread of potentially deadly infections throughout the world. The goals of the IHR are to identify, reduce, and destroy sources of infections, to improve sanitation, and to prevent further circulation (Shine et al., 1999).

Another important development in preventing introductions was the creation of Agenda 21, which was adopted at the United Nations Conference on Environmental Security and Development in Rio de Janeiro in 1992 (Nauke, 1998; Shine et al., 1999). The agenda urged states to take action to address the impacts of non-indigenous species in a number of critical areas. These areas included deforestation, managing fragile ecosystems and combating desertification, conservation biology, protecting the oceans, seas and coastal areas, and protecting freshwater resources. The Convention on Biological Diversity (CBD), which was also drafted in 1992, requested that parties, where possible and appropriate, prevent the introduction of non-indigenous species, as well as to control and destroy those that threaten native ecosystems and species (Shine et al., 1999).

In 1995, the Food and Agriculture Organization (FAO) created a Code of Conduct for Responsible Fisheries, which required enlisted states to adopt measures to prevent and reduce the damaging effects of introducing non-indigenous species or genetically modified organisms used in aquaculture into natural ecosystems. These guidelines are especially important for the preventing the spread of exotic species within national waters as well as to waters of boarding states (Shine et al., 1999).

The International Maritime Organization (IMO) of the United Nations also plays a significant role in regulating non-indigenous species movements across the world's oceans. Given that there has been exceptional growth in international marine transportation, which is an important pathway for exotic species, the IMO strives to improve safety of life at sea and prevent marine pollution from shipping (Nauke, 1998; Shine et al., 1999). In 1991, the Marine Environment Protection Committee (MEPC) of the IMO accepted guidelines, which were based on national control measures from Australia, Canada, and the US, for preventing the introduction of undesired aquatic organisms and pathogens from ships' ballast water and sediment discharge. The MEPC stressed the need for such guidelines as the first step towards addressing the problem and that future measures may require legally binding agreements (Nauke, 1998).

Although there are numerous international organizations dealing with issues of non-indigenous species introductions, it is still relatively difficult to monitor the extensive activities of member countries. In addition, international law requires countries to be responsible for ensuring that activities within their jurisdiction or control do not cause damage to other countries or to areas beyond national boundaries. However, international law is ambiguous when placing responsibility for unintentional or intentional export of exotic species to territory of another country where it then becomes invasive (Shine et al., 1999). Therefore, future international regulations and agreements need to lay the foundations for placing responsibility for activities generating biological invasions and measures for repairing impacts of existing introductions.

7.3 Foreign Approaches

Non-indigenous marine species have been reported for the majority of geographic regions of the world and it is apparent that these species are a source of significant stress and modification in marine communities (Ruiz et al., 1999). However, there is only a minimum estimate for the actual extent of non-indigenous invasions, because many invasive species are not recognized as such. Given the global range of non-indigenous species invasions, it is not surprising that many countries have implemented management and control measures to deal with the problem within national waters. Therefore this section of the report will highlight some foreign approaches to non-indigenous species invasions, particularly for Australia, New Zealand, and the United States.

7.3.1 Australia

Responsibility for regulating the introduction of species in Australian is the primary responsibility of the Australian Nature Conservation Agency (ANCA) under the authority of the Wildlife Protection Act of 1982. However, responsibility for managing infectious diseases falls under the Australian Quarantine Inspection Service (AQIS), Department of Primary Industry and Productivity. Each state and territory has a separate legislation that deals with controlling exotic marine introductions, which means that they all have administrative powers under Fisheries Act(s), Wildlife Protection Act(s), and/or Flora and Fauna Protection Act(s) (Elston, 1997).

Ballast water introductions are the primary concern for marine habitat modification in Australian waters, especially given its geographical isolation and dependence on marine shipping for imports and exports (Thresher and Martin, 1998). Presently, there are over 70 known exotic marine species identified in Australia, with 20 of these known to have been introduced through ships' ballast water (Jones, 1991). In addition, scientific research has shown that ballast water introductions are responsible for causing toxic algal cysts (Hallegraeff and Bolch, 1992), which are know have serious implications for shellfish operations.

Australia has taken an international position in an effort to reduce the potential risks associated with ballast water introductions (Thresher and Martin, 1998). Current management for preventing ballast water introductions falls under the direction of the AQIS (Elston, 1997; Thresher and Martin, 1998), through its chairmanship of the marine Environmental Protection Committee of the IMO. The AQIS has been a strong advocate in establishing international controls for discharging ballast water and in developing a National (Draft) Strategy on Ballast Water Management (1994 Ballast Water Symposium) (Thresher and Martin, 1998).

The strategy recommended the creation of an Australian Ballast Water Management Advisory Council, which would be supported by a Research Advisory Group and core funding for research. The council objectives are to allocate responsibility for ballast water management, develop a secure funding base for research, and create a strategic research plan. The council consists of government departments, key industry groups, such as fishing, shipping and aquaculture, and a senior science representative (CSIRO). By contrast, the Research Advisory Group is made up primarily of industry representatives and scientific agencies, which evaluate council decisions and suggest alternatives (Thresher and Martin, 1998).

7.3.2 New Zealand

One of the predominant environmental issues facing New Zealand has been the decline of indigenous biodiversity (Christensen, 1999). As with Australia, New Zealand is almost totally dependent on the shipping industry to sustain their economy, which makes it extremely vulnerable to exotic invasions (Hayden, 1998). Consequently, the country has taken a high profile stance against the intentional introduction of non-indigenous species. This increase in conservation ethics is related to the physical distance between New Zealand and most other land masses, which allows self-control of introductions. There has also been a growing awareness of past mistakes causing irreversible ecological impacts and public opinion is becoming increasingly opposed to introductions. Another contributing factor is the inability to compete globally in non-indigenous species aquaculture as a result of its isolated geographical location (Elston, 1997).

In 1988, a New Zealand Ballast Water Working Group (BWWG) was established. The group is composed of representatives from research facilities, regional councils, port companies, fishing, aquaculture, shipping industries, and various government departments. The group is chaired by the Ministry of Agriculture and Fisheries Regulatory Authority (MAF RA), which creates policies and guidelines dealing with the importation of plants and animals and their associated pest, parasites and diseases. This group was seen as the most appropriate agency to establish management and control measures for unwanted organisms in ballast water (Hayden, 1998).

