Habitat Management Qualitative Risk Assessment : Water Column Oyster Aquaculture in New Brunswick

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ABSTRACT

The Department of Fisheries and Oceans Canada (DFO) is responsible for evaluating potential environmental impacts on fish habitat associated with project development. Aquaculture of the native oyster (*Crassostrea virginica*) has been expanding in gulf New Brunswick's (N.B.) coastal communities, thus, a qualitative risk assessment was initiated. This involves an evaluation of water column oyster aquaculture and its interactions with fish habitat, as defined in the *Policy for the Management of Fish Habitat,* by integrating a thorough review of the current scientific information and a description of the oyster aquaculture industry. This assessment follows the work of the National Advisory Process which characterized the potential environmental risks of bivalve aquaculture in the marine environment. That scientific review is complemented with technical data as well as additional information to specifically characterize the potential effects of oyster aquaculture in N.B. The present qualitative risk assessment is intended to assist habitat managers in their decision-making process and is based on the *Habitat Management Program Risk Management Framework*. The framework provides a structured process for characterizing the potential risks and assessing their significance in regards to the productive capacity of fish habitat. An Ecological Risk Assessment and a Net Ecological Benefit Analysis are used to make determinations as to the effects and functions, respectively, of water column oyster aquaculture in gulf N.B. Using the risk assessment, we conclude that the overall "scale of potential negative effects" of water column oyster aquaculture and the "sensitivity of fish and fish habitat" correspond to a low-risk activity which is not likely to significantly harm the productive capacity or the ecological integrity of fish habitat. Moreover, our analysis suggests that oysters in aquaculture can potentially be of significant benefit to these estuaries and can help to restore many important ecological functions which were reduced following the historical decline of natural populations. Given the nature of this activity, we conclude that the risks associated with water column oyster aquaculture can be managed in a sustainable manner with adequate planning and mitigation measures through an adaptive management approach.

RÉSUMÉ

Le Ministère des Pêches et des Océans du Canada (MPO) est responsable d'évaluer les effets environnementaux potentiels des projets de développement sur l'habitat du poisson. L'aquaculture de l'huître indigène (*Crassostrea virginica*) est une activité en croissance au Nouveau-Brunswick (N.-B.). Pour cette raison, une évaluation qualitative du risque de cette activité a été entreprise. Une évaluation des interactions entre l'ostréiculture en colonne d'eau et l'habitat du poisson a été effectuée, tel que définie sous la Politique de gestion de l'habitat du poisson, par l'entremise d'une revue d'informations scientifiques et une description de l'activité ostréicole. Cette évaluation fait suite au processus officiel d'avis scientifique qui a caractérisé les risques environnementaux potentiels de la culture marine des bivalves. Cette revue scientifique ainsi que d'autres études et informations techniques ont été utilisées afin de caractériser plus spécifiquement les effets de l'ostréiculture dans la colonne d'eau au N.-B. L'évaluation qualitative du risque a comme objectif d'aider les gestionnaires dans le processus de prise de décisions selon le *Cadre de gestion de risques* du *Programme de gestion de l'habitat*. Ce cadre offre un processus structuré qui permet de définir les risques et déterminer leur importance en fonction de la capacité productive de l'habitat du poisson. Une évaluation du risque écologique et une analyse du bénéfice écologique net ont été utilisées afin de déterminer les effets et les fonctions, respectivement, de l'ostréiculture dans la colonne d'eau au N.-B. Cette analyse nous a permis de conclure que l'*échelle des répercussions défavorables* de l'ostréiculture en colonne d'eau et la *vulnérabilité du poisson et de l'habitat du poisson* correspondent à une activité ayant un risque faible qui a peu de probabilité de nuire de façon importante à la capacité de productivité ou à l'intégrité écologique. De plus, notre analyse suggère que les huîtres en aquaculture peuvent potentiellement jouer un rôle bénéfique dans ces systèmes et servir à combler plusieurs fonctions écologiques qui ont été perdues suivant les déclins historiques des populations d'huîtres. Étant donnée la nature de cette activité, nous concluons que les risques associés à l'ostréiculture dans la colonne d'eau peuvent être gérés de manière durable à l'intérieur d'un cadre de gestion adaptive qui comprend des mesures adéquates de planification et d'atténuation des impacts.

1 HABITAT MANAGEMENT QUALITATIVE RISK ASSESSMENT OF WATER COLUMN OYSTER AQUACULTURE IN NEW BRUNSWICK

1.1 Introduction

The Habitat Protection and Sustainable Development (HPSD) section of the Department of Fisheries and Oceans Canada (DFO) is responsible for evaluating potential environmental impacts on fish habitat associated with project development under the Habitat Management Program (HMP). DFO has been conducting environmental assessments of aquaculture impacts to fish habitat on a site-by-site basis under Section 35 of the *Fisheries Act* and coordinating the review of other federal authorities (FA) and expert authorities under the *Canadian Environmental Assessment Act* (CEAA). Given that the development of oyster aquaculture is among the growing activities in New Brunswick's (N.B.) coastal communities, the following qualitative risk assessment was conducted under the guidance of the HMP Risk Management Framework. This assessment of water column oyster aquaculture (i.e. suspended or off-bottom culture) integrates a thorough review of the relevant scientific information and a characterization of "works" (defined by CEAA) associated with oyster aquaculture, as it relates to fish and fish habitat *and the Policy for the Management of Fish Habitat*.

Risk is unavoidable and present in virtually every human situation. It is present in our daily lives, and in public and private sector organizations. The World Trade Organization (WTO) defines Risk Analysis as a "*systematic way of gathering, evaluating, recording and disseminating information leading to recommendations for a position or action in response to an identified risk*". Risk can be defined as a function of the probability of an adverse effect and the severity of that effect. In fact, this approach is used worldwide to manage the ever-changing uncertainties associated to human health, international trade, food safety, etc. (e.g. World Health Organization (WHO), WTO, Food and Agriculture Organization (FAO) Sanitary and Phytosanitary agreement, Hazard Analysis and Critical Control Point (HACCP)). Thus, a Risk Analysis is a tool intended to provide decision-makers with an objective, repeatable and documented assessment of the risks posed by an action. This approach recognises that every facet of life involves risks which can range from significant and adverse to negligible and inconsequential. Risks needs to be characterized, their significance assessed and thereafter managed to ensure a degree of comfort and control despite the uncertainties.

In context of the HMP Risk Management Framework, we define “Risk” as an event that has a specific likelihood of occurrence and identifiable impacts on the productive capacity of fish and fish habitat. A risk-based approach allows habitat managers to prioritize and focus efforts on regulating the activities which are considered to have the greatest potential impact to fish and fish habitat. This entails the review of available relevant information in order to categorize the risks associated with development proposals and associated management options. Through an objective and science-based decision-making process, activities are rated according to risk (e.g. low, medium and high) and then evaluated against the sensitivity of habitat and the scale of effects. This approach recognizes that high risk projects need to be managed differently than low risk projects. It is from this perspective that the following qualitative risk assessment of water column oyster aquaculture was prepared.

In collaboration with Maritimes Region and National Headquarters, a panel of scientists was brought together in 2006 under the *National Science Workshop: Assessing Habitat Risks Associated With Bivalve Aquaculture in the Marine Environment* National Assessment Process (NAP), to identify and characterize the potential environmental risks of bivalve aquaculture in the marine environment. The NAP was based on the peer review of working papers that addressed the identification, prediction, and measurement of the effects of marine bivalve aquaculture. The majority of the information presented at the workshop was based on the suspended culture of mussels on the east coast of Canada, but provided some indications as to the risk associated with bivalve culture in general. We have since undertaken the task of integrating the scientific advice which was relevant to water column oyster aquaculture into this Risk Assessment based on these frameworks and international definitions.

1.2 Regulatory context

In 1999, the Navigation Water Protection Program (NWPP) and CEAA recognized the need to consider aquaculture structures as having a fixed location and thus constituting a “work” under the *Navigable Water Protection Act* (NWPA). Therefore, these operations needed to be reviewed and approved under the NWPA. This led DFO to become a Federal Responsible Authority (FRA) for the review of aquaculture works under CEAA for the NWPP and a more formal federal review process which includes a fish habitat assessment under the habitat provisions of the *Fisheries Act*.

Following organizational changes in 2004, the responsibilities of FRA were transferred to Transport Canada (TC), with HPSD remaining involved on aquaculture files. To assist with that transition, DFO and TC developed a Memorandum of Understanding (MOU) whereby it was proposed that DFO help TC in the development of a Replacement Class Screening Report (RCSR) under section 19 of the CEAA to implement a more coherent approach in Environmental Assessment (EA) of these works. Rather than completing an EA for each project, the Act allows for the EA of some repetitive projects to be streamlined through the use of a class screening report. This signifies that if a project qualifies and meets the criteria set forth in the RCSR, it may not need an individual EA. This kind of report is built on and uses the knowledge accumulated through past environmental assessments of a given type of project. The class screening approach is considered compatible with an earlier proposal made by DFO to the New Brunswick Shellfish Aquaculture Environmental Coordination Committee (NBSAECC) operating under the 1995 Canada-New Brunswick MOU on aquaculture to develop an integrated shellfish aquaculture planning exercise. The Bay-by-Bay planning approach for aquaculture development was proposed to the Province of New Brunswick (aquaculture leasing and licensing is managed by the Province), in order to pre-define suitable areas for aquaculture based on an analysis of conservation and regulatory concerns of provincial and federal departments. It was presented to federal expert departments as a means to address cumulative impacts and inter-governmental regulatory concerns. The concept was accepted by the NBSAECC.

An initial pilot-project for the bays of Tabusintac and Richibucto was initiated in 2004. GIS databases were used to identify Valued Ecosystem Components (VECs) as well as potential conflicts with aquaculture works. Ecological reviews of the bays and layers of information, such as locations of bird colonies, avian species at risk, migrating and staging areas for waterfowl, fish habitat, wetlands, dunes, salt marshes, fisheries etc. were presented on maps. Potential use scenarios in conjunction with various management options were evaluated. This approach combined a number of GIS databases with current knowledge on user impacts to create an analytical tool to guide towards sustainable development. Zones were subsequently defined where shellfish leases could be best located to avoid potential spatio-temporal interactions with VECs. After a review of the pilot project results, the New Brunswick Department of Agriculture and Aquaculture (NBDAA) decided to continue the planning project, in collaboration with DFO and TC, for the remaining bays on the eastern coast of the Province.

1.3 Risk Analysis initiation

The current Risk Assessment expands on the scope of the evaluation of this activity and integrates the regulatory context which was required to support decision-makers in their review of water column oyster aquaculture works as they relate to fish and fish habitat. This is also compatible within the larger context of a Bay Management Framework developed in collaboration with the Province of New Brunswick. The geographic area for which the risk assessment was needed is Gulf New Brunswick (N.B.), but could also apply to Prince Edward Island (P.E.I.) and Gulf Nova Scotia (N.S.). In order to alleviate the remaining text, oyster aquaculture in N.B will refer to the Gulf portion along the eastern shore of N.B. and exclude the Bay of Fundy. The risk assessment was conducted to provide information to habitat managers about the potential effects of oyster aquaculture works and management options.

The format used for this assessment was inspired in part by the US Environmental Protection Agency Guidelines for Ecological Risk Assessment (ERA) (US EPA 1998). These types of tools are used to identify and characterize potential risks of the activity and to make a determination as to their significance as they relate to the productive capacity of fish habitat. In the HMP Risk Management Framework, this assessment is important for qualifying the residual negative risks after mitigation measures as well as subsequently determining options to manage the risks specific to the activity.

Additionally, because oysters in nature are recognized as providing beneficial ecological services and are often used as a compensation option for other works, a Net Environmental Benefits Analysis (NEBA) approach, as proposed by the US Department of Energy, was used to look at the potential gains minus the potential environmental costs of this activity (US Department of Energy 2003). Although the NEBA is not factored in to the HMP Risk Management Framework, we believe that a NEBA is consistent with the “Net Gain of Habitat for Canada’s Fisheries Resources” in the *Policy for the Management of Fish Habitat*. The policy states that the objective is to: “Increase the natural productive capacity of habitats for the nation's fisheries resources, to benefit present and future generations of Canadians”. We also believe that a NEBA can play a valuable role in considering the development of integrated management plans and in moving towards to DFO’s emphasis on an ecosystem approach.

The following diagram (Figure 1) illustrates how the two frameworks are used in parallel in this risk assessment on water column oyster aquaculture.

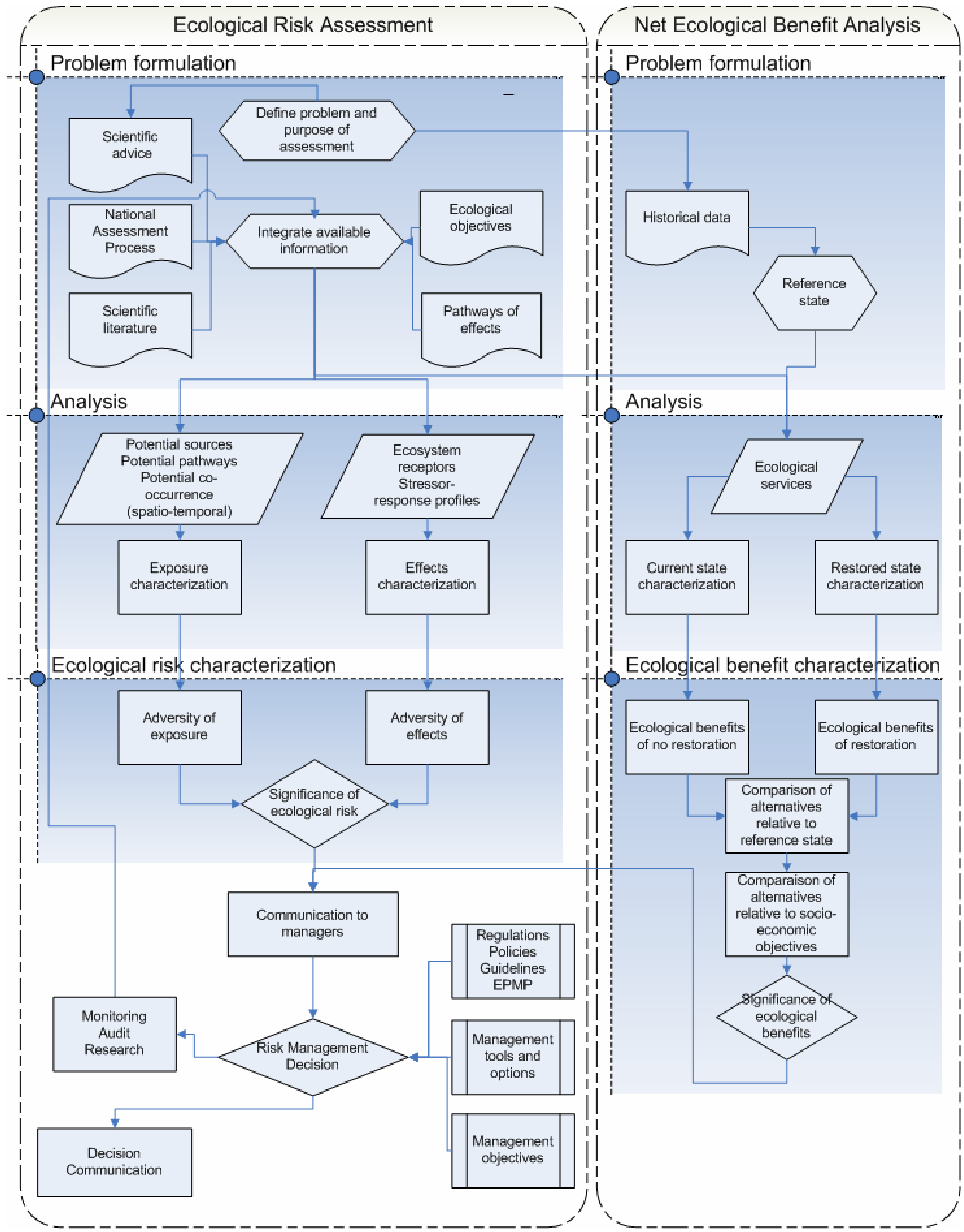

Figure 1 - Frameworks for Ecological Risk Assessment and Net Ecological Benefit Analysis

2 DESCRIPTION OF WATER COLUMN OYSTER AQUACULTURE

In the Maritimes, oyster culture is an activity which is usually practiced on a technically simple small-scale level. This activity is spread throughout coastal areas along the southern Gulf of St. Lawrence. In N.B, operations are mainly family owned; with a single proprietor for whom this is not their main occupation (75-90% of their income originates from other sources). The majority of these operations employ fewer than six employees, on a seasonal basis, but this number may range from one to sixteen employees. Most owners operate only one or two leases (Bastien-Daigle & Friolet 2006).