In addition to the national Ballast Water Working Group, voluntary programs for ballast water introductions were developed and implemented in 1992. The voluntary programs are based on the IMO's 'Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ships' Ballast water and Sediment Discharge' and the AQIS control for ballast water entering Australian waters (Hayden, 1998).

New Zealand has long recognized a need for more national ballast water research and the creation of a long-term management plan to reduce the impacts of non-indigenous species introduction. Future initiatives will have to focus on prevention rather than control, because research has found that there is rarely a means to eliminate invasive species once they have become established. Preventing the introduction or transfer of non-indigenous species will be most effectively accomplished through studies into alternative ballast water discharge approaches and new techniques for treating the water that does enter national ports (Hayden, 1998).

7.3.3 United States

As with many other countries, the United States has been coping with the effects of non-indigenous marine species since human settlement began. However, scientific research into the impacts of accidental or intentional transfers of exotic species only began in the 1950's, with the most intense interest within the last decade. Because the United States has a relatively large coastline that extends long distances along the Pacific and Atlantic oceans, the authority for management and control of non-indigenous marine species falls under Federal and State jurisdictions.

President Bill Clinton created the Committee on Environmental and Natural Resources (CENR) in order to encourage a new multi-agency, interdisciplinary approach to environment and natural resource development instead of the ineffective, traditional single-agency discipline. The CENR and its associated stakeholders have identified numerous deficiencies in the nation's understanding of important environmental issues and have therefore focused its research on five main areas. These areas include natural disaster reduction, ecological systems (environmental monitoring), toxics and risk assessment, global change research, and air quality. Through federal funding programs, the CENR is able to address concerns about non-indigenous species invasions, such as assessment of harmful algal blooms and impacts to estuarine environments by exotic pests (CENR).

In addition to the CENR, the federal government passed a Non-indigenous Aquatic Nuisance Prevention and Control Act on November 29, 1990, which was amended by the National Invasive Act of 1996. The Act has five main purposes. First, the Act seeks to prevent accidental introduction and distribution of exotic species to US waters by effective ship ballast water management and control. Second, the Act coordinates federally conducted, funded or authorized research on prevention, or other activities regarding aquatic nuisances. The third purpose is to develop and implement environmentally sound management measures to prevent, monitor, and control accidental introductions through mechanisms other then ballast water. The fourth objective is to reduce economic and ecological impacts of introductions. Finally, the Act proposes to create a program of research and technology development within each state for the purpose of prevention and management of exotics (ANS Task Force).

The federal government also established a National Invasive Species Council (NISC), to provide national leadership on invasive species. The specific focus of the council is to ensure that federal agencies and programs are interrelated, cost efficient, and effective. The NISC is required to develop a management plan that will enhance planning and action at the local, tribal, state, regional and ecosystem-based levels. Furthermore, the NISC will encourage international communication and cooperation, and monitor and evaluate the impacts from invasive species.

At the State level there are several organizations that deal with invasive aquatic species, such as the Chesapeake Bay Program, California Ballast water Control and San Franciso Estuary Project. Commercial ports in the United States received greater then 79,000,000 metric tonnes of foreign ballast water in 1991. The main area for foreign ballast water introductions on the Atlantic coast is the Chesapeake Bay region, particularly Baltimore, Maryland, and Norfolk, Virginia (Carlton et al., 1995). In December 1993 the Chesapeake Bay Program adopted a policy on the introduction of aquatic non-indigenous species. The basic objective of the program is to prevent first time introductions of non-indigenous aquatic species into the waters of Chesapeake Bay and its tributaries, unless environmental and economic evaluations are conducted first. The program is also committed to developing a multi-jurisdictional approach to preventing accidental introductions and to reduce potential impacts to the Chesapeake ecosystem (Elston, 1997).

In an effort to control ballast water introductions in the State of California, a bill was passed (California Assembly Bill 3207 Campbell) which stated that the people of the state have a primary stake in regulations preventing the discharging of foreign ballast water in any water system or coastal area within the State. Furthermore, the bill created a policy to prevent the dispersal of non-indigenous aquatic species into rivers, estuaries, bays or coastal regions. However, these policies were never legally implemented because the State had no authority to interfere with interstate or foreign jurisdiction and commerce (Chesapeake Bay Commission, 1995).

The San Francisco Estuary Project is a component of the Environmental Protection Agency's National Estuary Program that supports the implementation of strict regulations to control and manage the expulsion of ballast waters from vessels within the estuary. Furthermore, the program hopes to prevent the accidental introduction and dispersal of aquatic non-indigenous species within the region (Elston, 1997).

The above agencies and programs are only a few examples of non-indigenous aquatic species management in the United States. At the federal level there is very little statutory law, and no genuine legislation regarding non-indigenous species identification and response to existing invasive species. The majority of federal law has acted on threats from a particular species in a given region, such as zebra mussels in the Great Lakes region, or to the pathway of introduction, such as ballast water management. But it often fails to address issues such as identifying, preventing, screening and understanding non-indigenous species. State legislation is even less defined and is considered a general outline of federal statutory law (Miller, 1999). Although many of the programs and organizations mentioned have attempted to incorporated an interdisciplinary and multi-jurisdictional approach, future initiatives for management and control of non-indigenous species will have to be more clearly defined and outlined so that responsibility is easily determine.

8.0 Conclusion

In conclusion, the introduction of exotic or non-indigenous species has been a topic of considerable concern in recent years. Although there are numerous pathways for introducing marine organisms throughout the world, the most widespread and serious mode is through ships ballast water (Carlton, 1985; Ruiz et al., 1997). It is clear that the spread of diseases, parasites and nuisance organisms are among the greatest concerns associated with the introduction of non-indigenous species, especially those that could have detrimental affects on aquaculture and wild commercial species. There is also major concern for habitat destruction of native marine populations as a result of competition, changing predator-prey dynamics, hybridization, colonization and ecological alterations. The concerns are not limited to native populations because the loss of habitat can have serious implications for existing and potential aquaculture businesses. In addition, genetic alterations and release of genetically modified species into the natural environment could potentially affect the productivity or reduce genetic variability of the local resource.