Procedures and activities associated with oyster culture in N.B. estuaries have a substantial history and record of development. Oyster aquaculture projects in New Brunswick have similar design, construction, operation and decommissioning characteristics. The following section summarizes the nature of the industry; the reader can consult Doiron (2006) for more detailed descriptions. Prince Edward Island and Nova Scotia use similar water column growing techniques. Prior to completing this risk assessment, a phone survey was conducted with individual growers to obtain an accurate picture of equipment and techniques currently in use (Bastien-Daigle & Friolet 2006).

2.1 Culture techniques

Unlike many parts of the world and the western region of Canada, where the exploitation of native species contributes little to commercial production (FAO 2005), the harvest and aquaculture of oysters along the Atlantic coast of Canada and the United States of America relies on a native species, the eastern oyster *Crassostrea virginica*. This species is found along the entire Northwest Atlantic seaboard, from Louisiana to N.B. with a large population in the southern Gulf of St. Lawrence (sGSL) (Kennedy *et al.* 1996).

In water column aquaculture, oysters are floated or suspended in the subtidal zones. Raising oysters above the substrate and placing them in bags or cages serves to enhance water circulation, water temperatures, and food availability. This in turn improves growth and decreases predation rates. Oysters grown in this manner are generally kept at low densities to help ensure that they can reach market-size within 3 to 4 years, rather than the 5 to 8 years normally required when grown on the substrate (DFO 2003b).

Presently, a variety of water column culture methods are used in N.B for growing oysters.; these include longline culture using bags, trays, or rope strings, or cages, and off-bottom culture using bags on French tables or on trestles. Provincial authorities define suspended culture as a form of aquaculture conducted in the water column or at the water's surface, where the structures are anchored but can float or move with the tides. They define off-bottom culture as being conducted in the water column where the structures are fixed in place on the substrate and do not move with the tides. The present risk assessment covers these two categories of techniques, commonly referred to as water column oyster culture. It does not include bottom culture, which is conducted directly on, or in, the substrate of an aquaculture site.

2.1.1 Suspended culture

Grow-out bags made of high density, UV-resistant polymer mesh (often referred to by the manufacturer's name, such as Vexar™ or Durethene® bags) are used to contain the oysters. The bags are either equipped with individual floats and attached to a longline system or inserted in a cage structure equipped with floats. Bags measure 85 cm (long) by 40 cm (wide) by 10 cm (high). The density of oysters in the bags is progressively reduced over the 3-4 year grow-out period as the oysters grow (Doiron 2006). Initially, 15-25 mm oysters are placed at densities of 1000-1500 oysters per bag (2-3 kg). In the final year of production, oysters typically measure 50-75 mm and are held at densities of 200-250 per bag (4-6 kg) to ensure adequate growth and a desirable shape (i.e. choice or fancy grade rather than commercial or standard) (Doiron 2006).

In the longline system, grow-out bags are lie flat on the surface of the water with one buoy on each side and secured by parallel lines anchored to the bottom (Figure 2). The most common design usually consists of two rows of approximately 50 floating bags, but many variations of this system can be observed. Two main anchors maintain the longline in a fixed location; these consist of concrete blocks, metal anchors or screw anchors. The lines are kept separated by spreader bars installed approximately every ten bags. Growers can adjust the buoyancy of the grow-out bags by changing the location of the buoys on the bags. Each longline system measures approximately 60 m from anchor to anchor, and is spaced 6-10 m from other longlines to provide water circulation around the bags and boat access for regular maintenance. Growers typically install 15 to 20 longlines per hectare. Longlines are usually oriented along the most appropriate axis to reduce wear from tides and currents on equipment.

Cages are made of a plastic coated wire-meshed material (similar to the Aquamesh used in many lobster traps) and are designed to contain between 2 to 6 grow-out bags; six being the most common configuration. The grow-out bags are placed in divided sections of the cage, which function as drawers. In order to ensure adequate water circulation, no more than two bags are placed over one another. Each cage is equipped on the upper side with two buoys allowing it to float immediately below the water surface. Buoys can be made of a variety of materials, including Styrofoam and PVC. The cages are secured either by using single anchors or by attaching them to longlines. Generally, growers will install 12 cages per 50 m longline with a maximum of 20 lines per hectare (240 cages/ha). As above, lines are separated by a corridor to allow boat access.

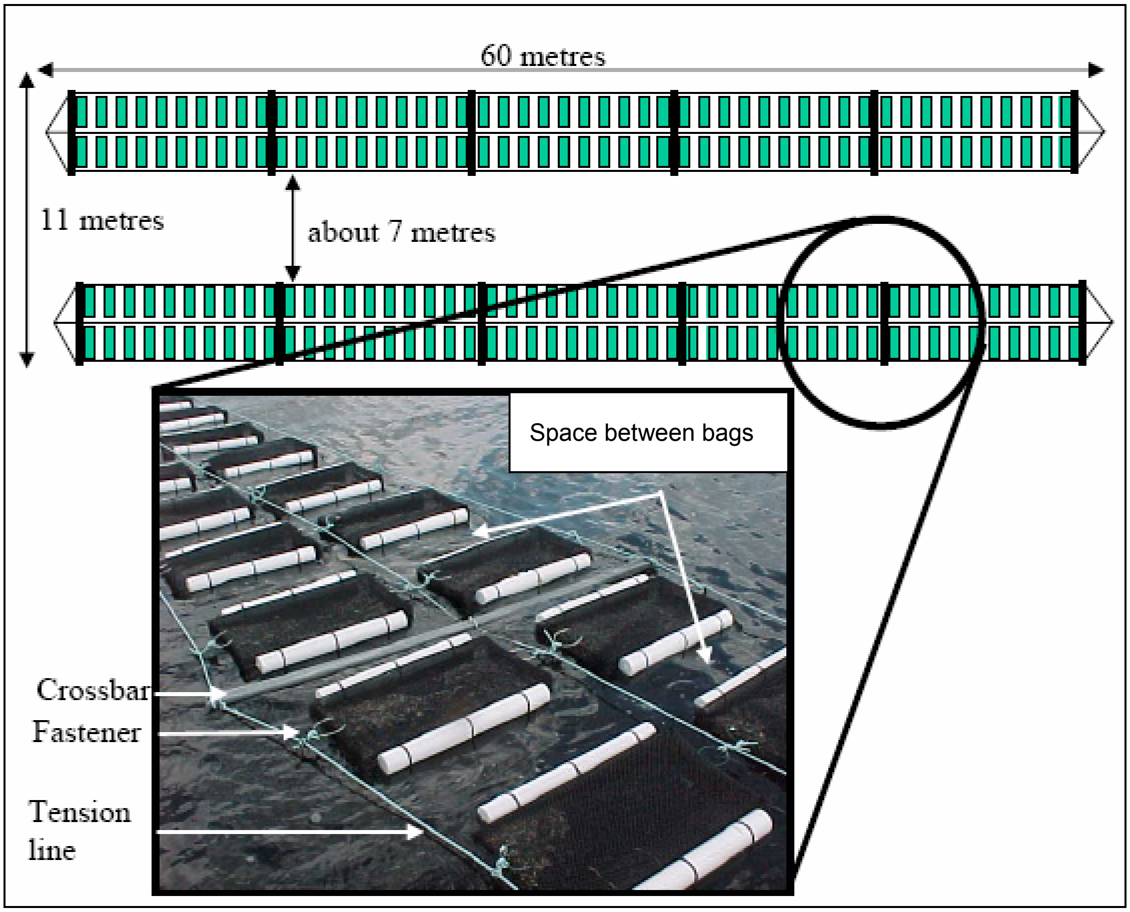

Figure 2 - Description of the longline structures used in N.B. (modified from Doiron 2006)

A less common suspended technique is known as rope culture, whereby clusters of oysters are attached directly to a rope at regular intervals (without any housing). Ropes are suspended in the water column or floated at the water surface level using specifically designed supports, which function similar to longline systems. Oysters cultured on rope remain submerged at all times.

2.1.2 Off-bottom culture

Oyster tables, also known as French tables, consist of a metal rod structure on which grow-out bags containing the oysters are supported. This platform raises the bags sufficiently to ensure water circulation around the oysters. Depending on the site, oysters can be uncovered during each tidal cycle or remain constantly submerged. Another off-bottom technique consists of raising the oyster bags on runners or pipes placed on the sediment. Both of these techniques typically require setting the structures in sections of the lease with little or no eelgrass to ensure proper water circulation. Oyster tables and runners are removed at the end of the growing season to avoid ice damage.

2.1.3 Site preparation

Unlike some types of on-bottom shellfish aquaculture that require extensive bottom preparation (e.g. dragging, additions of gravel, dredging, removal of vegetation, etc.), no specific site preparation activities are required for water column oyster aquaculture sites other than installing the equipment and anchors.

2.2 Installation

The installation of structures is generally done from a boat or from the ice surface during winter. For longlines, anchors are installed either directly on the marine sediment (concrete blocks) or driven into the sediments (anchors). In general, the anchoring system is designed to be permanent. French tables and runners are installed directly on the substrate but are removed seasonally.

2.3 Operation

Maintenance of the inventory includes stock rotation and reducing the density of oysters to ensure optimum growth and quality; this may occur 2 to 3 times during the growing season. As the bags float at the surface of the water, with one side submerged and the other exposed to air, fouling by epifaunal plants and animals can be removed simply by turning the bag (180°) to allow the attached organisms to desiccate or by pressure washing. The frequency of this maintenance depends on the growth of epifauna which varies during the season; being more pronounced in the summer and less so in the fall. In general, air drying takes a few days. Oyster culture does not require food supplements, treatment with pharmaceuticals, disinfectants, or hormones.

2.4 Oyster spat collection

Oyster spat or oyster seed can be collected by the producer or can be purchased from other local growers. Oyster seed can only be collected from approved oyster collection areas or on private leases. Oysters typically spawn between early and mid-July depending on latitude and annual conditions. A variety of collectors are used to attract oyster larvae, which preferentially settle on clean and textured surfaces. It is critical to deploy these collectors in the appropriate areas at the correct time. After approximately two to three weeks of drifting in the currents, competent larvae cement themselves to the collector's surface. Afterwards, when oyster seed reach a sufficient size, the collectors are transferred to the lease (if seed are not collected from the lease area itself). Depending on their size, the seed oysters are stripped from the collectors in the fall or the following spring, sorted by size and transferred to the grow-out bags.

2.5 Overwintering

In much of gulf N.B., the upper water column freezes in winter. In order to protect the oysters, structures must be overwintered in below the depth to which the ice can extend or in areas that are not prone to ice jams, or frequent ice movement. Typically, oysters are moved to the deepest portion of the aquaculture site and sunk to the bottom during the winter months. This period corresponds to a period of dormancy for the oysters, where filtration and feeding effectively stop.

Oysters are overwintered in bags or cages. The longlines can be either submerged below the surface, deep enough to avoid the ice, but not touch the seabed (using weights to counter the buoyancy of the equipment), or the floats are removed from the bags/cages and the structures are allowed to lie on the substrate. Sunken lines are located by GPS or by triangulation to facilitate retrieval during winter harvesting or for re-suspension. Oysters are re-deployed to the grow-out site the following spring; re-suspension is carried out as soon as possible after ice break-up.

2.6 Harvesting

Harvesting occurs when oysters reach marketable size. During the ice-free period, harvesting is generally done by boat; grow-out bags are light enough to be removed by hand from the structures and loaded onto vessels. The heavier cages may require a winch to hoist them onto the boat. The transport boat typically unloads the bags and product at a landing from where it is delivered by truck to a processing facility.

During the winter harvesting, the overwintering sites are typically accessed by all terrain vehicles or snowmobiles. An access hole is cut through the ice with a chain saw or auger and a portion of the stock is retrieved manually or with the use of manually-operated hydraulic equipment. Divers may be required to assist in retrieval of the stock.

2.7 Predator Control

Predators are of greatest concern during the spat collection phase when oysters are small and not protected within the grow-out bags. In some cases, predators such as crabs and starfish are controlled by dipping the collectors for a few seconds in a freshwater or diluted lime bath. Competitors or predators found within the grow-out bags are manually removed during regular maintenance activities.

In gulf N.B. oyster culture, there are no control measures which could harm marine life such as birds or mammals (i.e. anti-predator nets, acoustic scaring devices, etc.). The need for predator removal is rare in the case of off-bottom oyster culture, because the stock is protected within the grow-out structure.

2.8 Decommissioning

Within 90 days of cessation of aquaculture activities, the holder of the aquaculture occupation permit or the aquaculture lease is required under provincial jurisdiction (N.B. *Aquaculture Act*, 1988, c. A-9.2, and 91 158 of the N.B. Regulation under the *Aquaculture Act*) to restore the site to the satisfaction of the Minister. If the holder does not restore the aquaculture site within the prescribed time or in a manner considered satisfactory by that authority, NBDAA will have the site restored, and the holder will be liable for all restoration costs.

3 RISK MANAGEMENT FRAMEWORK

The Risk Management Framework is intended to provide a structured approach to decision-making that takes into account the concepts of risk, uncertainty and precaution. A Risk Assessment is a process used to determine the level of risk that residual effects pose to fish and fish habitat based on the information currently available. Risk Assessments are used to determine the technical parameters that are useful and feasible for risk management.

To assess risk to fish and fish habitat, one must consider the severity of the effects in the context of the sensitivity of fish and fish habitat being affected by the activity. The Risk Assessment Matrix (Figure 3) incorporates these two factors in order to characterize the level of risk posed by the development proposal on the productive capacity of fish habitat. The rationale used to locate the residual effects on the matrix forms the basis for decision-making.

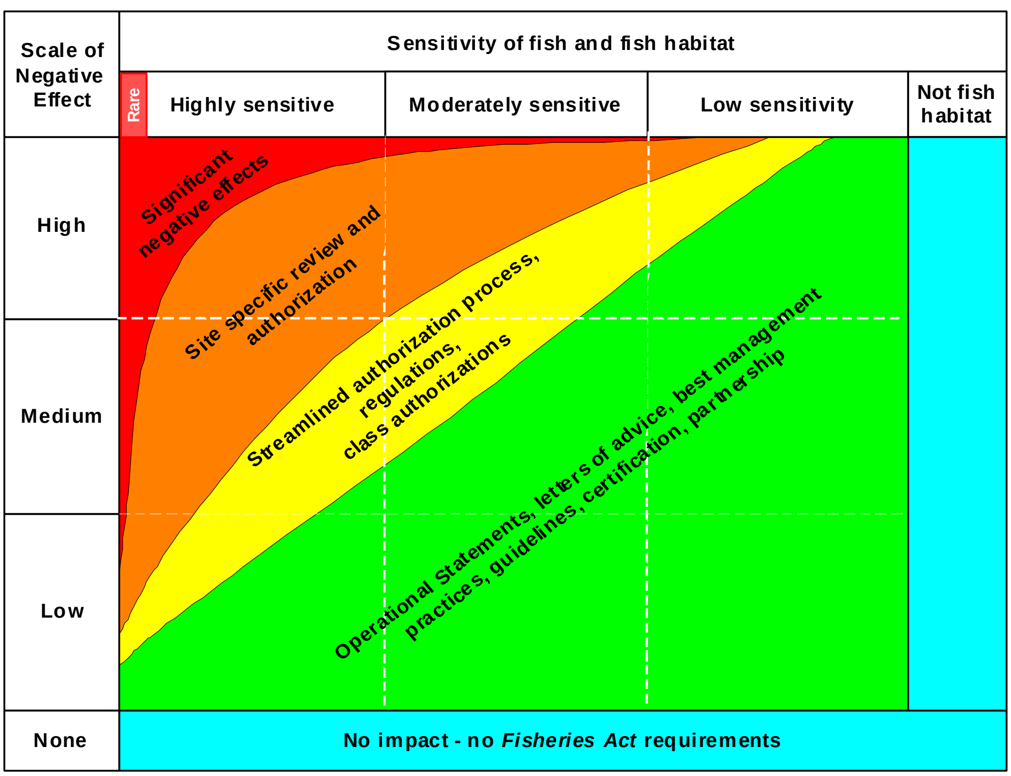

Figure 3 - DFO Habitat Management Program's Risk Assessment Matrix

3.1 Scale of negative effects

The following attributes are used to scale residual effects on the y-axis of the risk assessment matrix (Table 1) and are adapted to aquaculture. Ratings are assigned to evaluate the predicted effect of the activity. For every effect, the degree of adversity of each attribute is assessed and this helps to determine the overall residual effect significance.

Table 1 - Attributes used to describe the scale of negative effects to fish habitat

Criteria	Importance level rating		
	Low	Medium	High
Magnitude	Localized effect on specific group, habitat, or ecosystem, returns to pre-Project levels in one generation or less, within natural variation	Portion of a population or habitat, or ecosystem, returns to pre-Project levels in one generation or less, rapid and unpredictable change, temporarily outside range of natural variability	Affecting a whole stock, populations, habitat or ecosystem, outside the range of natural variation, such that communities do not return to pre-Project levels for multiple generations
Geographic Extent	Limited to aquaculture footprint and vicinity	Limited to aquaculture lease and vicinity	Extends beyond the aquaculture lease area
Duration of Effect	Less than one season	Less than one year	A year or longer
Frequency of Effects	Occurs on a monthly basis or less frequently	Occurs on a weekly basis	Occurs on a daily basis or more frequently
Reversibility	Effects are reversible over short term without active management	Effects are reversible over short term with active management	Effects are reversible over extended term with active management or effects are irreversible

3.2 Sensitivity of fish and fish habitat.

The sensitivity of fish and fish habitat (represented by the x-axis of the matrix) can be defined in relation to the degree and duration of damage caused by a specified external factor. Sensitivity may refer to the structural fragility of the entire habitat in relation to a physical impact, or to the intolerance of individual species comprising the habitat to environmental factors, such as exposure, salinity fluctuations or temperature variation.

Habitat can be defined as "the structural component of the environment that attracts organisms and serves as a center of biological activity" (Peters & Cross 1992 cited in Auster & Langton 1998). In this example, habitat would include the range of sediment types (e.g. mud, sand, pebble, etc.); and bed forms (e.g. sand waves and ripples, mudflats, etc.) as well as the co-occurring biological structures (e.g. shell, burrows, submerged aquatic vegetation, etc.). Defining sensitivity for all these components is problematic. Ideally, models of sensitivity indices for specific habitats, communities, and key taxa-based on the effects of specific activities, levels of effort, and life history patterns (of both fish and taxa which serve a habitat function) would be developed (Auster & Langton 1998). Such indices are not currently available; as a substitute, the *Habitat Management Policy* recommends the use of a matrix analysis to determine the sensitivity of fish and fish habitat.

This matrix uses general qualifiers to describe fish and fish habitat attributes (summarized in Table 2). Sensitivity is defined in terms of species or habitat susceptibility to changes and perturbations as result of an activity or modifications in environmental conditions, such as suspended sediments, water temperature or salinity. Dependence is defined in terms of the use of habitat by fish species; for example, some species may be able to spawn in a wide range of habitats, while others may have very specific habitat requirements. Rarity is defined in terms of the relative strength (abundance within a range) of a fish population or the prevalence (ecological redundancy) of a particular type of habitat in a community. Resilience refers to the ability of an aquatic ecosystem to recover from changes in environmental conditions.

Table 2 - Attributes used to define sensitivity of Fish Habitat

Criteria	Importance level rating		
	Low sensitivity	Moderately sensitivity	Highly sensitivity
Sensitivity	Species/habitat present are not sensitive to change and perturbation	Species/habitat present are moderately sensitive to change and perturbation	Species/habitat present are highly sensitive to change and perturbation
Dependence	Not used as habitat; or used as migratory habitat only	Used as feeding, rearing, and/or spawning habitat	Habitat critical to survival of species
Rarity	Habitat/species is abundant within its range or community; ecological redundancy is widely present	Habitat/species has limited distribution; is confined to small areas; ecological redundancy is present	Habitat/species is rare; ecological redundancy is absent
Resiliency	Species/habitat is stable and resilient to change and perturbation	Species/habitat is stable and can sustain moderate level of change and perturbation	Species/habitat is unstable and not resilient to change and perturbation

4 ECOLOGICAL RISK ASSESSMENT

Ecological risk assessment is based on the characterization of the potential effects and characterization of exposure (US EPA 1998). Effects are linked to ecosystem receptors and stressor-response profiles. Exposure is linked to potential pathways of effects, potential sources and potential co-occurrence. Exposure is also related to the scale and intensity of activities. The scope of this ecological risk assessment focuses on water column oyster aquaculture as it relates to fish and fish habitat.

4.1 Effects characterization

4.1.1 Potential pathways of effects

The analysis of the potential pathways of effects is largely based on information contained in the NAP documents (Anderson *et al.* 2006, Chamberlain *et al.* 2006, Cranford *et al.* 2006, DFO 2006, McKindsey *et al.* 2006a, Vandermeulen *et al.* 2006) as well as the Statement of Knowledge (SoK) reports (DFO 2003a). These various papers, which undertook comprehensive reviews of the science available, provide extensive details on shellfish aquaculture in general and aid in the specific characterization of the potential effects of water column oyster aquaculture. Consequently, the following sections only discuss some of the major points in a cursory manner.

Many of the adverse effects and concerns in the conclusions from the NAP were linked to studies conducted in Tracadie Bay, P.E.I. Much of the discussion and most of the modeling results presented focused on the evaluation of carrying capacity for this bay, which is one of the most intensively cultured and studied bays for shellfish aquaculture in the Gulf Region. Approximately 40% of Tracadie Bay's surface is leased for mussel cultivation, with an annual mussel production of 2,000 t. From 1990 to 2001, the leased area grew from approximately 20% to 40%, while the biomass of mussels increased by over 300%. This corresponds to an atypical scenario and is not considered entirely representative of other bays or other types of shellfish production in the region. Tracadie Bay has thus become a focal point for research on the negative environmental effects of shellfish aquaculture. However, it remains unclear as to the net effects of the culture on the overall productivity of the bay even in these circumstances. Miron *et al.* (2005) found that the absence of a strong relationship between husbandry practices and the studied benthic parameters might be related to the oceanographic characteristics and land-based activities associated with the water system rather than direct and cumulative effects of mussel culture. Nonetheless, the NAP highlighted a series of concerns with regards to bivalve aquaculture in general which are useful in this analysis. The reader may also refer to the documents listed above for more information on benthic and water column effects.

Potential effects can be linked to the presence of oysters and the presence of structures in the water. In the particular case of oyster aquaculture, one must also understand the functional effects of natural oyster populations in an attempt to understand their role in aquaculture operations. Interactions in the coastal zone between farmed bivalves and other organisms are highly complex. Net habitat effects of bivalve aquaculture are difficult to disentangle from effects of other anthropogenic activities (McKindsey *et al.* 2006a). In addition, net pathways of effects on the environment can be both negative and positive. Figures 4 and 5 represent simplified views of some of the complex ecological interactions that can occur in relation to bivalve aquaculture. The scientific literature indicates a variety of levels of effects of bivalve farming activities on the many compartments of estuarine ecosystems.

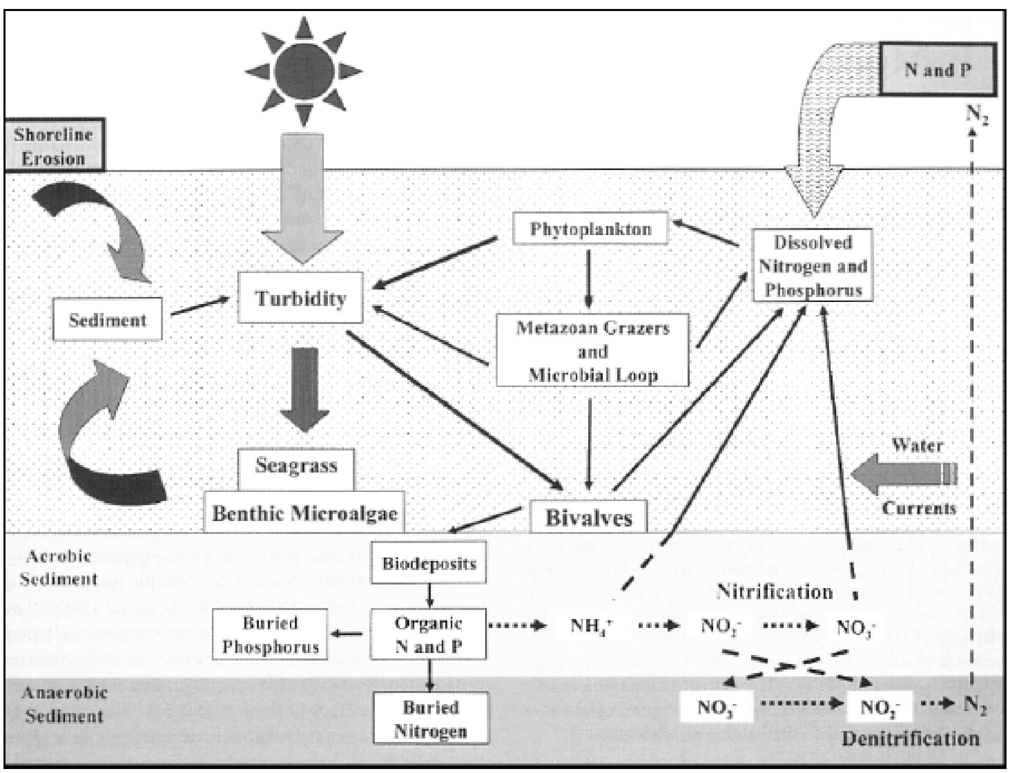

Figure 4 - Conceptual diagram of the ecosystem effects of suspension-feeding bivalves. Solid lines indicate transfer of materials; dashed lines indicate diffusion of materials; dotted lines indicate microbially mediated reactions (Vandermeulen 2006 from Newell 2004).

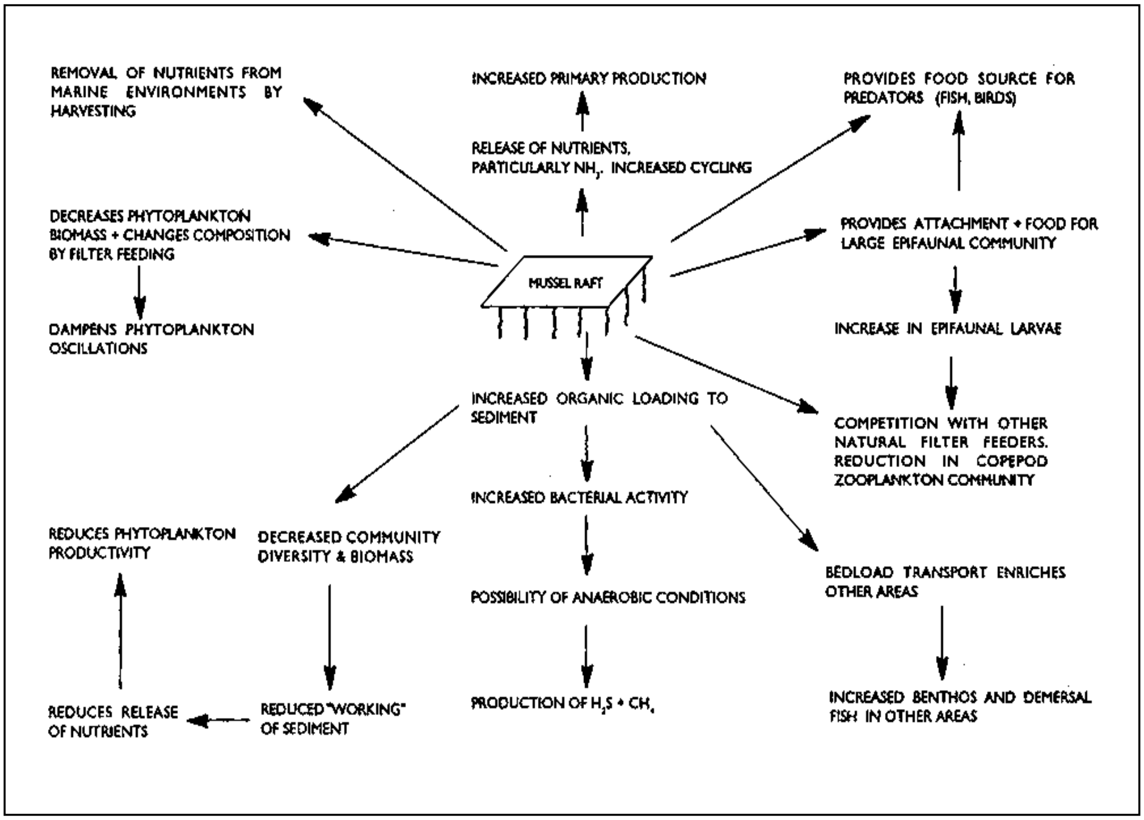

Figure 5 - Potential pathways of effects from mussel culture systems; (FAO 2006)

4.1.2 Potential sources

Potential sources of effects that can be expected from shellfish aquaculture have been identified by ICES (2004) and only the effects relevant to fish and fish habitat are summarized in the table below (Table 3).

4.2 Exposure characterization

4.2.1 Adversity of exposure and effects

DFO used the lists of pathways of effects and endpoints of concerns to scope potential interactions between oyster aquaculture and Valued Ecosystem Components (VECs). A compilation of mitigation measures currently requested of the industry to protect fish habitat was done and applied in the analysis of effects (Table 4). The information provided by the NAP, scientific literature, and monitoring results was also used in the evaluation of the potential residual negative effects to fish habitat.

Table 3 - Summary of steps in bivalve aquaculture and their potential to influence fish habitat. Based on ICES 2004 and adapted to N.B. water column oyster aquaculture.

1.	Seed collection	
a.	artificial collectors	
i.		removal of juveniles from wild population of target species
ii.		increasing recruitment success of oysters or other species
iii.		alteration of the hydrodynamic regime
iv.		acting as fish attraction device (FAD)
2.	Grow-out	
a.	effects common to all techniques	
i.		organic enrichment of seafloor
ii.		alteration of hydrodynamic regime (current speed, turbulence)
iii.		food web effects: competition with other filter feeders, increasing recycling speed of nutrients
iv.		providing food for predators of shellfish
v.		control of predators and pests
vi.		acting as artificial reef or FAD (attraction/displacement or enhancement of animals)
b.	artificial structures (trestles, poles, rafts, longlines)	
i.		risk of attraction of birds
ii.		risk of damage to eelgrass
3.	Harvesting	
a.	effects common to all techniques	
i.		removal of biomass/nutrients
ii.		removal of non-target species
iii.		competition with predators
b.	collection of off-bottom structures	
i.		risk of trampling of substrate and vegetation
4.	Processing	
a.	effects common to all techniques	
i.		discard of epibionts
ii.		discard of shells

Table 4 - Review of potential ecological concerns of water column oyster aquaculture.

PATHWAY OF EFFECT	CONCERN	POTENTIAL EFFECT	DURATION OF EFFECT	MITIGATION / OBSERVATIONS
Addition of physical structure in the water column	Changes in physical environment	Physical structures can modify the hydrodynamic patterns of water movements by impeding or altering water flow.	Grow-out period	• Site infrastructure is required to be aligned with dominant currents to minimize impacts on water flows. • Minimal spacing recommended between structures of 3 m (industry currently spaces structure 7-10 m apart) • NWPA prohibits works in navigation channels. • Structure is considered permeable to fish and marine mammals, no leader, net or entrapment mechanism that could impede migration or organism movement. • No leader, lures, nets or other obstacles that could impede movement, cause entanglement or attract predators.
		Physical structures can change flow patterns and increase sedimentation under the structures.		
		Physical structures may become obstacles for the movement or reproduction of organisms.		
		Overwintering of physical structures may affect benthic fauna or flora.	Overwintering period	• Minimal concern as bags is typically overwintered during the period of dormancy for most organisms. • Overwintering is generally conducted in deeper waters where presence of flora is limited. • Re-suspension is done as early as possible after ice-out to reduce losses.
	Changes affecting species composition	Physical structures in the water column may displace certain organisms from the footprint of the structure.	Grow-out period depends on local husbandry methods and faunal community	• In water column oyster aquaculture, the footprint which can exclude organisms from an area is considered minor. • Oysters not available to predation within grow-out bags. • No lures or bait that could attract predators or scavengers. Oysters not within diet of large marine predators, such as seals. • Presence of epibionts on or falling off structures may attract crustaceans, fish and birds.
		Physical structures in the water column create habitat for organisms by providing a substrate similar to the effect of an artificial reef.		