The introduction of non-indigenous species into marine waters of Canada has had a greater measurable impact on the Pacific coast than the Atlantic. It has been illustrated throughout the report that there have been both positive and negative implications for the aquaculture industry as a result of exotic species introductions, especially in British Columbia. It is also important to note that the majority of non-indigenous species that are used in marine aquaculture activities in Canada are producing higher volumes and values in comparison to native species. Although Canada has been diligent in establishing regulations and regionally-based infrastructure to control the introduction of non-indigenous species, some diseases have still entered local waters and caused ecological changes, particularly in shared waters between British Columbia and Washington State. Future management guidelines and practices will need to be more transparent, effective, and flexible and will need to address existing and inevitable introductions. Furthermore, Canada should evaluate and incorporate management and control measures that have been adopted by other countries, such as Australia, New Zealand, and the United States. These measures will need to include more effective controls on ballast water introductions, the development of management plans at local, regional, provincial, and ecosystem-based levels and more federally conducted research into accidental and intentional introductions. However, each country's political and economic situation is unique, and any guidelines modeled after them should therefore be designed to fit the Canadian situation.

Although this report focuses on the biological aspects of the introduction of non-indigenous marine species and their impacts on Canadian marine aquaculture ventures, it also provides background information for any potential aquaculture investor. Most investors are aware of the more common risks associated with aquaculture businesses, such as government regulations and loss of product due to environmental or disease factors. However, they often fail to realize the potential impacts of introductions of non-indigenous species, either by their company, other operators, the general public, or through ship ballast water. In addition, it is important to realize that even though there are many economic benefits resulting from the introduction of some exotic species, what are the future implications of those decisions and how will the aquaculture industry and society address these issues in the near future.

9.0 Recommendations

As presented throughout the report, the introduction of non-indigenous species, either intentionally or unintentionally, is a vital area of study because introductions have affected the majority of the world's coastal environments. It is also an important area of study for any group preparing to open or acquire a preexisting aquaculture site, particularly if the objective is to rear a species that is not endemic to the region. Furthermore, potential growers will need to know of other possible introductions, accidental or intentional, in the region, and government regulations regarding laws and enforcement procedures.

Recommendations to be made regarding the management and evaluation of non-indigenous species, whether it is for the world or Canada, can be broken into five main categories. The first is the need for appropriate baseline information and risk assessment methods. Currently, there is limited information regarding non-indigenous species' distributions and occurrence and therefore there is a necessity to assess the discontinuity in current information and develop a consolidated inventory regarding the identification and dispersion of non-indigenous species (Elston, 1997). This is especially important to the Atlantic region of Canada because there is limited information on the abundance and location of non-indigenous species. Much of the present research in Atlantic Canada is conducted either by provincial fishery and aquaculture departments or through the federal Department of Fisheries and Oceans (DFO). Future management and assessment efforts in this region will require collaboration between the different agencies and provinces. It is also important to evaluate and document the impacts of non-indigenous species (positive versus negative, or biological versus economic) by examining disease and parasite transfers, the effects of genetic alterations on native species, modification of the local marine ecosystem, and contribution to regional economies. By providing baseline information, marine industries, such as aquaculture, will have a better idea of the risks associated with introduced species and their distribution within a given region.

The second category relates to providing and distributing educational materials to reduce the possible accidental introduction of non-indigenous species to a particular region. Educational material needs to address potential risks associated with aquaculture activities, individual release, scientific research, and the popular demand for aquarium fish species (Elston, 1997). Educational materials should inform consumers about the impact associated with the release of living marine organisms that are sold as seafood products, which has become a growing prerequisite in world markets. Furthermore, providing material on the distribution networks of introduced species could prevent the accidental introduction of organisms via species that are used in aquaculture operations.

The third category is the need for more effective communication (Elston, 1997), especially between neighboring countries, such as Canada and the U.S, where restriction in one area may not be valid in the other or research may be more advanced in one location compared to the next. For example, the introduction of the majority of non-indigenous marine species into British Columbia has been the result of intentional introduction in the U.S during the early 1900's. Therefore, management and assessment of these species requires the exchange of information between the two countries and to promote constancy of biological criteria to regulate the movement of marine species. Communication between federal and provincial governments in Canada will also need to be improved. Present policies and regulations are often confusing, resulting in overlapping management responsibilities. Thus future initiatives will require more effective communication between federal and provincial agencies and the creation of practical and consistent guidelines for non-native species introductions and transfers.

A fourth category involves the need for immediate international cooperation in ballast water management. Given that ballast water and associated sediments is currently the most important vector of non-indigenous species introduction and transfer (Carlton and Kelly, 1998), it is vital for countries throughout the world to create international joint research and enforcement programs. This type of international agreement will require the standardization of current sampling methods and data collection (Carlton and Kelly, 1998), the identification of potential donor areas or 'hot spots'(Carlton and Kelly, 1998;

Cohen and Carlton, 1998; Ricciardi and Rasmussen, 1998), and the creation of more effective control methods, regulations, and enforcement procedures.

There also needs to be better ballast water management within Canada. At present there are no real policies, enforcement procedures, or voluntary programs for ballast water introductions in British Columbia (Gauthier and Steel, 1995) or Atlantic Canada. Marine traffic in Canada, especially in the Atlantic Provinces, is steadily increasing. Therefore, future management measures will need to incorporate more effective research and enforcement policies and increase public awareness about the growing concern for ballast water introductions.

The final category is the creation and restructuring of regulations, either voluntary or mandatory, concerning the introduction of non-indigenous species into a particular country. Voluntary programs, such as community-based management, are more effective than mandatory programs because they are usually more functional allowing, for an industry such as aquaculture to have a stake in the success of the program (Elston, 1997). Furthermore, non-indigenous species can enter an area through many different pathways and given that countries such as Canada have extensive coastlines the cost that would be required to effectively manage them could be better used in promoting educational materials and voluntary programs.

References

Abbott, I. A., and G.J. Hollenberg. (1976). *Marine Algae of California*. Standford University Press. Standford, California.

Achieng, A.P. (1990). The impact of the introduction of Nile perch, *Lates niloticus* (L.) on the fisheries of Lake Victoria. *Journal of Fish Biology* 37 (Supplement A): 17-24.

Allendorf, F.W., and R.F. Leary. (1988). Conservation and distribution of genetic variation in polytypic species, the cutthroat. *Conservation Biology* 2: 178-181.

Amos, K.H., and A. Appleby. (1999). *Atlantic salmon in Washington State: A fish management perspective.* (September 1999). Washington Department of Fish and Wildlife {On-line} Retrieved June 15, 2001 from the World Wide Web: http://www.wa.gov/wdfw/fish/atlantic/manage.htm.

Aquatic Nuisance Species (ANS) Task Force. Non-indigenous Aquatic Nuisance Prevention and Control Act. {On-line}. Retrieved July 15, 2001 from the World Wide Web: http://www.anstaskforce.gov/nanpca.htm.

AQIS (Australian Quarantine and Inspection Service). (1995). Australian ballast water management strategy. Australian Government Publishing Service, Canberra. *The Ballast Water Bulletin*. Number 3. Australian Government Publishing Service, Canberra.

BC Salmon Farmers Association (2000). Jobs and Economic Development in Coastal Communities. {On-line}. Retrieved March 10, 2001 from the World Wide Web: http://www.salmonfarmers.org/network/.

Benfey, T.J., and A.M. Sutterlin. (1984). Growth and gonadal development in triploid landlocked Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Science* 41: 1387-1392.

Bernard, J., M. Bermont, and J. Winton. (1991). Sequence homologies between the N Genes of the 07-71 and Makah isolates of viral hemorrhagic septicemia virus. In *Abstracts, Second International symposium on Viruses of Lower Vertebrates*, July 29-31, Corvallis, Oreg., 12.

Bird, C.J., M.J. Dadswell, and D.W. Grund. (1993). First record of the potential nuisance alga *Codium fragile* ssp. *tomentosoides* (Chlorophyta caulerpales) in Atlantic Canada. *Proceedings from the Nova Scotia Institute of Science* 40: 11-17.

Blewett, E., and J.D. MacDonald. (1998). *Potential Impacts of Patenting Lifeforms on the Aquatic Products Sector in Canada.* Industry Canada {On-line} Retrieved June 4, 2001 from the World Wide Web: http://strategis.ic.gc.ca/SSG/ip00047e.html.

Boghen, A.D. (1995). Preface. In *Cold-Water Aquaculture in Atlantic Canada Second Edition.* A. D. Boghen (Ed.). The Canadian Institute for Research and Regional Development, N.B., ix.

Bouck, G.B., and E. Morgan. (1957). The occurrence of *Codium* in Long Island waters. *Bulletin Torrey Botanical Club* 84: 384-387.

Bourne, N., C.A. Hodgson, and J.N.C. Whyte (1989). A manual for scallop culture in BritishColumbia. *Canadian Technical Report of Fisheries and Aquatic Science.* 1694: 230.

Bower, S.M., J. Blackbourn, G.R. Meyer, and D.W. Welch. (1999). Effects of *Perkinsus quqwadi* on various strains of scallops. *Diseases of Aquatic Organisms* 36: 143-151.

Bower, S.M. (1996). Synopsis of Infectious Disease and Parasites of Commercially Exploited Shellfish: *Marteilia sydneyi* of Oysters. {On-line} Retrieved June 22, 2001 from the World Wide Web: http://www-sci.pac-mpo.gc.ca/sealane/aquac/pages/marsydoy.htm.

British Columbia (BC) Fisheries Statistics. (1999). Aquaculture Statistics. {On-line} Retrieved March 10, 2001 from the World Wide Web: http://www.bcfisheries.gov.bc.ca/stats/salmon-aqua.html.

British Columbia Shellfish Growers Association. (2001). BC Shellfish Farming Industry Facts and Figures.{On-line}. Retrieved March 10, 2001 from the World Wide Web: http://www.island.net/%7bcsga/overview.htm.

Brunson, R. (1989). VHS virus isolated at Makah National Fish Hatchery. *American Fisheries Society Newsletter* 7: 3-4.

Campton, D.E. (1990). Application of biochemical and molecular markers to analysis of hybridization. In. *Electrophoretic and Isoelectric Focusing Techniques in Fisheries Management.* D.H. Whitmore (Ed.). CRC Press, Inc., Boca Raton, Florida.

Canadian Press Newswire. (1999). Atlantic lobsters said thriving in West Coast waters Burrard Inlet. {On-line}. Retrieved February 13, 2001 from the World Wide Web: http://134.153.34.164/uhtbin/cgisirsi/twngguOMRq/18751120/102.

Carlisle, D.B. (1954). *Styela mammiculata*, a new species of ascidian from the Plymouth Area. *Journal of the Marine Biological Association of the United Kingdom* 33: 329-334.

Carlton, J.T. (1999). The scale and ecological consequences of biological invasions in the world's oceans. In *Invasive Species and Biodiversity Management*. O.T. Sandlund et al. (Eds.). Kluwer Academic Publishers, Netherlands 195-212.

Carlton, J.T., and J. Kelly. (1998). Forward. In *Ballast Water: Ecological and Fisheries Implications*. James Carlton (Ed.). International Council for the Exploration of the Sea, Denmark. *ICES Coop. Res. Rep. No.224.*1-4.

Carlton, J.T., D.M. Reid, and H. Van Leeuwen. (1995). Shipping study. The role of shipping in the introduction of non-indigenous aquatic organisms to the coastal waters of the United States (other then the Great Lakes) and an analysis of control options. *The National Sea Grant College Program/ Connecticut Sea Grant project. R/ES-6.* Department of Transportation, United States Coast Guard, Washington, D.C. and Groton, Connecticut. Report Number CG-D-11-95. Government Accession Number AD-A294809.

Carlton, J.T., K. Thompson, L.E. Schemel, and F.H. Nichols. (1990). Remarkable invasions of San Franciso Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. II. Introduction and dispersal. *Marine Ecology Progress Series* 66: 81-94

Carlton, J.T., and J.A. Scanlon. (1985). Progression and dispersal of an introduced alga *Codium fragile* ssp. tomentosoides (Chlorophyta) on the Atlantic coast of North America. *Botanica Marina* 28: 155-165.

Carlton, J.T. (1985). Transoceanic and interoceanic dispersal of coastal marine organisms: The biology of ballast water. *Oceanography and Marine Biology Annual Review* 23: 313-374.

Carlton, J.T. (1975). Introduced intertidal invertebrates. In *Light's Manual: Intertidal Invertebrates of theCcentral California Coast*. Third Edition. J.T. Carlton and R. I. Smith (Eds.). University of California Press, Berkeley, California, USA. 17-25.