PATHWAY OF EFFECT	*CONCERN*	*POTENTIAL EFFECT*	*DURATION OF EFFECT*	*MITIGATION / OBSERVATIONS*
		Structures provide a hard substrate for opportunistic organisms or also for colonizing organisms which can serve as food for fish and invertebrates.		• Preliminary studies suggest that species diversity near structures appears to be maintained although the species composition may be altered. • Proponent has to select its site, deploy its structure and adopt appropriate husbandry practices to minimize colonization of other organisms.
		Structures may affect aquatic *Species At Risk Act* (SARA).	Grow-out period	• No species currently listed in N.B. estuaries. • Potential risk of spatio-temporal interaction between water column oyster aquaculture and aquatic SAR is not significant given the spatial area where culture occurs.
	Changes in light penetration	Physical structures in the water column may reduce the light availability to flora (i.e. eelgrass) directly under the structures.	Tidal dependant	• Siting of off-bottom aquaculture in eelgrass-free areas. • Minimal spacing of off-bottom aquaculture works at minimum of 3 m, not to exceed 50% coverage of the site. (industry currently spaces structure 7-10 m apart) • Suspended aquaculture is to be anchored to allow swaying with each tidal cycle and to avoid continuous shading of the same area of eelgrass. • Structures are to be designed and installed to maximize opening to increase light penetration. • The footprint of structures on the benthos is small.
Addition of filter feeding bivalves	Changes in population interactions	The oysters maintained in water column aquaculture may reproduce with wild populations of oysters.	Spawning period	• Not a concern given that the oysters are recruited yearly from wild sources and not from hatcheries.
		The addition of oysters may cause a competition for space with other organisms.	Grow-out period	Not expected to be an issue given that oysters are held in the artificial structures in the water column which create additional space.

PATHWAY OF EFFECT	***CONCERN***	***POTENTIAL EFFECT***	***DURATION OF EFFECT***	***MITIGATION / OBSERVATIONS***
		The addition of filter feeding bivalves in the water column may cause removal of eggs and larvae of fish and benthic organisms.	Sporadic, during egg and larval stages – within size preference for oysters	• Not expected to be an issue given that *C. virginica* is the native species of oyster and population interactions with that species are expected to be similar in aquaculture as they are under natural conditions. • Demonstrated preference by oysters for microzooplankton as opposed to mesozooplankton. • Narrow range of opportunity if within immediate vicinity of feeding current vs. total surface of estuaries. • Adaptation mechanisms within bivalve populations to limit egg and larval predation of con-specifics. • Observed presence of higher diversity of species within natural oyster beds (including other bivalves).
		The addition of oysters to the water column may attract predators.	Seasonal	• Oysters are protected within the grow-out bags, except for a limited time while on collectors. • Fouling organism fall-off from growing structure may add food to benthos. • Additional gametes and larvae may contribute to food web. • No documented evidence of large predators near these sites. • Not a preferred food-source for large predators.
	Changes in plankton abundance	The additional biomass of filter feeding bivalves to the water column may cause a depletion of plankton.	Grow-out period	• Not expected to be an issue given that *C. virginica* is the native species of oyster and population interactions with that species are expected to be similar in aquaculture as they are under natural conditions. • Current densities are lower than historical densities found in natural populations throughout the region.

PATHWAY OF EFFECT	*CONCERN*	*POTENTIAL EFFECT*	*DURATION OF EFFECT*	*MITIGATION / OBSERVATIONS*
	Changes in water quality	The addition of filter feeding bivalves to the water column may remove significant quantities of particles from the water column that can reduce turbidity.	Grow-out period	• This effect is largely considered to be beneficial by reducing turbidity, thus favouring the growth of aquatic vegetation.
	Changes in nutrient cycles	The addition of filter feeding bivalves to the water column may play a significant role in recycling nutrient and benthic/pelagic coupling.	Grow-out period	• This effect is largely considered to be beneficial by removing excess nutrients through bivalve feeding as well as harvesting.
	Changes in organic enrichment	Biodeposition from faeces and pseudofaeces may increase sedimentation and enrich the benthos which could affect benthic geochemistry and organisms.	Grow-out period	• Not expected to be an issue under current stocking oyster densities and given seasonal nature of operations. Bays where water column oyster aquaculture sites occur in N.B. are characterised as dynamic shallow water systems with frequent resuspension of upper layers of sediment by wind, wave, tides, storm-events and ice-scour which likely reduce the effect of biodeposition.
Husbandry Activities	Changes caused by equipment installation	Equipment installation and regular maintenance activities at the site may temporarily increase turbidity	Sporadic, during installation and maintenance activities	• Access to the intertidal zone by motor vehicles other than boats is prohibited under provincial regulations, unless operating such vehicle on ice or frozen ground that is completely covered by snow.
		May cause physical damage to the eelgrass.		• Anchors are to be sized and installed to minimize dragging, preferably during winter (eelgrass dormant period). • Trampling, anchoring in eelgrass, are to be minimized.
	Discard of epibionts	Discards of epibionts during maintenance may be deposited to the benthos.	Sporadic during maintenance activities	• Air-drying of the equipment through bag turning is the recommended method of removal in the aquatic environment. • Disposal and recycling of waste on land is controlled by provincial and municipal regulations

PATHWAY OF EFFECT	***CONCERN***	***POTENTIAL EFFECT***	***DURATION OF EFFECT***	***MITIGATION / OBSERVATIONS***
	Discard of shells	Discards of shells during maintenance may be deposited to the benthos.	Sporadic during maintenance activities	• Not expected to be a significant issue, discouraged by industry to prevent spread of boring sponge (*Cliona celata*) • Incidental loss of small quantities is considered positive for habitat creation
	Use of artificial food, pharmaceuticals or chemicals	Potential to release undesirable compound into the environment during production or cleaning activities.	Grow-out period	• Bivalve aquaculture does not require the use of artificial food, pharmaceuticals or chemicals for production purposes. • Air drying is the typical method for cleaning equipment in the aquatic environment. Pressure washing with water is also used although less frequently. These methods do not require chemical cleaning agents. • Use of lime bath to remove predators on collectors is sporadic.

4.2.2 Scale and intensity of exposure

Concerns with regards to the adverse effects of bivalve aquaculture appear to be linked to the scale and intensity of aquaculture rather than the type of culture or infrastructure used (McKindsey *et al.* 2006b). In aquaculture, the scale and intensity is typically related to the rearing density of the animals (numbers per area) and to the extent of the activity (area occupied) (i.e. the level of exposure). Exposure is a function of sources, distribution and co-occurrence in space and time between an effect and the receiving environment. The following sections attempt to characterize the scale and intensity of oyster aquaculture in the sGSL.

4.2.2.1 Oyster production in the Maritimes

It is difficult to obtain precise landing values from oyster aquaculture in the Maritimes because of the way statistics on oyster production are collected and estimated. For instance, DFO keeps records of oyster purchases, as reported on sales slips, including data on both commercial wild-harvested and aquacultured oyster statistics and it is not currently possible to disentangle the respective proportion of cultured versus fished oyster from the values reported.

The Province of N.B. estimates aquaculture production based on an assessment of the number of oyster growing bags in use. In 2004, for example, the Province estimated that 165,000 oyster bags were in production, with an average of 500 oysters per bag, which would have signified approximately 82.5 million oysters (Government of New Brunswick 2004). Only one fourth of these would have been available for harvest (production time of 4 years), which would amount to 20.6 million harvestable oysters (approximate size of 60 mm @ 39.10g/oyster for an approximate total of 805t) (Government of New Brunswick 2004). Robichaud (unpublished) conducted an audit of oyster aquaculture leases in N.B. in 2006 and arrived at a slightly lower estimate of approximately 140,000 bags.

A comprehensive survey (interviews, boat and aerial photography) of oysters under production in N.B. concluded that between 990 and 1,249 tonnes of oysters (all sizes included) were under cultivation in 2005 (Comeau *et al.* 2006). The discrepancy in production estimates between the three main sources of information (producers, government officials and sales slips) illustrates some of the difficulty in quantifying actual production. Comeau *et al.* (2006) estimated the actual production of marketable oysters in 2005 to have been 679 t from aquaculture and 75 t from commercial harvesting, which puts the estimated total landings at 754 t.

4.2.2.2 Scale of oyster aquaculture production

According to Morse (1971) interest in oyster farming, characterized by an expansion in the number of leases and the development of seed production facilities and assistance programs, began in earnest in the Maritimes in the 1940's. Twenty years later, in 1966, it was estimated that 87% of the total landings of oysters could be attributed to the public fishery and 13% from public lease production.

Attempts have been made to project future landings by Unic Marketing which estimated that the future contribution of aquaculture would gradually begin to increase and that it would equal the contribution from the wild fishery by 2010 (Unic Marketing Group Ltd 2003). However, based on the numbers above, it appears that these predictions have failed to materialize and that aquaculture production remains below expectations. Landings from aquaculture production may only be gradually replacing commercial landings, perhaps because natural oyster reefs continue to be depleted (C. Noris, personal communication) and/or the industry may not be expanding as rapidly as initially predicted.

4.2.3 Relative intensity of aquaculture production

The intensity of aquaculture production has been equated with densities of bivalves under production for a specific surface area, or annual yield. Moreover, the culture intensity and yields speak in part to the concept of carrying capacity.

Comeau *et al.* (2006) calculated that average densities of oysters grown in N.B. were seven times lower than densities used in Normandy, France. The biomass of oysters (0.23 kg/m^2 of leased area) in N.B. by comparison to mussels or with oysters cultured in other areas in the world (10 – 85 kg/m^2) is considered to represent a low intensity production (Comeau *et al.* 2006). In Spain's Rias Bajas, one raft (average 19 x 16m) is estimated to produce 50 metric tons, or 164 kg/m^2 (Tenore *et al.* 1982). This is one of the highest reported protein yields per unit area and is only possible given the nutrient-rich upwelling conditions and high primary productivity observed in this region. To illustrate the range of densities used in oyster aquaculture, the following table (Table 5) shows oyster densities reported in the literature, along with reported environmental effects. By comparison to the scale and intensity of these operations, oyster aquaculture densities used in the Maritime Provinces, which are among the lowest described in the literature, constitute a low-intensity culture situation.

The comparison of yields and reported effects also provides some indications of thresholds of exploitation, as well as site-specific environmental conditions, that can occur and in which detectable and significant negative impacts can be observed. We are unaware of any study which can demonstrate significant adverse effects of bivalve culture at the densities observed in New Brunswick water column oyster aquaculture.

It is also interesting to note that the transition to off-bottom culture resulted in an actual reduction of stocking densities of oysters compared to on-bottom operations and natural oyster reefs. Moreover, oyster densities in natural reefs are estimated to have been 17 to 530 times greater than those currently measured in aquaculture (Comeau *et al.* 2006). Oysters in natural and healthy oyster reefs (Table 6) occur at densities in excess of hundreds of oysters/m^2 (500 – 4,000 oysters/$m^{2,}$ roughly equivalent to 25 to 55 kg/m^2) (DeAlteris 1988; Paynter 2002; Harris 2003).

Table 5 - Yields of oysters produced in aquaculture, from temperate ecosystems, converted when applicable to a standard equivalent of metric tonnes per hectare per year (McKinnon et al. 2003)

Species	Region, country	Average yield t ha^{-1} yr^{-1}	Method	Reported environmental effects			Reference
				Benthic infauna / epifauna	Organic / inorganic loading	Redox / sulphides	
C. gigas	Tasmania, (Australia)	20	Longlines	No significant differences in benthic infauna	No significant trends in organic carbon along farm transects	No negative redox measurements found beneath farms	(Crawford *et al.* 2003)
C. gigas	River Exe, (England)		Trestles	Decreased abundance of macrofauna (half) restricted to footprint	Increased sedimentation rate, increased organic content (footprint)	Reduction in depth of oxygenated layer (footprint)	(Nugues *et al.* 1996)
C. gigas	Arcachon (France)	13	Tables	Increase in meiofauna abundance (3-4 times) and decreased macrofaunal abundance (half)	Elevated organic carbon levels (footprint)	Elevated oxygen demand and anoxic conditions	(Castel *et al.* 1989)
C. gigas	Thau (France)	10	Rafts, "semi-intensive"				(Chapelle *et al.* 2000)
C. gigas	New Zeland	8	Racks	No marked trend in macrofauna species richness, species composition and dominance patterns	More elevated sedimentation directly under racks	No evidence of highly enriched conditions	(Forrest & Creese 2006)
C. gigas	B. C. (Canada)	4					http://www.agf.gov.bc.ca/fish_stats/statistics-aqua.htm
C. virginica	NB (Canada)	4	Tables	Macrofauna biomass, abundance and number of species higher or similar	No organic enrichment	Seasonal variations but no significant differences between control and culture sites	(Mallet *et al.* 2006)
C. virginica	NB (Canada)	2	Longlines				(Comeau *et al.* 2006)

Table 6 - Documented biomass of oysters and macrofauna at natural oyster reefs

Author	Location	Oyster densities (approx # $\cdot m^{-2}$)	Oyster size (cm)	No. species associated macrofauna	Total macrofauna (# $\cdot m^{-2}$)*	Total macrofauna biomass (g $\cdot m^{-2}$)**
Dame *et al.* 1984; Dame 1979	South Carolina	1,000 – 2,000		37	2,476-4,077	214
Bahr & Lanier 1981	Georgia	4,000	6+	42	38,000	705
Lehman 1974 cited in Bahr and Lanier 1981	Florida	3,800	All sizes	31	6,200	253
DeAlteris 1988	Virginia	10 -1,000	5-7			
Harris 2003	Chesapeake Bay (constructed)	500 -1,000	Spat on shell	18		
Milewski & Chapman 2002	Caraquet N.B.	67 - 84	All sizes	3 - 14	32 - 216	
ibid	Miramichi N.B.	16 - 164	All sizes	15 - 25	360 – 2,572	
ibid	Cocagne, N.B.	35 - 379	All sizes	18 - 27	440 – 2,848	
ibid	Bouctouche, N.B.	60 – 1,603	All sizes	19 - 29	504 – 6,448	
Sephton & *Bryan 1989*	Caraquet N.B.	250 - 420	All sizes			

* Min-Max reported, **soft tissue wet weight

4.2.4 Potential co-occurrence

Another element to consider is the potential for co-occurrence between the activity and the environment (i.e. competition for space). A common proxy to help assess the potential impact of aquaculture operations is to estimate the proportion of the total bay surface which is occupied by leases. Shellfish aquaculture lease sizes in the Maritime Provinces are mostly small, averages range from 3.51 ha to 15.71 ha (Table 7), but some leases can be considerably larger. In N.B. approximately 60% of oyster leases are smaller than 4 ha (Figure 6). Of the total number of lease sites not registered as vacant, an unknown number of sites essentially lie fallow with little or no effective activity (C. Noris, pers. com.).

Table 7 - Number and surface area of active leases issued by area in the southern Gulf of St. Lawrence, 2001-2002.

	Leases	Total surface area of leases	Average surface area per lease
AREA	Number	Hectares	Hectares
Prince Edward Island	776	2,721	3.51
Eastern New Brunswick	624	2,513	4.03
Gulf Nova Scotia	33	518	15.71
TOTAL	1,433	5,752	4.01

Includes all estuaries in N.B. where oyster aquaculture is conducted, except Baie des Chaleurs.