Cawthorn R.J. S. Backman, J. O'Halloran, D. Groman, and D. Spears. (1991). *Perkinsus* sp. (*Apicomplexa*) in farmed Atlantic salmon (*Salmo salar*). *Bulletin of Aquaculture Association of Canada* 91: 61-63.

Chen, S. G.H .Kou, R.P. Hedrick, and J.L. Fryer. (1985). The occurrence of viral infection of fish in Taiwan. In *Fish and Shellfish Pathology*. A.E Ellis (Ed.). Acad. Press, N.Y.

Chesapeake Bay Commission (CBC). (1995). The introduction of non-indigenous species to the Chesapeake Bay via ballast water. *A Chesapeake Bay Commission Report*, January 5, 1995. Annapolis, Maryland. Chesapeake.

Christensen, M. (1999). Global invasive species project: Focus country report, New Zealand. At the Workshop on the *Legal and Institutional Dimensions of Alien Invasive Species Introduction and Control*. IUCN Environmental Law Center, Bonn, Germany 10-11 December 1999.

Cohen, A.N., and J.T. Carlton. (1998). Accelerating invasion rate in a highly invaded estuary. *Science* (Washington, D.C.) 279: 555-558.

Cohen, A.N., J.T. Carlton, and M.C. Fountain. (1995). Introduction, dispersal and potential impacts of the green crab *Carcinus maenas* in San Francisco Bay, California. *Marine Biology* 122: 225-237.

Collis, K., R.E. Beaty, and B.R. Crain. (1995). Changes in catch rate and diet of northern squawfish associated with the release of hatchery-reared juvenile salmonids in the Columbia River reservoir. *North American Journal of Fisheries Management* 15: 346-357.

Committee on Environmental and Natural Resources (CENR). General Information. {On-line}. Retrieved July 15, 2001 from the World Wide Web: http://www.nnic.noaa.gov/CENR/cenr.html.

Cook, R.H., and F.J. Simpson. (1995). Roles of Government Agencies in Aquaculture Development in Atlantic Canada: Regulation and Incentives. In *Cold-Water Aquaculture in Atlantic Canada Second Edition*. A. D. Boghen (Ed.). The Canadian Institute for Research and Regional Development, N.B., 501-536.

Cordell, J.R., and S.M. Morrison. (1996). The invasive Asian copepod *Pseudodiaptomus inopinus* in Oregon, Washington, and British Columbia estuaries. *Estuaries* 19(3): 629-638.

Counts, C. L., III. (1986). The zoogeography and history of the invasion of the United States by *Corbicula fluminea* (Bivalvia: Corbiculidae). *American Malacological Bulletin*, Special Edition No. 2: 2:7-39.

Couturier, C.Y., P. Dabinett, and M. Lanteigne. (1995). Scallop culture in Atlantic Canada. In *Cold-Water Aquaculture in Atlantic Canada second edition*. A.D. Boghen (Ed.). The Canadian Institute for Research and Regional Development, N.B., 297-340.

Couturier, C.Y. (1990). Scallop aquaculture in Canada: Fact or Fantasy? *World Aquaculture* 21(2): 54-62.

Crossmann, E. J. (1991). Introduced fishes: A review of the North American perspective with emphasis on Canada. *Canadian Journal of Fisheries and Aquatic Science* 48: 46-57.

Devlin, R.H and E.M. Donaldson. (1992). Containment of genetically altered fish with emphasis on salmonids. In: *Transgenic Fish*. C.L. Hew and G.L. Fletcher (Eds.), Word Scientific Pub.Co., Singapore 13: 229-265.

DFO. (1994). *Transgenic Aquatic Organisms: Policy and Guidelines for Research with, or for Rearing in Natural Aquatic Ecosystems in Canada*. Draft 2, February 1994.

DFO. (1995). *Exotic Phytoplanton from Ships' Ballast Waters*. {On-line} Retrieved January 30, 2001 from the World Wide Web: http://www.mar.dfo-mpo.gc.ca/science/mesd/he/ballast.html.

DFO. (1999). Aquaculture Statistics. {On-line} Retrieved March 1, 2001 from the World Wide Web: http://www.dfo-mpo.gc.ca/communic/statistics/aquacult/aqua99.htm.

DFO and P.E.I. Department of Fisheries, Aquaculture and Environment (P.E.I.FAE). (2000). *Notice to Fisheries and Aquaculturists*. Information provided by Richard Gallant, Department of Fisheries, Aquaculture and Environment (P.E.I.).

Drinnan, R.E. (1970). *The Introduction of the European Flat Oyster (Ostrea edulis) to Eastern Canada*. ICES Fisheries Improvement Committee CM 1970/E.10.

Elner, R.W. (1981). Diet of the green crab *Carcinus maenas* (L.) from Port Hebert, Southwestern Nova Scotia. *Journal of Shellfish Research* 1: 89-94.

Elston, R. A., C.A. Farely, and M.L. Kent. (1986a). Occurance and signifance of biomass in European Flat oysters *Ostrea edulis* in North America. *Diseases of Aquatic Organisms* 2: 49-54.

Elston, R.A., L. Harrell, and M. Wilkinson. (1986b). Isolation and *in vitro* characteristics of chinook salmon (*Oncorhynchus tshawytscha*) rosette agent. *Aquaculture* 56: 1-21.

Elston, R.A. (1997). Pathways and Management of Marine Non-indigenous Species in Shared Waters of British Columbia and Washington. {On-line}. Retrieved January 30, 2001 from the World Wide Web: http://www.wa.gov/puget_sound/shared/nis.html.

Fletcher, G.L., and P.L. Davies. (1991). Transgenic fish for aquaculture. In: *Genetic Engineering*. J.K. Setlow (Ed.). Plenum Press, N.Y. 13: 331-370.

Fralick, R.A., and A.C. Mathieson. (1972). Winter fragmentation of *Codium fragile* (Suringar) Hariot ssp. *tomentosoides* (Van Goor) Silva (Chlorophyseae Siphonales) in New England. *Phycologia* 11: 67-70.

Fryer, J.L., C.M. Lannan, L.H. Garces, J.J. Larenas, and P.A. Smith. (1990). Isolation of Rickeetsiales-like organisms from diseased Coho salmon (*O. kistuch*) in Chile. *Fish Pathology* 25: 107-114.