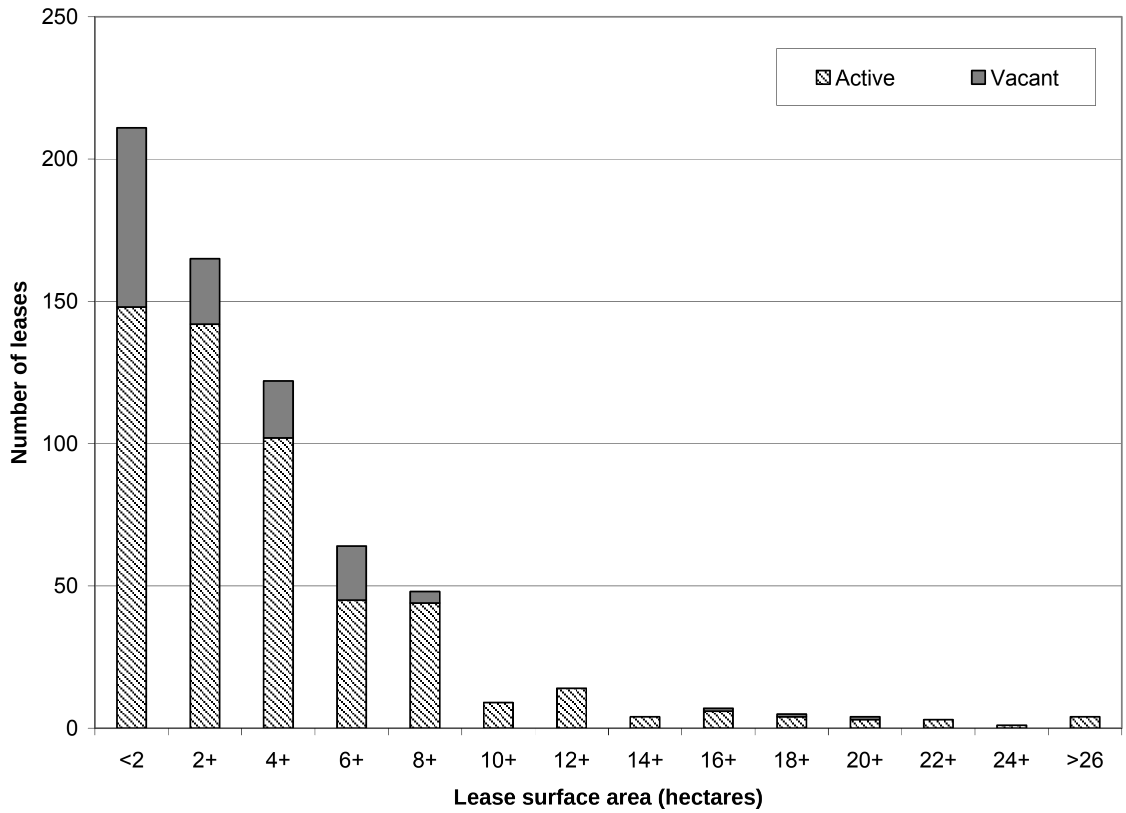

Figure 6 - Surface areas covered by active and vacant oyster leases in N.B. (data from NBDAA, 2007; n=658)

A GIS analysis of the area of leases area to total estuarine waters surface area shows that less than 5% of the surface of N.B. estuaries is defined as lease area, for all techniques included (data from NBDAA). Within these leases, the effective coverage or actual footprint of the aquaculture gear is limited by several factors (e.g. vacant space, navigation channels, unsuitable water depths in the lease, etc.). Thus the effective coverage is calculated as follows:

For a lease with a total surface area of 1 hectare: 100 m X 100 m = 10,000 m^2 (x)

Longlines -10 per hectare
Total surface area occupied by longlines = (60 m X 2.0 m) X 10 = 1,200 m^2 (y)
Percentage of lease covered by gear = (y ÷ x) X 100 = 12%
Cages -240 per hectare
Total surface area occupied by cages = (2 m^2 X 240) = 480 m^2 (y)
Percentage of lease covered by gear = (y ÷ x) X 100 = 4.8%

Therefore the aquaculture gear typically occupies between 5 to 15% of the surface area of a lease; or less than 1% of most bays. The footprint associated to the gear should likely be considered more representative of the affected area, in terms of fish habitat, rather than the total surface of the lease of which much of the lease area is not utilized.

4.3 Sensitivity of fish habitat

4.3.1 Characteristics of estuaries in N.B.

The biological composition of fish habitats in estuaries is generally found to be dynamic, constantly evolving and responsive to varying environmental gradients (Attrill & Rundle 2002; Attrill & Power 2004). In general, estuaries in eastern N.B. share similar characteristics. They are partially enclosed and protected from the open sea by systems of dunes and barrier islands. The different combinations of freshwater and saltwater inflow, precipitation, temperature, tidal range, dissolved oxygen, sediments loading and wave action lead to the development of a range of connected fish habitats within the estuary. Spatial delimitation between these various fish habitats is defined by nuances in physical, chemical and biological characteristics. These in turn affect the sediment characteristics, nutrient and oxygen availability, desiccation and immersion profiles, water temperature and salinity, etc. Current flow and wave action generally determine the sorting of sands, gravels and silts and the formation of mud and sand flat areas, salt marshes, sand or gravel beaches, shallow inlets and bays.

Eastern N.B. estuaries are generally shallow; as a result, the seasonal range in surface water temperature is among the highest in Atlantic Canada. Typically, water temperatures will reach 16-22°C in the summer; and -1°C to 5°C in the winter (DFO 1996). Seasonal ice generally covers these estuaries between December and March. Hence, overlap of boreal and temperate fish species can be observed with a north-south gradient in species composition.

The sGSL is considered a biologically diverse region and an important spawning ground and nursery area for a number of commercially important fish species (DFO 2001). N.B.'s estuaries contribute significantly to the overall ecological richness and productivity of this region. Two characteristics of this production is the large seasonal increase in plankton and the variety and abundance of larval fish and invertebrate species (DFO 2001).

Intertidal and subtidal areas support pelagic, benthic and burrowing communities of organisms. The location and composition of these communities is determined mainly by the suite of physico-chemical variables. Plant and animal communities depend on ambient conditions for providing nutrients, oxygen and carbon supplies. Another factor influencing the nature of these communities is the bathymetry or depth profile and the degree of wave action. Wave action, particularly during storms, ice-scouring (Robertson and Mann 1984) and exposure may in turn affect intertidal communities. This is likely to be more observable in shallow waters and can result in varying levels of sediment and biota transport and turbidity.

The salinity structure in estuaries is primarily determined by the seasonal freshwater discharge. Attrill and Rundle (2002) suggested that estuarine compartments are mainly defined by salinity which is a primary factor affecting the distribution of estuarine communities. Stable groupings of species tend to follow thermal or salinity boundaries (Attrill & Rundle 2002). In eastern N.B., the salinity gradient typically increases from low levels near the inshore freshwater source to higher levels where the estuary opens into marine conditions of the sGSL. Salinity stratification may occur in deeper regions of the estuary during certain seasons, but typically the shallow periphery of the estuary is homogenous because of active wave and current mixing. Relatively stable salinities are found near the freshwater tributaries and the estuary mouth.

4.3.2 Sensitivity characterization

The principal distinction between natural oyster populations and oyster aquaculture with regards to its influence on the sensitivity of fish habitat is tied to the presence of physical structures which have the potential to have localized affects on the physical characteristics of estuaries, such as wave and tidal currents, turbidity and sediment mixing. When compared to storm events, the influence of physical structures in the water appears minimal, and unlikely to affect the sensitivity of fish habitat. Stochastic natural events are more likely to have significant and widespread impacts on estuarine plants and animal communities than aquaculture activities (Mallet *et al.* 2006). These natural disturbances are believed to be necessary conditions for the maintenance of stable biotic communities, since they promote the redistribution of resources within the ecosystem (Rykiel 1985).

As seen above, variability is inherent to the physico-chemical and biological characteristics of estuaries. Estuarine plant and animal communities need to be able to endure significant seasonal and geographic variability in conditions. They have to be well adapted to survive the physical stresses imposed by these extremes.

4.3.3 Sensitivity of fish species

Many species in the sGSL region are dependent on estuaries for at least a phase of their life history as feeding, nursery, migration and/or spawning habitat. They are thus potentially vulnerable to impacts from habitat alteration. Particularly susceptible are species or species groups that require estuaries or freshwater tributaries as primary larval or post-larval habitat. In the N.B. region, these species include anadromous fish such as striped bass, blueback herring, alewife, American shad, sturgeons, rainbow smelt, Atlantic tomcod and winter flounder.

Other commercial fish species found in estuaries include various species of bivalves, such as mussels, quahogs and clams and crustaceans, such as rock crab and lobster. The effect of water column oyster aquaculture on these fish species is generally considered minimal as the structures do not impede fish movement. In addition, Powers *et al.* (2007) and DeAlteris (2004) demonstrate that aquaculture structures can provide biogenically structured habitats that function as nursery and feeding habitats for juvenile fishes and mobile invertebrates.

4.3.4 Sensitivity of submerged aquatic vegetation

In N.B. the fish habitat most likely to co-occur and to be affected by oyster aquaculture is eelgrass (*Zostera marina*) beds. *Zostera* is considered important in maintaining desirable ecological properties of estuaries due to photosynthetic activity, its role in biomass accumulation and in nutrient cycling. In addition, eelgrass plays a important role as a nursery habitat for a variety of fish and invertebrate species (Locke & Hanson 2004) such as juvenile white hake and small cunners (Joseph-Haché *et al.* 2006).

Several factors are known to affect potential eelgrass growth and recovery (UK Marine special areas of conservation 2006), such as: the removal of habitat; the creation of unstable substrata; the fragmentation and destabilization of *Zostera* beds caused by factors such as changes to coastal processes; physical damage or stochastic weather events; reduced rhizome growth and seed production; reduced light penetration caused by increased turbidity, changes in salinity, pollution or epiphyte smothering; nutrient enrichment; declines in epiphyte grazer populations; unusual increases in waterfowl grazing pressure; non-native macrophyte species, exposure to extreme temperatures, which may increase the susceptibility to disease.

Worldwide, two of the most important threats to submerged aquatic vegetation are disease and anthropogenically induced eutrophication (Short *et al.* 2001). Nutrient pollution effects on eelgrass and nitrogen loading from a variety of sources such as agriculture run-off, sewage, and fish plants are described to varying degrees in N.B. estuaries (Conservation Council of New Brunswick 2004, Lozte *et al.* 2004).

In oyster aquaculture, eelgrass may be affected principally by incidental removal (mooring, boat wash, trampling, etc.), by biodeposition or by shading. This effect is variable in spatial distribution and severity and appears tied to the equipment's footprint. Table 8 describes some impacts of different activities on *Zostera* populations and observations about its resilience. It shows that in general, *Zostera* is not overly sensitive to changes and perturbations. Auster & Langton (1998) observe a consistent pattern of resilience of *Zostera* populations in studies of the impacts of fishing activities. Table 8 also lists pre and post impacts from a number of activities, such as oil spill, herbicide application and wildlife grazing. Other than those cases of intense removal of stems and meristems, effects on *Zostera* appear to have minimal long term impacts.

At present, rarity is generally not a concern in N.B., as *Zostera* meadows are ubiquitous throughout the region and eelgrass is the dominant attached vegetation in these estuaries (Joseph-Haché *et al.* 2006). There are signs, however, that cumulative human activities are having growing impact on these meadows. Increased shoreline developments, recreational and touristic activities are having notable physical impacts.

Globally, studies show that increased nutrient loading to estuaries can lead to eelgrass disappearance (Hauxwell *et al.* 2001,Lotze *et al.* 2003, Cardoso *et al.* 2004). Locke (2005) has observed that the above-ground biomass and percent cover of eelgrass in estuaries along the Northumberland Strait are showing signs of decline; disturbance by the introduced green crab and global environmental changes are mentioned as possible explanations (Locke 2005). Thom *et al.* (2003) suggest that climate variations can have profound effects on eelgrass. They found that large-scale changes climate may strongly influence eelgrass abundance that can vary by as much as 700% annually.

Table 8 - Summary of findings on Zostera sp. recovery and sensitivity to various impacts.

Habitat	Source of effect	Location	Results	References
Eelgrass	Scallop dredge	North Carolina	Comparison of reference quadrats with treatments of 15 and 30 dredging in hard sand and soft mud substrates within eelgrass meadows. Eelgrass biomass was significantly greater in hard sand than soft mud sites. Increased dredging resulted in significant reductions in eelgrass biomass and number of shoots.	Fonesca *et al.* 1984 in Auster & Langton 1998
Eelgrass and shoalgrass	Clam rake and "clam kicking"	North Carolina	Comparison of effect of two fishing methods. Raking and "light" clam kicking treatments, biomass of seagrass was reduced approximately 25% below reference sites but recovered within 1 year. In "intense" clam kicking treatments, biomass of seagrass declined approximately 65% below reference sites. Recovery did not begin until more than 2 years after impact and biomass was still 35% below the level predicted from controls.	Peterson *et al.* 1987 in Auster & Langton 1998
Eelgrass and shoalgrass	Clam rakes (pea digger and bull rake)	North Carolina	Compared impacts of two clam rake types on removal of seagrass biomass. The bull rake removed 89% of shoots and 83% of roots and rhizomes in a completely raked 1 m2 area. The pea digger removed 55% of shoots and 37% of roots and rhizomes.	Peterson *et al.* 1987 in Auster & Langton 1998
Seagrass	Trawl	Western Mediterranean	Noted loss of *Posidonia* meadows due to trawling; 45% of study area. Monitored recovery of the meadows after installing artificial reefs to stop trawling. After 3 years plant density increased by a factor of 6.	Guillen *et al.* 1994 in Auster & Langton 1998

Eelgrass	Recreational clam harvesting	Oregon	Experimentally tested by raking or digging for clams in 1 m2 plots in eelgrass meadows. After three monthly treatments, eelgrass measures of biomass, primary production (leaf elongation), and percent cover were compared between experimental and control (undisturbed) plots. Clam digging reduced eelgrass cover, above-ground biomass and below-ground biomass in measurements made 1 month after the last of three monthly treatments. 10 months after the last clam digging treatment, differences between treatment and control were not statistically significant.	Boese 2002
Eelgrass	Physical exposure	Danish sites	Shallow eelgrass populations form characteristic landscapes with a configuration that is highly related to the level of physical exposure; the size and position of eelgrass beds changes substantially among years	Frederiksen *et al.* 2004
Eelgrass	Experimental removal	San Francisco Bay + Puget Sound	Eelgrass was removed from experimental plots. Substantial vegetative recolonization (64.3 -81.8%) of test plots occurred within five months of treatment. Rapid recolonization was explained by the presence of new shoots migrating to excavated plots and reseeding.	Fonsecal *et al.* 1983
Eelgrass	Mussel dragging	Maine	Aerial photography, underwater video, and eelgrass population- and shoot-based measurements were used to quantify dragging impacts within 4 sites that had been disturbed at different times over an approximate 7 year interval, and to project eelgrass meadow recovery rates. Dragging had disturbed 10% of the eelgrass cover. Dragging removed above- and belowground plant material from the majority of the bottom in the disturbed sites. One year following dragging, eelgrass shoot density, shoot height and total biomass of disturbed sites averaged respectively 2 to 3%, 46 to 61% and <1% relative to the reference sites. Substantial differences in eelgrass biomass persisted between disturbed and reference sites up to 7 year after dragging. The pattern and rate of eelgrass bed recovery depended strongly on initial dragging intensity; areas of relatively light dragging with many remnant eelgrass patches (i.e. patches that were missed by the mussel dredge) showed considerable revegetation after 1 year.	Neckles *et al.* 2007

Eelgrass	Canada geese grazing	Maine	A flock of Canada geese Branta canadensis L. over-wintered and grazed on eelgrass for 3 months. Before Canada geese were present, eelgrass parameters demonstrated seasonal fluctuations typical of the region. During the grazing event, eelgrass parameters declined drastically, and biomass losses were significant. After the event, eelgrass recruitment via sexual reproduction was minimal, and vegetative recovery was impeded by Canada goose consumption of the plant meristems. Unlike studies in other locations, which show seagrass quickly rebounding from annual grazing events, eelgrass in this location showed little recovery from grazing 1 year after the event.	Rivers & Short 2007
Eelgrass	Wasting disease	Delaware USA	Eelgrass declined precipitously in the 1930s due to the pandemic wasting disease and a destructive hurricane in 1933. Natural recovery of *Z. marina*, possibly deriving from either small remnant stands or undocumented transplant projects was significant in four northern bays, with over 7319 ha reported through 2003 compared to 2129 ha in 1986, an average expansion rate of 305 per year. This rapid spread was likely due to seeds and seed dispersal from recovering beds.	Orth *et al.* 2006
Zostera sp.	Exposure to herbicides Atrazine, Diuron and Irgarol	Laboratory & Australia	*Zostera capricorni* was exposed to 10 and 100 µg herbicide solutions for 10h. Laboratory samples exposed to these herbicides were severely impacted during the exposure period and most treatments did not recover fully after 4 days. In situ samples were severely impacted by Irgarol and Diuron exposure whereas samples recovered completely after exposure to Atrazine at the same concentrations as the laboratory experiments.	MacInnis & Ralph 2003
Zostera sp.	Brant goose grazing	Europe	”Wasting disease" affecting Atlantic Zostera stocks during the 1930s was at least partly responsible for a steep decline in Brant goose population sizes on both sides of the Atlantic. While *Zostera* is of outstanding importance as food for Brant geese, the impact of the geese on *Zostera* stocks seems to be less important - at many sites, the geese consume only a small amount of the available *Zostera*, or, if they consume more, the seagrass can regenerate fully until the following season.	Ganter 2007

Eelgrass	Oil spill	Alaska	A year after the Exxon Valdez oil spill, eelgrass densities were 24% lower at oiled sites compared to control sites. Recovery of eelgrass occurred by the second year, with no significant differences noted between oiled and control sites in subsequent years.	Dean & Jewett 2001
Zostera sp.	2-4-D herbicide	New Brunswick	The industrial herbicide 2-4-D was used to clear eelgrass from oyster grounds in part of Baie Brulée in 1968. Surveys in 1986 showed that the area was densely vegetated with eelgrass; eelgrass beds covered 97.7% and 46.1% of the area of the bay in St. Simon Sud and St. Simon Nord, respectively.	*Mallet pers. com.* SEnPAq 1990a
Zostera sp.	Oyster aquaculture	California	Study plots were established to test the effect of oyster line spacing distances of 1.5 ft (narrow), 2.5 ft (standard), 5 ft (wide) and 10 ft (very wide). They examined the eelgrass, benthic infauna cores, deployed baited fish traps and measured water quality, sedimentation, light intensity, and oyster growth. After two years, eelgrass spatial cover and shoot density were consistently high within the control (reference areas) and lowest within the 1.5 ft oyster line spacing plot. Eelgrass metrics generally scaled directly with oyster density, and the spatial cover and density of eelgrass plants within the 10 ft spacing plot were within the range of variability observed in the reference (control) study plots.	Rumrill & Poulton 2004

4.4 Significance of ecological risk

The concept of significance can not be separated from the concepts of "adversity" and "likelihood" and must be considered by taking into account the implementation of mitigation measures (CEAA 1994). The following definitions represent guidance for the determination of significance and were elaborated based on the CEAA and the HMP Risk assessment framework:

- *Significant* : A residual environmental effect is considered significant when it induces frequent, major levels of disturbance and/or when the effects last longer than a year and extend beyond the project boundary following the application of mitigation measures. It is either reversible with active management over an extended term or irreversible.

- *Not-significant* : A residual environmental effect is considered not significant when it is infrequent, minor or negligible levels of disturbance and/or damage and when the effects last less than a year and are contained within the project boundary following the application of mitigation measures. An effect that is not significant is reversible with or without short-term active management.

The significance of the ecological risks associated with water column oyster aquaculture is based on the best current available information in the context of our understanding of the ecosystem dynamics. The following points discuss some of the more complex concerns that are typically raised and where ongoing research occurs in regards to water column oyster aquaculture effects on fish and fish habitat.

4.4.1 Biodeposition

One of the principal concerns with regards to the potential negative effects of bivalve culture is related to the increased deposition of organic matter associated with the accumulation of faeces and pseudofaeces as well as the deposition of shells and attached epifauna from the structures and changes to the hydrodynamics of the site. The impact of these effects on the benthos can range from significant, in the case of intensive Asian and European culture practices, to minimal in the case of semi- to low-intensity operations; (Chamberlain *et al.* 2001, Crawford 2003, McKindsey *et al.* 2006a). It would therefore appear that there is a potential for localized negative effects on the ecosystem due to increased organic loading within the footprint of individual farms under certain conditions (e.g. heavy loading, low flushing rates, shallow water depth, etc.).

Models can be used to predict the dispersion of biodeposits as they fall from the aquaculture works and assess the extent of the activity's footprint. Chamberlain et al. (2006) show that in shallow depth sites, such as in water column oyster aquaculture, deposits are expected to fall largely under the equipment. They also show that particle flux is correlated to the stocking density of the cultured species and also that resuspension and mixing of these particles are likely to occur in shallow systems. Thus, the impact of biodeposition depends largely on the density of shellfish present at the site and extent to which water exchange will disperse of the deposits.

In the case of water column oyster aquaculture, studies on sedimentation rates in St. Simon Bay N.B. showed that deposition rates increased at culture sites possibly from the oysters, fouling organisms and hydrodynamic effects of the equipment (Mallet *et al.* 2006). However, the mean organic content of the sediment deposited at the Oyster Table site (20.2%) was not significantly different from the Floating Bag (20.8%) or the Reference sites (21.8%) (Mallet *et al.* 2006). The authors suggested that the lack of enrichment of the sediments indicated that the organic matter in the biodeposits was not being incorporated into the sediments and was either washed away and/or rapidly processed by the benthic community.

When organic enrichment occurs, as seen in intense finfish aquaculture, it can cause alterations in the benthic community; reducing species diversity and richness as the impact accentuates (Pearson and Rosenberg 1978; Rosenberg 2001). Mallet *et al.* (2006) concluded that, the number of species and macrofaunal abundance was similar at the culture and the reference sites, and there was no evidence of opportunistic species typically associated to highly disturbed areas.

The use of Eh/Sulphide analyses of the sediments was developed for finfish aquaculture as a quantitatively index of organic enrichment and the formation of anoxic sediments and levels were correlated with the composition of the benthic community (Wildish *et al.* 2001). This technique has been applied elsewhere but to date no significant impact was detected for the analyses of the sediments under oyster sites (Mallet *et al.* 2006) in Baie St. Simon N.B., one of the most intensively cultured bays in the Province. Mallet *et al.* (2006) found that Eh/Sulphide levels at oyster sites were not significantly different from reference sites. Additionally, as part of an MOU with the N.B. provincial government, the NBDAA has initiated surveys to measure

Eh/Sulphide levels in and around oyster aquaculture sites. In 2006, sites within two bays which are considered important oyster aquaculture areas were assessed on and off leases. They found that in Baie St. Simon and in Richibucto, levels of sulphides in the sediments averaged 314 µM and 159 µM, respectively (data from NBDAA). The maximum levels observed 1410 µM and 1165 µM for Baie St. Simon and Richibucto respectively, occurred outside the leases in the deeper areas of the navigation channels (data from NBDAA). Hypoxic conditions in the sediments occur at sulphide values of 1,500-3,000 µM while anoxic conditions correspond with levels of 3,000-6,000 µM or more (e.g. Wildish *et al.* 2001, Holmer *et al.* 2005).

Therefore, there is no indication to date of significant or adverse effects associated with the increase in biodeposition under water column oyster aquaculture sites in N.B.

4.4.2 Carrying capacity

There is concern over to the potential effect of increasing the oyster biomass on the carrying capacity of estuaries. As shown in section 4.2, the intensity observed in water column oyster aquaculture in N.B. differs significantly from other regions in the world.

Several attempts have been made internationally to determine the carrying capacity of estuaries for shellfish production. One of the main obstacles is the lack of clarity in the definition of carrying capacity. For shellfish culture, McKindsey *et al.* (2006b) favour the use of "ecological carrying capacity" which represents the point where the stocking density on the farm is high enough that it can cause *unacceptable environmental impacts*. Typically, the carrying capacity for shellfish is based on the biomass which can be supported in a given bay in terms of food, habitat, water quality and other necessary parameters. Research in this area has been limited by the complexity of seasonal and size related changes in energy requirements of shellfish, seasonal changes in productivity, trophic characteristics of estuarine communities and hydrodynamics of many areas. Various problems have been reported in the literature about models used to determine carrying capacity and their requirement for long term environmental data collection. Newell (2007) highlights the shortcomings of current models in accurately representing conditions observed in shellfish aquaculture and lists the steps required to improve these efforts; including a better account for ecosystem functions provided by bivalves which have desirable (e.g. economic, environmental remediation and nutrient trading scheme) outcomes. In particular, these models need to take into consideration the cumulative effects of neighbouring human activities (e.g. nutrient run-off, sedimentation, etc.) (ICES 2003).

The carrying capacity of a given system is not at a static or unchanging level. Seasonal changes in temperature, food supply or other factors can affect the capacity of a bay or estuary to support the organisms within it (Carver and Mallet 1990). Bivalve culture is strongly influenced be the quantity of food (i.e. plankton and organic particles) which is available in the water column. The Aquatic Ecosystem Section of DFO in the Gulf region initiated the Shellfish Monitoring Network (DFO 2007) (https://www.glf.dfo-mpo.gc.ca/sci-sci/smn-rmm/intro-e.jsp) in order to examine spatial and temporal variations in shellfish productivity using standardized cage systems in bays with oyster or mussel culture in the sGSL. For example, differences in growth rates of bivalves in different bays between years are often more important than differences between bays despite varying intensities of bivalve culture within the bays. This suggests that productivity is linked more strongly to broad annual changes in nutrient inputs, plankton blooms or temperatures than to grower interventions within a given bay. This monitoring of shellfish productivity is ongoing and will continue to provide a baseline of shellfish growth so as to provide an indication of ecosystem effects if changes outside of the natural variability are observed.

Given historical levels of natural oysters within N.B. estuaries (see section 5.2 *Historical state of oyster populations*) as well as the comparisons with bivalve production in other regions of the world, it appears that the ecological carrying capacity of these systems is not likely to be adversely affected by the anticipated level of water column oyster aquaculture.

4.4.3 Nutrients

The effect of nutrient releases such as nitrogen and phosphorous from farmed oysters in the form of faeces and pseudofaeces is generally considered of lower importance compared to the regional inflow of nutrients in open water masses (Folke & Kautsky 1989, Kirby & Miller 2005, Ferreira *et al.* 2007). Generally, the excretions that oysters do produce are thought to be rapidly assimilated by plankton in the water column (Pietros and Rice 2003). Shellfish in culture consume ambient plankton and are not artificially fed. Thus they do not add nutrients but rather can alter the nutrient dynamics and concentrate nutrients in the farm's immediate surroundings (McKindsey *et al.* 2006a). This concentration of nutrients can be difficult to assess in the water column and explains why appreciable efforts are made to study benthic enrichment and biodeposition, as discussed above.

Unlike finfish aquaculture, where one of the main ecosystem stressors is related to the addition of nutrients, chemicals and pharmaceuticals in the form of fish food, bivalve aquaculture represents an extractive activity, by which the bivalves filter food out of the water column and these nutrients are removed from the ecosystem entirely at harvest. Sarà (2006) conducted a meta-analysis on the ecological effects of aquaculture on nutrients by comparing shrimp, fish, bivalve culture as well as polyculture. The author concluded that the effect of aquaculture on nutrients was highest in freshwater and lowest in marine water. Moreover, the author found that bivalves appeared to have no significant influence on the dissolved nutrients and their "mean size of effect" was negative (-0.03) unlike the positive values seen in shrimp (+0.71), fish (+1.10) and polyculture (+1.80) (Sarà 2006).

That said, although oysters are known to have been highly abundant historically, the role of shellfish aquaculture in influencing the nutrient dynamics in estuaries, as well as in selective grazing of plankton, remains an ongoing research topic.

4.4.4 Submerged aquatic vegetation

Another common concern relates to the potential damage to submerged aquatic vegetation which is considered valuable habitat for several fish species (e.g. Chambers *et al.* 1999; Joseph *et al.* 2006; Vandermeulen *et al.* 2006). Marine plants such as eelgrass are considered critical habitat in many parts of the world because they serve important ecological functions, are often considered rare, and thus are often the subject of monitoring programs (Short *et al.* 2001). It is important for many fish and invertebrates and contributes to the ecological richness of the region. In N.B. estuaries, the eelgrass (*Zostera marina*) is considered abundant in many bays. Surveys have shown that eelgrass beds can represent appreciable portions of N.B. estuaries (SEnPAq 1990ab). For example, in Baie St. Simon Sud and in Richibucto Bay 98% and 78% of the surface area of the bays, respectively, was covered by eelgrass beds; these values do not exclude sediment types unsuitable for eelgrass. The SEnPAq (1990ab) study is currently being used as a baseline with which to compare eelgrass distribution. A DFO working group is presently assessing eelgrass as a potential indicator for evaluating bay health in N.B. in collaboration with Environment Canada, Parks Canada and universities.

Eutrophication remains the main concern to eelgrass productivity and is recognized as a threat by increasing epiphytes on the leaves, and reducing water clarity which cause shifts in the primary productivity from benthic vegetation towards phytoplankton. It is clear from the scientific literature that shellfish filtration plays a critical role in improving water clarity which increases light availability and enhances bioavailability of nutrients and thereby stimulating eelgrass growth (e.g. Kennedy V.S. 1996; Newell & Koch 2004; Kirby & Miller 2005; Newell *et al.* 2005). This positive interaction can apparently be reduced in certain highly eutrophic settings such as in the Thau Lagoon in France (e.g. DeCasabianca et al. 1997 and 2003).

Other concerns may relate to physical disruptions as eelgrass can be dislodged by aquaculture activities such as trampling, anchoring, and powerboat wash. Past practices, whereby oyster culture was conducted by partial removing of eelgrass in order to facilitate removal of oysters and increase water flow, are no longer carried out. Vandermeulen *et al.* (2006) state that the preservation of habitat can be achieved by ensuring adequate spacing between lines and by minimizing physical impacts. Rumrill and Poulton (2004) found that oyster aquaculture gear placed line-spacing at 3m exhibited eelgrass metrics that fell within the range of variation observed in a series of reference areas while significant impacts occurred at smaller line spacing. The current space left for boat navigation (typically >7 m) is typically greater than the (>3 m) minimum spacing which was recommended by the NAP (Vandermeulen *et al.* 2006). Dumbauld (2005 cited in Vandermeulen *et al.* 2006) states that eelgrass can recover in 1-2 years if left undisturbed.

Stephan *et al.* (2000) compiled results on the effects of impacts of fishing gear (i.e. dredging, trawling, raking, etc.) on submerged aquatic vegetation and qualified the "injury recovery potential" of eelgrass Zostera marina as "moderate" in comparison to ten other species marine vegetation. Peterson et al. (1987) evaluated the effect of different intensities of mechanical harvesting of clams (*Mercenaria mercenaria*) including the "clam-kicking" technique which involves directing the propeller wash downward with sufficient force into the sediment to displace the sediments thus exposing the clams for easy collection with a trawl. They found that "intense kicking" had significant effects in reducing eelgrass biomass while "light-kicking" and raking had much lower impacts. Eelgrass in the "light-kicking" and raking treatments recovered to the level of the controls within 1-year.

Based on the studies of eelgrass resilience to anthropogenic activities presented above and natural disruptions (e.g. grazing, ice-scours, annual variability with environmental conditions), the potential effect of these physical disruptions associated to water column oyster aquaculture is likely to affect a limited area and to be fully reversible.

4.4.5 Species interactions

Concerns with regards to species interactions typically relate to the presence of additional oysters in the water column. Abgrall *et al.* (in prep.) completed a review of intra and inter-specific interactions between the oyster and softshell clam (*Mya arenaria*). Although cultured and wild population interactions, such as predation, competition, etc. are likely to occur, there is no indication that these interactions differ significantly from those occurring between wild populations. Oysters cultured in the sGSL are native to this region and have co-existed with other native species; therefore they are expected to retain similar biological interactions with existing populations.

Other concerns relate to the structures in the water column. The study of the effects of these types of structures has evolved into a research field which refers to them as Fish Aggregation Devices (FAD) (e.g. Castro *et al.* 2002). Some authors have proposed that the aquaculture equipment itself, and other structures, may contribute to estuarine productivity by creating a hard substrate; availability of these surface areas can limit the colonization of certain organisms (McKindsey *et al.* 2006a). Passing from an essentially two-dimensional sand-mud habitat to a three-dimensional hard surfaced habitat can dramatically alter the surface area available.

DeAlteris *et al.* (2004) conducted a study to compare the relative habitat value of aquaculture gear (rack and bag), submerged aquatic vegetation (*Zostera marina*), and shallow non-vegetated seabed. They found that the ecological value of aquaculture gear was significant based on an assessment of resident and transient marine organism's abundance and diversity in the respective habitats. Aquaculture gear increased habitat complexity and supported higher abundances of organisms than non-vegetated seabed; this was determined to be particularly beneficial to recreational and commercial fish and invertebrate species in their early life stages. DeAlteris *et al.* (2004) concluded that the relative habitat value of aquaculture gear is at least equivalent to submerged aquatic vegetation. Powers *et al.* (2007) demonstrated that flora and fauna associated to clam aquaculture gear (netting) was significant and that community structure of mobile invertebrates and juvenile fishes utilizing leases was more similar to that of seagrass than sandflat habitats. They found that the utilization by juvenile fishes was 3 times greater in seagrass and 3 to 7 times greater in epibiota on mesh in clam leases than on sandflat habitat.

Similarly, a study done in the sGSL in 2006 monitored levels and types of epifauna found on floating oyster bags (Mallet *et al. in preparation*). Undisturbed oyster aquaculture bags can accumulate 500 g to 1500 g (wet weight) of epifauna (e.g. amphipods, algae, arthropods, molluscs, etc.) per bag in one season. This can have important ramifications for the food web. For example, the estimated abundance of the tube amphipod *Jassa* sp. reached over 185,000 individuals per bag in the fall. This may represent an abundant food source for small fish (e.g. sticklebacks, silversides, cunner, etc) which appeared to be feeding on the surface of the bags (Mallet *et al. in preparation*).

In addition, the epibenthic fauna community was assessed in areas of suspended bag oyster aquaculture in three N.B. bays in 2006. Trawls were collected within leases (0 m) and at subsequent distances of 25 m, 100 m and 500 m away from lease edge (Skinner *et al.* in preparation). In general, it was found that the total organism abundance and species richness was significantly higher at lease sites than off-lease; lease site communities were generally dominated by shrimp species and blue mussels. The contribution of aquaculture gear to habitat value is explained in part by the fact that oyster culture creates several compartments (hard and soft substrata, foraging, refuge and nursery habitat) and trophic levels (primary producers, filter-feeders, deposit-feeders) within the water column (Mazouni *et al.* 2001). However, opportunistic predators such as sea stars and rock crab (*Cancer irroratus*), which can be abundant in mussel aquaculture sites and seen feeding on mussel fall-off, were only observed infrequently at the oyster aquaculture sites (Hardy, unpublished data).