Garbary, D.L., and C.B. Jess. (2000). Current status of the invasive green alga *Codium fragile* in Eastern Canada. *Journal of Phycology* 36(5): 23-24.

Garbary, D.J., H. Vandermeulen, and K.Y. Kim. (1997). *Codium fragile* ssp. *tomentosoides* (Chlorophyta) invades the Gulf of St. Lawerence, Atlantic Canada. *Botanica Marina* 40: 537-540.

Gauthier, D., and D.A. Steel. (1995). A synopsis of the Canadian situation regarding ship transported ballast water. In *Proceedings of International Council for the Exploration of the Seas session Ballast Water: Ecological and Fisheries Implications*. J.T. Carlton (Ed.). September 1995, Aalborg, Denmark. (in press)., 91-101.

Ginetz, R. (1996). Impacts of farmed salmon escaping from net pens. Environmental Assessment Office, British Columbia, Canada. {On-line}. Retrieved January 30, 2001 from the World Wide Web: http://www.eao.gov.bc/project/aquacult/salmon/escape.htm.

Gjedrem, T. (1997). Selective breeding to improve aquaculture production. *World Aquaculture* 28(1): 33-45.

Gorman, J. (1995). *Farming the Sydney Rock Oyster*. {On-line}. Retrieved June 22, 2001 from the World Wide Web: http://members.ozemail.com.au/~dkgsoft/oyster/oysdid.html.

Grosholz, E.D., and G.M. Ruiz. (1996). Predicting the impact of the introduced species: Lessons from the multiple invasions of the European green crab *Carcinus maenas*. *Biological Conservation* 78: 59-66.

Hallegraeff, G.M. (1993). A review of harmful algal blooms and their apparent global increase. *Phycologia* 33: 79-99.

Hallegraeff, G.M., and C.J. Bolch. (1992). Transport of diatom and dinoflagellate resting spores in ships' ballast water: implications for plankton biogeography and aquaculture. *Journal of Plankton Research* 14: 1067-1084.

Hallermann, E.M., and A.R. Kapuscinski. (1992). Ecological and regulatory uncertainities associated with transgenic fish. In *Transgenic Fish*. C.L. Hew and G.L. Fletcher (Eds.). World Science, Singapore, 209-228.

Haworth, J. (2001). Single seed oyster spat improves production. {On-line}. Retrieved October 3, 2001 from the World Wide Web: http://www.fis.com/fis/worldnews/worldnews.asp?1=e&id=20458.

Hayden, B. (1998). A New Zealand perspective on ballast water. In *Ballast Water: Ecological and Fisheries Implications*. J. Carlton (Ed.). International Council for the Exploration of the Sea, Denmark. *ICES Coop. Res. Rep. No. 224.*, 65-73.

Hew, C.L., and G. Fletcher. (1997). *Transgenic Fish for Aquaculture*. {On-line} Retrieve June 15, 2001 from the World Wide Web: http://ci.mond.org/9708/970812.html.

Hinder, K., N. Ryman, and F. Utter. (1991). Genetic effects of aquaculture on natural fish populations. *Aquaculture* 98: 259-261.

Houghton, D.R., and R.H. Millar. (1960). Spread of *Styela clava* Herdman in Haysham Harbour, Lancashire. *Porcupine Newsletter* 3: 85-97.

Hume, S. (1998). European green crab (*Carcinus maenas*). Fisheries management the Pacific region. Department of Fisheries and Oceans, Canada. {On-line} Retrieve May 31, 2001 from the World Wide Web: http://www.pac.dfo-mpo.gc.ca/ops/fm/shellfish/Green_Crab/ARTICLE.HTML.

Inada, Y., and N. Taniquchi (1991). Spawning behavior and after-spawning survival in induced triploid ayu (in Japanese) *Plecoglossus altivelis*. *Nippon Suisan Gakkaishi* 57: 2265-2269

International Council for the Exploration of the Sea (ICES). (1994). *Report of the Working Group on Introductions and Transfers of Marine Organisms*. Mystic Connecticut, 20-22 April 1994.

Iyengar, A., F. Muller., and N. Maclean. (1996). Regulations and expression of transgenes in fish-a review. *Transgenic Research* 5: 147-166.

Jamieson, G.S., E.D. Grosholz, D.A. Armstrong, and R.W. Elner. (1998). Potential ecological implications from the introduction of the European green crab, *Carcinus maenas* (Linneaus), to British Columbia, Canada and Washington, USA. *Journal of Natural History* 32: 1587-1598.

Jones, M. (1991). Marine organisms transported in ballast water. *Bureau of Rural Resource Bulletin*. 11, Australian Government Publishing Service. Canberra, p. 48.

Juanes, F. (1992). Why do decapods crustaceans perfer small-sized molluscan prey? *Marine Ecology Progress Series* 87: 239-249.

Judson, I. (1992). Some observations on mollusc culture in Atlantic Canada. *Bulletin of Aquaculture Association of Canada* 92(4): 10-17.

Kent, M.L. (2000). Marine netpen farming leads to infections with some unusual parasites. *International Journal for Parasitology* 30: 321-326.

Kent, M.L., D.J. Whitaker, J. Moran, and Z. Kabata. (1997). *Haemobaphes disphaerocephalus* (Pennellidea: Copepoda), an accidental parasite of seawater pen-reared Atlantic salmon. *Canadian Veterinary Journal* 38: 110-1.

Kitamura, S., H. Ogata, H. Onozato, and H. Nagoya. (1993). Induced masu salmon spawning of diploid females by triploid males. National Research Institute of Aquaculture, Nasei, Mie 516-08, Japan. In: *Interactions Between Cultured Species and Naturally Occurring Species in the Environment*. M.R. Collie and J. P. Mavey (Eds.). Alaska Sea Grant Report AK-SG-95-03.

Lafferty, K. D., and A.M. Kuris. (1996). Biological control of marine pests. *Ecology*. Ecological Society of America 77(7): 1989-2000.

Lincoln, R.F., and V.J. Bye. (1984). Triploid rainbow trout show commercial potential. *Fish Farmer* 7: 30-32.

Lincoln, R.F., and A.P. Scott. (1984). Sexual maturation in triploid rainbow trout, *Salmo gairdneri*. *Fish Biology* 25:385-392.

Loosanoff, V.L. (1955). The European oyster in American waters. *Science* 121:119-21.