4.5 Conclusion of Ecological Risk Assessment

This Ecological Risk Assessment identifies and characterizes many of the risks to fish and fish habitat relating to water column oyster aquaculture and discusses them in the context of the scientific literature and ecosystem dynamics. It is important to note that this assessment should be considered by habitat managers as a starting point and be revisited as new information becomes available.

The research priorities identified in the NAP as well as others, once completed, will further enhance and clarify some of the uncertainties involved with this activity. Moreover, we recognize that uncertainties exist and will continue to exist as these are complex ecosystems and more scientific research in this field is encouraged.

It is clear that the “scale and intensity” of the shellfish aquaculture operation is the main driver leading to potential negative effects. Culture of the native oyster in N.B. is practiced at densities much lower than other regions in the world and the potential effects are considered reversible and generally limited to site footprint. Based on the risk assessment matrix, our view is that the residual “scale of negative effects” associated with water column oyster aquaculture, as practiced in N.B., is low.

In terms of sensitivity, eelgrass beds are the principal driver in the risk matrix as they are considered important but are ubiquitous in many N.B. bays. Eelgrass also appears to be resilient to severe impacts, provided water quality is maintained. Eutrophication and turbidity appear to be the main factors affecting water quality and thus eelgrass sensitivity. Ensuring water quality should likely be the focus for eelgrass health. Because of concerns with water quality in general, our view is that level of "sensitivity of fish and fish habitat", based on the risk assessment matrix, is moderate.

In our view, the potential residual negative effects associated to this activity can likely be managed with appropriate planning and mitigation measures. Water column oyster aquaculture, as practiced in Gulf N.B., is not considered likely to significantly harm the productive capacity or the integrity of the fish habitat in these ecosystems. Therefore, overall based on the current state of knowledge and the scale of water column oyster aquaculture, we conclude that the potential residual risk for significant adverse impacts on fish and fish habitat to occur is low and that this constitutes a low-risk activity.

This view is also consistent with a DFO's Aquatic Ecosystem Section advice on water column oyster aquaculture as practiced in Gulf N.B., with a broader view on the role of aquaculture (similar to NEBA considered in the following section). They concluded that this activity represents a low risk to cause negative effects on fish habitat based on:

- *the current husbandry practices* (and the Code of Practice) *employed by the oyster aquaculture industry;*
- *the relatively low biomass of oysters on an aquaculture lease;*
- *the existence of naturally occurring reefs at densities in excess of the biomass used in aquaculture;*
- *the high historical landings of oysters in N.B. which suggests a high natural carrying capacity;*
- *the nature of shellfish as filter feeders in consuming and recycling nutrients;*
- *the problem of increasing nutrient load of estuaries associated with human activities and the ability of filter feeders to help mitigate these effects;*
- *the harvesting of the shellfish on a yearly basis which can remove tonnes of organic and inorganic matter from the bays; and*
- *the culture of oysters over the past decades in N.B. without significant demonstrable adverse effects.*

5 NET ECOLOGICAL BENEFIT ANALYSIS

In the above risk assessment, the potential for environmental impacts of aquaculture works were considered, here we consider the potential remediation role that oysters can play. The NAP concluded that bivalves in culture appear to fill many of the same ecological roles as natural bivalve communities, a role considered generally beneficial for a number of components of temperate estuarine ecosystems.

Although oysters in aquaculture differ from reefs in their structural form, it is useful, in the current assessment, to consider the ecological services played by oysters. Coastal ecosystems and estuaries dominated by bivalves exhibit complex responses that are not easily explained by linear dynamics (Dame *et al.* 2002). Net environmental benefit analysis (NEBA) is an elaboration upon the conclusions of an ecological risk assessment which considers benefits, along with risks, which can help managers in their decisions (US Department of Energy 2003).

5.1 Historical state of oyster populations

Milewski and Chapman (2002) provided a synopsis of the history of oysters in the province as well as their ecological function and the challenges they face. A relatively complete time series of oyster landings spanning between 1876 and today can be reconstructed from published information allowing us to retrace the evolution and trends in landings for the last 130 years. This gives a relatively reliable chronological series for the evolution of the oyster harvesting industry prior to the arrival of aquaculture. Newell (1988) proposed the use of this kind of time-series as a means to infer information about past standing stocks of oyster reefs. Based on Newell's example, data for landings were obtained from a number of sources; from 1876 to 1969 data obtained from Morse (1971); from 1971-1984 data obtained from Jenkins (1987) in imperial pounds was converted to metric tonnes; from 1984 – 2004 data was compiled by DFO from statistics obtained via sales slips, shown in the following graph (Figure 7). This data demonstrates the general trends in the exploitation of natural stock of oysters. It also helps to illustrate the scale of natural populations prior to current harvests.

At their highest in N.B., reported landings reached a peak in the order of 4,000 t, around the end of the 1940's. They had remained between the 1,000 to 1,500 t in the 75 years prior to that. Since then, NB landings have remained consistently below the 500 t mark, with no indication of commercial landings returning to pre-Malpeque numbers (Table 10).

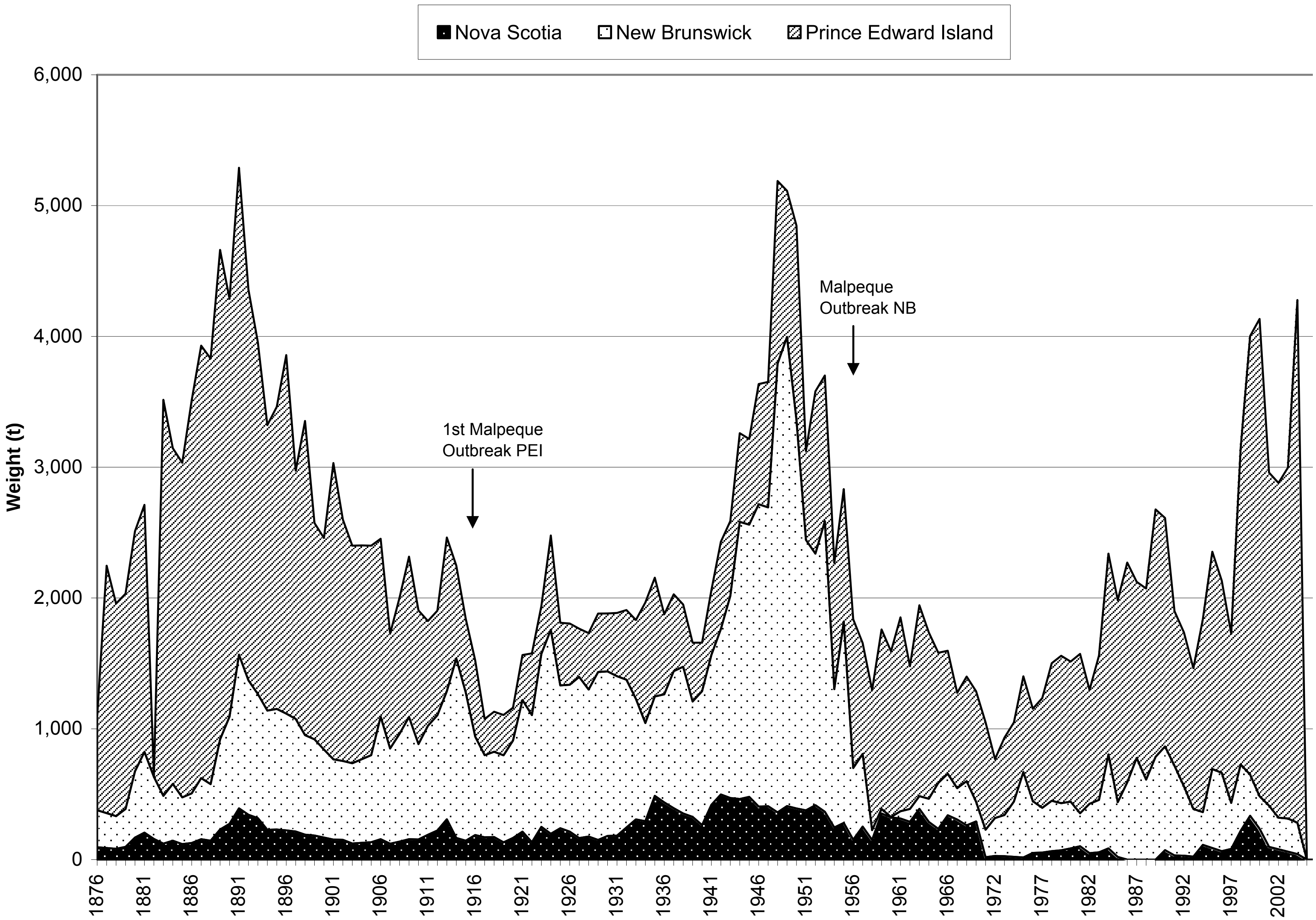

Figure 7 - Reported landings of oysters from commercial harvest 1876-2004 (Morse 1971,Jenkins 1987, DFO 2003b).

Table 9 - Estimated historical quantities of oysters in the Maritime Provinces (based on Newell, 1988) compared to present aquaculture and fishery levels.

	Gulf NS Total Weight (t)	*Gulf NB Total Weight (t)*	*PEI Total Weight (t)*	*Total Total Weight (t)*
1870-1900 estimated oyster biomass	10 161	35 912	130 565	176 638
Estimated total aquaculture production (NBDAA, 2006; DFO statistics)	232	1 857	2 849	4 939
Estimated total aquaculture production –all sizes (Comeau, 2006)		1 249		
Estimated oyster fishery landings 65 mm + (Comeau, 2006)		75		

From these values, and based on Newell's (1988) approach, we can estimate that there would have been a standing stock in the order of 176,000 t of oysters in all three Maritime Provinces prior to the 1900's; 10,161t for N.S; 35,912 t for N.B. and 130,565 t for P.E.I. Considering the fact that landings are generally under-reported and that by the turn of the 20th Century, a number of oyster beds in the Maritimes were already considered depleted (Morse, 1971) it is fair to assume that these numbers would represent a conservative estimate.

Based on the provincial estimates and the Comeau *et al.* (2006) survey, current commercial and aquaculture productions combined would represent less than five percent of the historical biomass of oysters. Therefore, this suggests that the combined standing stock of oysters found in N.B. estuaries is significantly lower than the biomass that would have been observed at the turn of the 20th Century. This is consistent with trends reported elsewhere in the literature (Kirby, 2004).

This historical data of oysters in the Maritime Provinces suggest a high natural carrying capacity and a natural dominance of oysters in these estuarine ecosystems.

5.2 Characterization of reference state

Reference states are typically established based on pre-activity levels (i.e. before the introduction of aquaculture). However, as shown above, the "baseline" by which we typically compare the development of these activities have already shifted drastically from historical levels. Determining where to locate the benchmark for comparisons and assessing what is a "natural and productive ecosystem" is difficult given that our current viewpoint is already far removed from previous levels. The reference state of many estuaries in N.B., as in many areas on the Atlantic coast of North America, was characterized by an abundance of oysters at a level which is now difficult to imagine (Gosling, 2003, Kennedy, 1996). The exercise above of examining historical levels does provide a better perspective for evaluating the scale current changes in our ecosystems and assessing the role of the oyster as a key component to what was presumably a diverse, functional and productive ecosystem.

5.3 Ecological benefit characterization

McKindsey *et al.* (2006) describes effects of shellfish aquaculture on fish habitat. The report provides detailed information on the role of bivalves in the ecosystem under natural conditions, describes various shellfish culture methods, and evaluates whether those roles are mimicked under aquaculture conditions. Their review of literature shows that bivalves are key components of healthy fish habitat.

Moreover, several of authors have argued that oyster reefs can play a critical role in the dynamics and resiliency of temperate estuaries. The reader can refer to the extensive review by Dame (1996): *The ecology of marine bivalves, an ecosystem approach*. They make the argument that oysters and their reefs contribute to the robustness of temperate estuaries; for that reason, they have been termed keystone meta-populations (Dame *et al.* 1984,Ray *et al.* 1997); biogenic habitats (Kennedy V.S. 1996,Lenihan 1999,Cranfield *et al.* 2004,Kirby & Miller 2005); ecosystem engineers (Coen *et al.* 1999,Gutierrez *et al.* 2003); essential fish habitat (DeAlteris *et al.* 2004); and critical estuarine habitats (Coen *et al.* 1997,McCormick-Ray 2005). These ecological roles are summarized in Table 10.

Table 10 - Summary of the functional effects of natural oyster populations on estuarine components (based on Ray et al. 1997; Kennedy V.S. 1996; Ruesink et al. 2005; McCormick-Ray 2005)

ESTUARINE FUNCTION	ECOLOGICAL SERVICES PROVIDED BY OYSTERS
Benthic productivity	Adds nutrients and precipitates faeces and pseudofaeces to benthos to feed demersal feeders, including lobster, crabs and endobenthic organisms. May depress the ratio of centric diatoms (planktonic and eutrophic waters) in favour of pennate diatoms (benthic and clear waters).
Biodiversity	Provides increased niche space for ecological complexity and faunal abundance; supports stenohaline species along a salinity gradient; sustains epizoan diversity; modulate estuarine population structure toward desirable equilibrium. Provide substrate attachment for plants and invertebrates.
Coupling of nutrients to other habitats	Benthic-pelagic coupling of nutrient. Consumption of phytoplankton containing organic nitrogen NH_4^+. Enhances N releases by sediment to atmosphere. NH_4^+ re-uptake by phytoplankton. Enhances composition of nutrient readily available to SAV.
Estuarine resilience and ecosystem robustness	Forms meta-populations and contribute to other communities as sources to restock disturbed areas; long-term life span of oysters contribute to biomass stability in estuaries. Increase habitat heterogeneity in the system and increase habitat redundancy, which can add optional choices in species survival.
Filtration capacity	Permanent presence of long-lived bivalves exerts effective grazing control on phytoplankton. High turnover rate potential of estuarine waters. Preferential sorting of organisms by size, limits impacts on zooplankton; dampens algal blooms; filters bacteria from water column.
Habitat structure	Reefs form discrete hard substrate islands which provide limiting substrate. Shells provide 3D substrate to other organisms for spawning, nursery and refuge habitats. 1 m^2 of shell bottom represents 50 m^2 of surface area for epifauna. These organisms act as food sources for a variety of predators. Reefs provide migration and feeding halts, creates matrix of seascape habitats which connects resource patches to the benthos, marshes and other estuarine habitats. Dead shells can help stabilize benthos, substrate for spat settlement and are recycled over time. Provide refuge from extreme environmental conditions.
Light regime	Removes POM/PIM from water column and enhances depth of Photosynthetically Active Radiation (PAR).
Metabolic conversion	Feeds on phytoplankton and converts energy into secondary production; release gametes and larvae which feed other organisms, including zooplankton and other filter-feeders. Forms spatial nodes of biological activity and couples benthic heterotrophic activity to intense predator-prey interactions. This helps make temperate estuaries among the most productive natural systems known (1 514 $gCm^{-2}y^{-1}$).
Shoreline and sediment processes	Reefs buffer against moderate storms and wave actions. Prevent the erosion of channel banks, stabilize and protect the edges of salt marshes. Mucus-bound biodeposits have enhanced particle cohesion and can resist erosion. Water flow patterns. Alters benthic boundary layer and water column hydrodynamics which enhances particle movements, feeding opportunities and particle dispersions.

5.4 Comparison of alternate states

The critical role of oyster reefs is made the more apparent when they disappear from estuaries, such has been the case in the eastern United States (Kirby 2004). Rothschild *et al.* (1994), for instance, estimated that total oyster habitat in the Maryland portion of Chesapeake Bay is probably 50% or less of what it was a century ago, that the remaining habitat is of substantially poorer quality on average, and that the biomass per unit habitat is about 1% of that at the turn of the century.

Such dramatic reductions in oyster populations are believed to have lead to cascades of undesirable effects on community and ecosystem dynamics, such as the loss of top-down control mechanisms on phytoplankton, which may have resulted in increases in nuisance and toxic algal blooms, reduced water clarity, loss of submerged aquatic vegetation and loss of fish populations (Kennedy V.S. 1996,Kirby & Miller 2005). It is reasonable to assume that a comparable state of reduced contribution of the oysters to estuarine ecology exists in our region, as that historical trend of systematic reef depletion has followed a similar course along the eastern seaboard (Kirby 2004). This would represent a significant loss to the productivity and function of these ecosystems as well as a likely reduction in water quality.

The current state is one of depleted natural oyster populations. It is estimated that populations diminished by more than 90% following the Malpeque disease. In some regions a 100 to 1,000 fold increase in population would be required to restore the desired services provided by oysters (Luckenbach 2004). Bivalve aquaculture is increasingly recognized as being critical in providing important ecosystem services and public benefits, such as mitigating water quality degradation (Powers *et al*., 2007).

5.5 Significance of ecological benefits

The significance of the ecological benefits of oysters can be observed in the decisions to invest a great deal of resources in the restoration and reintroduction of oysters. In particular, the rehabilitation of oyster reefs in temperate estuaries is considered critical in promoting a desirable state of equilibrium, characterized by a production of fish species considered useful to society (Ulanowicz & Tuttle 1992, Peterson *et al.* 2003). They conclude that increasing the number of oysters, naturally or via aquaculture, would result in increased benthic primary productivity, fish stocks, and zooplankton densities.

Bivalve shellfish are increasingly considered for their role in restoration programs and their use in mitigating negative impacts of land use activities (Landry 2002). Over the past years, DFO-HPSD has issued several *Fisheries Act* subsection 35(2) Authorizations on projects located in the estuarine and marine environment. Because these projects (e.g. wharfs, bridges, etc.) were determined to cause harmful alteration, disruption or destruction (HADD) of fish habitat, the proponents were required to compensate for lost fish habitat. In the Gulf Region, most of the marine fish habitat compensation projects are related to reef creation because of their positive ecological functions (Godin pers. com.). Restoration of oyster reefs is typically recommended as compensation to offset the damages to fish habitat in other regions of the world as well, and the net environmental benefits of such interventions are considered positive (Newell 2004, Kirby & Miller 2005, Newell *et al.* 2005). Restoration of natural oyster reefs is recognized as having significant ecological benefit and is often recommended as the preferable option because of the overall gains in habitat structure and function.

In the United States, the National Oceanic & Atmospheric Administration (NOAA) is actively involved and making significant investments in the restoration of oyster populations: in Chesapeake Bay alone, this funding represented 5.4$ million in 2006 (http://chesapeakebay .noaa.gov/RestorationMain.aspx). They state that: "*At one time, oysters were so abundant in the Chesapeake Bay that their reefs posed a navigational hazard to ships sailing up the Bay. Now, because of disease, poor water quality, and decades of overharvest, the oyster population in the Bay is at about 1% of what it once was. Federal and state agencies, industry, academic institutions, and nonprofit groups have all been working hard to restore the native oyster population to levels that will once again provide the level of ecological and economic services that it once did.*"

As shown above (e.g. Dealteris 2004; Powers *et al.* 2007), shellfish aquaculture equipment can also serve as significant biogenic reefs which can increase the productivity of many invertebrates and fishes. Although artificial means of increasing oyster populations through aquaculture may not provide all functions of oyster reefs such as the 3-D habitat associated to natural reefs (Coen *et al.* 1999), oysters aquaculture can be considered of significant ecological benefit (Ulanowicz & Tuttle 1992). Aquaculture of the native oyster can also indirectly provide broodstock sanctuaries as bottom oyster populations are re-established. There are anecdotal reports of a number of bays where spawning and settlement of oysters have been restored, with the presence of water column oyster culture, where none had occurred for a few decades (C. Noris, personal communication).

5.6 Conclusion on Net Ecological Benefit Analysis

Bivalve culture, by its very nature, is an extractive activity where success is tied directly to environmental quality, natural supply of larvae and natural food availability. The FAO (2007) states that the "*Culture of molluscs is considered highly environmentally friendly as they do not require any inputs for growth and utilizes nutrients from the surrounding waters"*. In addition to the value of the oysters themselves, the secondary productivity associated to the culture is also likely of significant value to fisheries resources (e.g. Powers *et al.* 2007).

We estimate that the natural population of oysters in N.B. estuaries at the turn of the 20th Century was approximately twenty times higher than current levels, including wild and aquaculture levels. Removal of endemic habitat created by oyster reefs has likely resulted in fragmentation, disturbance or elimination of ecosystem services, and net degradation of desirable estuarine functions. Newell (1988) suggested that the loss of oysters in Chesapeake Bay, due to disease and overfishing, contributed to undesirable ecosystem shifts in the food webs leading to a rise in the biomass of predators such as ctenophores and jellyfish. The author concluded that "an increase in the oyster population by management and aquaculture could significantly improve water quality by removing large quantities of particulate carbon".

There is mounting evidence that increasing the abundance of oysters is likely to restore some of the ecological services such as water filtration, benthic-pelagic coupling, and top-down control on phytoplankton once provided by natural stocks. These functions provide net benefits beyond the provision of fish habitat over an extended time-frame. Oysters in aquaculture structures are not considered different from oysters in nature. Thus, they can provide a number of ecological services, which can potentially increase the functional and structural sustainability of the ecosystem (Prins *et al.* 1997) and reduce the symptoms of ecosystem distress caused by eutrophication (Newell 1988, Jackson *et al.* 2001, Newell & Koch 2004).

Habitat restoration plans increasingly recognize the role of shellfish in improving water quality by assimilating and recycling large amounts of nutrients by feeding on plankton and thus aiding to mitigate the effects of anthropogenic eutrophication (Officer *et al.* 1982). Ferreira *et al.* (2007) discusses the economic potential for aquaculture operations as "nutrient sinks" to essentially remove the nutrient pollution from other industries and profit from this clean-up; similar to global emission trading mechanisms. In the U.S., in particular, where the loss of the American oyster has resulted in dramatic shifts in ecosystem equilibrium, there is consensus that restoration of oyster populations is critical in maintaining ecosystem health.

This Net Ecological Benefit Analysis allowed us to gain a greater perspective on elements which are not typically considered in an Ecological Risk Assessment. There remains a need to better understand how distinct habitat types, such as oyster reefs, interact within landscapes in order to better understand the contribution of aquaculture to supporting complex ecosystem linkages (Duffy 2006). The exercise of examining both positive and negative effects of shellfish aquaculture is informative, particularly in illustrating the challenge faced by managers in weighing the effects of certain activities. This is particularly true when the dynamics of this activity include non-linear relationships between multiple effects, both positive and negative, such as the ones associated with increasing shellfish abundance (Figure 8).

We conclude that, when properly managed, oyster aquaculture is likely to provide positive ecosystem services. This warrants further consideration as a key component in achieving healthy ecosystem objectives.

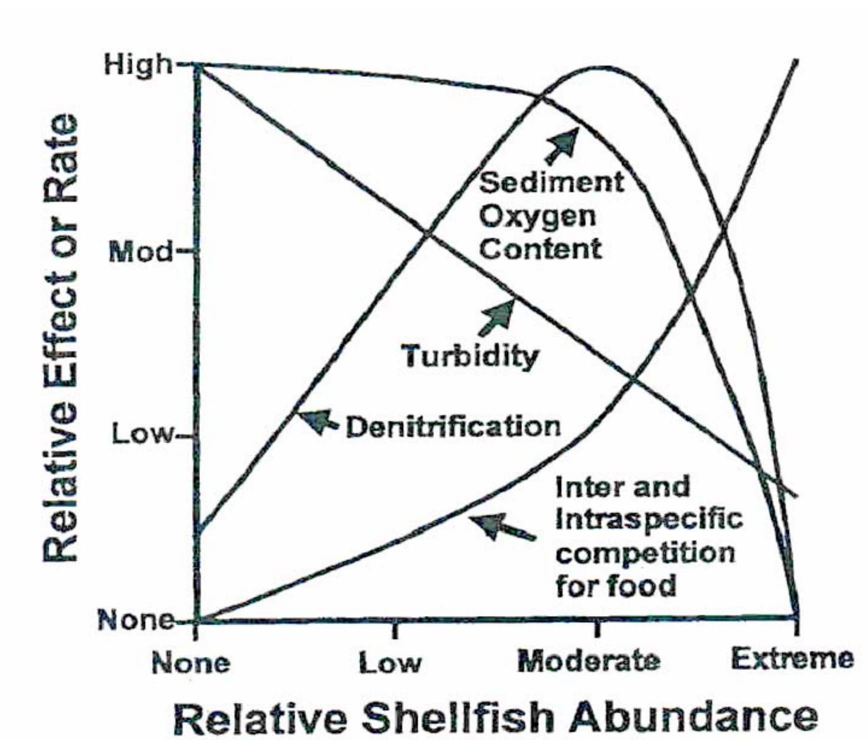

Figure 8 – Conceptual figure of relative effects associated to increased abundance of shellfish (from Newell 2004)

6 RISK MANAGEMENT ASSESSMENT

6.1 Identification of appropriate risk management options

The guiding principle for risk management is to achieve a reasonable degree of certainty that significant adverse effects can be avoided through a rationalised and feasible approach given the present knowledge limits, available options and resources. The HMP Risk Management Framework identifies a number of mechanisms to address low risk projects. Based on the framework and the perceived low risk associated with water column oyster aquaculture activity through the Ecological Risk Assessment, DFO considered the use of Operational Statements, letters of advice or Best Management Practices could have been acceptable options as operational tools to address the level of risk.

However, given the projected growth of the water column aquaculture industry, DFO Gulf Region favoured that EAs be managed by using the more rigorous Replacement Class Screening Report (RCSR) approach for this activity. This approach is built on the knowledge of the environmental effects of a given type of project while consolidating mitigation measures from governmental federal authorities involved in the process. A RCSR typically includes mitigation measures and Best Management Practices identical to those normally found in a site-by-site evaluation and letter of advice. This approach is also favoured because of the heightened public awareness and scrutiny surrounding aquaculture in general. The approach also implicitly requires that the authorities reflect on the activity in the context of their longer-term planning and bay-wide objectives as well as the acceptable levels of development that balance socio-economic and ecological sustainability.

As explained earlier, a replacement class screening consists of a single comprehensive report that defines the class of projects and describes the associated environmental effects, design standards and mitigation measures for projects assessed within the report. It includes a conclusion of significance of environmental effects for all projects assessed by the replacement class screening. This type of report presents a summary of the accumulated knowledge on the environmental effects of a given type of project and identifies measures that are known to reduce or eliminate the likelihood of these adverse environmental effects. A RCSR is also considered consistent with the more comprehensive Bay Management Framework (BMF), which constitutes a broader integrated planning and regulatory framework. In addition, a RCSR is a living document which includes provisions for revisions every five years, or whenever new information comes to light. Under a RCSR, yearly reporting of site review to the public registry is also required.

6.2 Risk Communication

Management of oyster aquaculture will require communication of the findings of this risk assessment. In N.B., like elsewhere in the world, the emergence of aquaculture as a relatively new and growing resource use can be perceived to be a disruption of the long-established *status-quo* between existing users (Burbridge *et al.* 2001,Shumway *et al.* 2003). The recent growth of aquaculture has occurred along coastlines where there is already a high concentration of other commercial, recreational and traditional resource users. This can provoke socio-economic concerns relating to aesthetics, property value and boating access, which is not unexpected, particularly in prime coastal real estate and recreational areas. In addition, the utilization of maritime space for aquaculture purposes raises potentially complex property and federal-provincial jurisdictional issues.

This risk assessment demonstrated that potential risks as they relate to fish and fish habitat have been identified and that the assessment of likelihood, consequences and probability of effects is based on reliable scientific evidence. The level of confidence in this approach is high, particularly in the context of a Bay Management Framework (BMF) where spatio-temporal interactions with ecological entities are reduced and/or avoided.

6.3 Risk monitoring, reporting and review

Research is being actively conducted by DFO, the Province of N.B., universities and the aquaculture industry itself. In August 2000, DFO launched its Program for Sustainable Aquaculture. The program reflects the federal government's commitment to increase scientific knowledge to support decision-making, strengthen measures to protect human health, and make the federal legislative and regulatory framework more responsive to public and industry needs. Specifically, the program allocates $75 million over five years with $15 million each year thereafter for: 1) environmental and biological science to improve the federal government's capacity to assess and mitigate aquaculture's potential impacts on aquatic ecosystems; 2) the Aquaculture Collaborative Research and Development Program, under which DFO partners with industry by jointly funding R&D projects to enhance sector innovation and productivity; 3) strengthening of the Canadian Shellfish Sanitation Program; 4) enhancement of the application of DFO's legislation, regulations and policies that govern aquaculture, particularly as they relate to habitat management and navigation.

Additionally, monitoring programs are ongoing in order to collect baseline data. For example, the Shellfish Monitoring Network has standardised cages housing mussels or oysters in multiple bays in the Maritime Provinces to provide a baseline of shellfish productivity. Also the Community Aquatic Monitoring Program's (CAMP) is being conducted in 26 sites in the Maritimes. CAMP is being used to build working relationships between DFO and community environmental groups, academia and other interested parties as well as to collect information on fish and invertebrate communities, water quality (e.g. temperature, pH, nutrients, etc.) and aquatic vegetation with the collaboration of watershed groups in several bays.

The development of the bivalve aquaculture industry is being closely supervised in N.B. The New Brunswick Shellfish Aquaculture Environmental Coordination Committee (NBSAECC) provides a forum for inter-agency communication which tracks the continuously evolving scientific and technical knowledge related to the activities of this sector and can recommend changes in shellfish aquaculture management practices when needed. Representatives of DFO, the Province of N.B., Transport Canada, Environment Canada as well as the New Brunswick Professional Shellfish Growers Association (NBPSGA) sit on this committee.

Yearly, through the *Canada-N.B. MOU for Aquaculture Development*, the NBSAECC meets to review the data resulting from field surveys and research conducted by academics, federal and provincial agencies. If significant changes occur in the risk posed by the husbandry methods (e.g. appreciable changes in intensity or techniques), the environmental conditions (e.g. water quality), or in the state of knowledge concerning water column oyster aquaculture, they are required to report updated assessments to senior managers of their respective agencies. The Canada-N.B. Aquaculture Management Committee can thereafter make decisions to address concerns.

Additionally, the BMF developed with the Province of N.B. is an example of a living tool and is based on the premises of Adaptive Management to ensure the sustainable development of the shellfish aquaculture sector. A management team has been established to regularly review the outcome of the overall planning and regulatory framework to ensure it is regularly adapted. The team will continue to evaluate the effectiveness of the BMF in regards to integrated sustainable aquaculture development, based on sound planning and management.

7 CONCLUSIONS

The Habitat Management Program's Risk Management Framework implicitly recognises that all activities entail some risks which must be weighed in terms of the *scale of negative effect* and the *sensitivity of fish and fish habitat* using the Risk Assessment Matrix (Figure 3). The Ecological Risk Assessment characterizes many of the risks and assesses their significance in the context of the scientific literature and ecosystem dynamics; in summary we conclude that:

- The overall *scale of potential negative effects* of water column oyster aquaculture in N.B. is low. In general the *sensitivity of fish and fish habitat* is low, eelgrass which is being affected by a number of anthropogenic impacts is considered moderately sensitive. For that reason oyster aquaculture works in N.B correspond to a low-risk activity on the HMP Risk Assessment Matrix;

- Given the low densities observed in water column oyster aquaculture in N.B., which differ greatly from other regions in the world, for an activity where "*most effects of bivalve aquaculture seem to be related to the scale (intensity and extent) of aquaculture rather than the type of infrastructure*" (DFO 2006), the potential for significant residual effects after mitigation is low;

- Thus the activity is considered unlikely to significantly harm the productive capacity or the ecological integrity of fish habitat. The risks associated with water column oyster aquaculture can be managed with adequate planning and mitigation measures through an adaptive management approach.

The development of this risk assessment has lead to the evaluation of a number of potential management tools available within DFO's regulatory mandate. Given the conclusion on the level of risk, the use of Operational Statements, Best Management Practices, etc is considered adequate. Because of the heightened public awareness and scrutiny surrounding aquaculture in general, the use of a RCSR is considered a prudent and appropriate operational tool for integrating several regulatory and expert advices of federal departments to manage the level of risk to fish and fish habitat posed by the oyster aquaculture industry.

Although the risk analysis framework generally focuses on negative effects and does not presently integrate the Net Ecological Benefit Analysis into the decision-making process, we found the exercise to be informative with regards to evaluating the complexities in ecosystem dynamics and in qualifying the overall effects of this activity. Accordingly, we believe that shellfish aquaculture, when managed effectively, can provide many ecosystem benefits and can contribute to the general environmental health of N.B. estuaries. The Net Ecological Benefit Analysis also served to illustrate how our current view of temperate estuaries in our region is that of an altered state (i.e. depleted oyster reefs) in comparison with the reference state which was dominated by extensive bivalve meta-populations. This conclusion supports the general approach taken by the HPSD of recommending the development of oyster reefs as compensation projects for habitat losses. These types of considerations will likely become increasingly important as governments continue to work towards planning and implementing a more formal ecosystem approach to managing coastal activities based on regional objectives of sustainable development.

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