Luiz, C.G. (1999). Genetics and breeding. Aquaculture stocks: evaluating genetics threats. *Aquaculture Magazine* July/August 1999: 67-70.

Maclean, N., and R.J. Laight. (2000). Transgenic fish: an evaluation of benefits and risks. *Fish and Fisheries* 1: 146-172.

Mallet, A., and C. Carver. (1987). *The Feasibility of Bay Scallop Culture in Nova Scotia: A Preliminary Study*. Nova Scotia. Department of Fisheries. ERDA Report.

McGladdery, S.E., B.C. Bradford, and D.J. Scarratt. (1993). Investigations into the transmission of parasites of bay scallop, *Argopecten irradians* (Lamarck, 1819), during quartine introductions to Canadian Atlantic waters. *Journal of Shellfish Research* 12(1): 49-58.

McGladdery, S.E. L., Murphy, B.D. Hicks, and S.K. Wagner. (1990). Pathology in marine science. In *The effects of stephanostomum tenue (Digenea: Acanthocolpidae) on Marine Aquaculture of Rainbow Trout, Salmo gairdneri*. F.O. Perkins and T.C. Cheng (Eds.). San Diego, California: Academic Press, Inc. 305-315.

Meakin Consultants (Undated). *Canadian Environmental Protection Act, Section 26(3) (a): Scope of Federal Legislation Pertaining to Biotechnology Products and Biotechnology Products Currently Not Notifiable*. Draft.

Medcof, J.C. (1961). Trial introductions of European oyster (*Ostrea edulis*) to Canadian East Coast. *Proceedings of the National Shellfisheries Association* 50: 113-24.

Mikkola, H. (1978). Experimental study of mortality in whitefish eggs through predation by bottom fauna and fish. *Aquaculture* 9: 68-72.

Millar, R.H. (1960). The identity of the ascidians *Styela mammicuulate* Carlisle and *Styela clava* Herdman. *Journal of Irish Naturalists' Journal* 22: 509-511.

Miller, M. (1999). The Paradox of the United States alien species law-IUCN country Report. At the *Workshop on the Legal and Institutional Dimensions of Alien Invasive Species Introduction and Control*. IUCN Environmental Law Center, Bonn, Germany 10-11 December 1999.

Morton, B. (1986). *Corbicula* in Asia - an updated synthesis. *American Malacological Bulletin*, Special Edition No. 2:113-124.

Nakamura, M., F. Tsuchiya, M. Iwabashi, K. Suzuki, and Y. Nagahama. (1987). *Oral Presentation at Japanese Society of Scientific Fisheries Biennial Meeting* in Spring 1987 (Abstr. 323, in Japanese).

National Invasive Species Council (NISC). (Undated). National Invasive Species Council Information. US Department of the Interior-South, Washington, D.C. {On-line}. Retrieved July 31, 2001 from the World Wide Web: http://www.invasivespecies.gov/council/nisinfo.shtml.

Natural Resource Consultants Ltd. (1997). *Escaped Farm Salmon Environmental and Ecological Concerns.* {On-line}. Retrieved January 27, 2001 from the World Wide Web: http://www.eao.gov.bc.ca/project/aquacult/salmon/concerns.htm.

Nauke, M.K. (1998). Provisions for the control and management of ballast water to minimize the transfer of harmful aquatic organisms and pathogens. In *Ballast Water: Ecological and Fisheries Implications.* J. Carlton (Ed.). International Council for the Exploration of the Sea, Denmark. *ICES Coop. Res. Rep. No. 224.*, 113-117.

Newkirk, G.F., B.C. Muise, and C.E. Enright. (1995). Culture of the Belon oyster, *Ostrea edulis*, in Nova Scotia. In *Cold-Water Aquaculture in Atlantic Canada Second Edition.* A.D. Boghen (Ed.). The Canadian Institute for Research and Regional Development, N.B., 225-254.

Nielsen, J. L. (1994). Invasive cohorts: impacts of hatchery-reared coho salmon on the tropics, developmental, and genetic ecology of wild stocks. In: *Theory and Application in Fish Feeding Ecology.* D.J. Stouder, K.L. Fresh, and R.J. Feller (Eds.). The Belle W. Branch Library in Marine Science Number 18, University of South Carolina Press, Columbia.

Nova Scotia (NS) Department of Fisheries and Aquaculture. (1999). Aquaculture Statistics.{On-line}. Retrieved March 10, 2001 from the World Wide Web: http://www.gov.ns.ca/fish/aquaculture/stats/1999.htm.

Orr, C. (1999). Introduced exotic species: introducing exotics into marine ecosystems in the traditional territory of the Heiltsuk First nation.{On-line}. Retrieved June 6, 2001 from the World Wide Web: http://www.heiltusk.cam/papers-exotics-print.htm.

Parsons, J. (2002). National Code on Introductions and Transfers of Aquatic Organisms-January 2002, Personal Communications.

Parsons, J. (1998). Status of genetic improvement in commercially reared stocks of rainbow trout. *World Aquaculture* 29(1): 44-47.

Pearsons, T.N., and C.W. Hopley. (1999). A practical approach for assessing ecological risks associated with fish stocking programs. *Fisheries* 24(9): 16-23.

Philipp, D.P., D.P. Burkett, J.M. Epifanio, and J.E. Marsden. (1995). Protection of aquatic biodiversity: Will we meet the challenge? In *Production of Aquatic Biodiversity: proceedings of the world fisheries congress.*(Theme 3). D.P. Philipp, J.M. Epifanio, J.E. Marsden, J.E. Claussen and R.J. Wolotira Jr. (Eds.). Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi., 1-10.

Pitkanen, T.I., A. Krasnov, M. Reinisalo, and H. Molsa. (1999). Transfer and expression of glucose transporter and hexokinase genes in salmonid fish. *Aquaculture* 173: 319-333.

Race, M.S. (1982). Competitive displacement and predation between introduced and native mud snails. *Oecologia* 34: 337-347.

Ricciardi, A., and J.B. Rasmussen. (1998). Predicting the identity and impact of future biological invaders: a priority for aquatic resource management. *Canadian Journal of Fisheries and Aquatic Science* 55: 1759-1765.

Ropes, J.W. (1968). The feeding habits of the green crab, *Carcinus maenas* (L.). *Fishery Bulletin for the U.S. Fish and Wildlife Service* 67: 183-203.

Ruiz, G.M., P. Fofonoff, A.H. Hines, and E.D. Grosholz. (1999). Non-indigenous species as stressors in estuarine and marine communities: Assessing invasion impacts and interactions. *Limnolnology and Oceanography* 44 (3, part 2): 950-972.

Ruiz, G.M., J.T. Carlton, E.D. Grosholz, and A.H. Hines. (1997). Global invasion of marine and estuarine habitats by non-indigenous species: Mechanisms, extent, and consequences. *American Zoology* 37: 621-632.

Ryman, N., and L. Laikre. (1991). Effects of supportive breeding on the genetically effective population size. *Conservation Biology* 5: 325-329.

Ryman, N., F. Utter, and L. Laikre. (1995). Protection of aquatic biodiversity. In *Production of Aquatic Biodiversity: proceedings of the world fisheries congress.* (Theme 3). D.P. Philipp, J.M. Epifanio, J.E. Marsden, J.E. Claussen and R.J Wolotira Jr. (Eds.). Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi., 11-35.

Saunders, R.G., and W.A. Heath. (1994). New developments in scallop farming in British Columbia. *Bulletin of Aquaculture Association of Canada* 3: 3-7.

Shine, C., N. Williams, and F.B. Guilmin. (1999). Global invasive species program: Legal and institutional frameworks. At the *Workshop on the Legal and Institutional Dimensions of Alien Invasive Species Introduction and Control.* IUCN Environmental Law Center, Bonn, Germany 10-11 December 1999.

Shumway, S.E. (1989). Toxic algae a serious threat to shellfish aquaculture. *World Aquaculture* 20: 65-74.

Sindermann, C.J. (1993). Disease risks associated with importation of non-indigenous marine animals. *Marine Fisheries Review* 54(3): 1-9.

Sindermann, C.J. (1990). *Principle Diseases of Marine Fish and Shellfish*. Volume 1. Second Edition. Academic Press, Inc. San Diego, California, USA.

Sindermann, C.J. (1986). Strategies for reducing risks from introductions of aquatic organisms: A marine perspective. *Fisheries* 11(2): 10-15.

Sindermann, C.J.(1984). Disease in marine aquaculture. *Helgolander Meeresuntersuchungen* 37: 505-532.

Sutterlin, A. M., and C. Collier. (1991). Some observations on the commercial use of triploid rainbow trout and Atlantic salmon in Newfoundland. Proceedings of the Fish Sterility Workshop, Feb. 20, Halifax, N.S. *Canadian Technical Report of Fisheries Aquatic Science*. No. 1789: 15-33.

Thresher, R.E., and R.B.Martin. (1998). Reducing the impacts of ship-borne marine introductions: focal objectives and development of Australia's new center for research on introduced marine pests. In *Ballast Water: Ecological and Fisheries Implications*. James Carlton (Ed.). International Council for the Exploration of the Sea, Denmark. *ICES Coop. Res. Rep. No 224.*, 85-90.

Thornton, B. (2000). *The Atlantic Salmon Controversy: East vs. West*. All Outdoors, Inc.{On-line}. Retrieved January 30, 2001 from the World Wide Web: http://www.alloutdorrs.com/aolibrary/fishing/fresh/natl_salmon_contrv.asp.

Townshend, E.R., and J. Worms (1983). *Introductions of a New Pectinid Species Argopecten irradians irradians to the Gulf of St. Lawerence, Canada*. International Council for the Exploration of the Sea C.M. K: 44.

Vermeij, G.J. (1982). Environmental change and the evolutionary history of the periwinkle *Littorina littorea* in North America. *Evolution* 36: 561-580.

Volpe, J.P., B.R. Anholt, and B.W. Glickman. (2001). Competition among juvenile Atlantic salmon (*Salmon salar*) and steelhead (*Oncorhynchus mykiss*): relevance to invasion potential in British Columbia. *Canadian Journal of Fisheries and Aquatic Science* 58: 197-207.

Waples, R.S. (1995). Genetic effects of stock transfers of fish. In: *Production of Aquatic Biodiversity: Proceedings of the World Fisheries Congress*. (Theme 3). D.P. Philipp, J.M. Epifanio, J.E. Marsden, J.E. Claussen, and R.J. Wolotira, Jr. (Eds.). Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, 51-69.

Welch, W.R. (1969). Changes in abundance of green crab, *Carcinus maenas* (L), in relation to recent temperature changes. *Fishery Bulletin of the U.S. Fish and Wildlife Service* 67: 337-345.

Welcomme, R.L. (1984). International transfers of inland fish species. In *Distribution, Biology, and Management of Exotic Fishes*. W.R. Courtney, Jr., and J.R. Stauffer, Jr. John Hopkins (Eds.). University Press. Baltimore, Md. 22-40.

Welcomme, R.L. (1992). A history of international introductions of inland aquatic species. *ICES Marine Science Symposium* 194: 3-14

Whitaker, D.L., and M.L. Kent. (1991). *Kudoa thrysites* (Myxosporea): a cause of soft flesh in farmed- reared Atlantic salmon (*Salmo salar*). *Journal of Aquatic Animal Health* 3: 291-294.

White, R.J., J.R.Karr, and W. Nehlsen. (1995). Better roles for fish stocking in aquatic resource management. *American Fisheries Society Symposium* 15: 527-550.

Whitlatch, R.B., and S. Obrebski. (1980). Feeding selectivity and coexistence in two deposit feeding gastropods. *Marine Biology* 58: 219-225.

Whoriskey, F. (2001). One organization's science-based approach to facing up to environmental footprint of aquaculture. Atlantic Salmon Federation, St. Andrews, New Brunswick, Canada. {On-line}. Retrieved may 23, 2001 from the World Wide Web: http://www.aims.ca/aqua/seasII/whoriskeynotes.htm.

Whyte, S.K., R.J. Cawthorn, S.E. McGladdery, R.J. MacMillian, and D.M. Montgomery. (1993). Cross-transmission studies of *Perkinsus karlssoni* (Apicomplexa) from bay scallop *Argopecten irradians* to native Atlantic Canadian shellfish species. *Diseases of Aquatic Organisms* 17: 33-39.

Wiley, C. (1997). Alien invasion the last threat to Canada from ship's ballast water discharge. Transport Canada. *Marine Safety Review*. 1(3): TP# 12988.