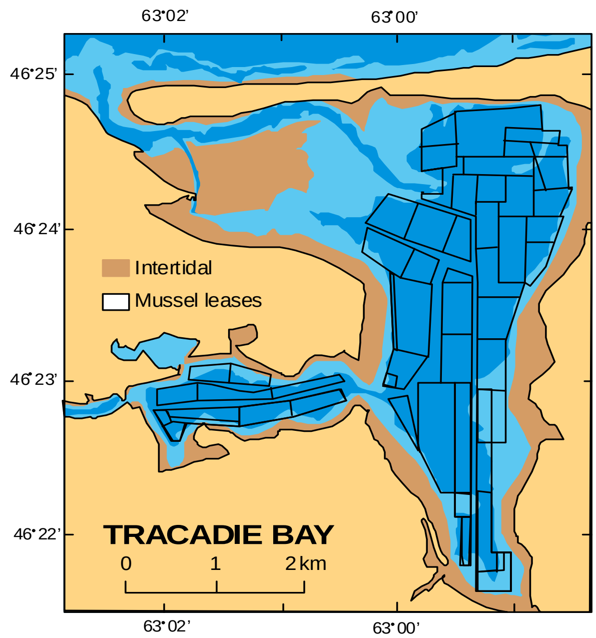
ASSESSING HABITAT RISKS ASSOCIATED WITH BIVALVE AQUACULTURE IN THE MARINE ENVIRONMENT

Suspended culture of mussels is an important component of Canadian bivalve aquaculture.



Map of Tracadie Bay, one of Canada's most intensive sites for bivalve aquaculture.

Context :

Open-water, marine bivalve aquaculture is conducted in British Columbia and in all five provinces of Atlantic Canada, including Quebec. The term bivalve is preferred to shellfish because in Canada most shellfish species used in aquaculture are bivalves. On the Pacific coast almost all of these species are non-indigenous. The opposite is true on the Atlantic coast, where, with the exception of the flat oyster and bay scallop, bivalve culture is conducted with native species. This industry is important in coastal communities and is growing rapidly. In contrast to finfish aquaculture, bivalves are sustained on food that occurs naturally in the ecosystem. A wide range of practices and habitats are used in the culture of bivalves.

A national workshop was held in Moncton NB, February 28 – March 3, 2006, to consider methods available to assess potential environmental risks of bivalve aquaculture in the marine environment. The workshop was based on the peer review of five working papers. Referees included scientists from around North America and Europe. Five teams, formed in August 2005, wrote the papers. Each paper focused on a particular theme and each theme was divided into a suite of questions. The themes were to identify:

1. *positive and negative impacts of marine bivalve aquaculture on fish habitat;*
2. *chemical, biological or physical indicators to measure these effects;*
3. *modeling methodologies available to predict any impacts of bivalve aquaculture;*
4. *cumulative and far-field effects; and,*
5. *sensitive habitats that may be affected by bivalve aquaculture.*

SUMMARY

- There are at least five main types of bivalve aquaculture (suspended mussel culture, suspended oyster culture, bottom oyster culture, near-bottom oyster culture and intertidal clam culture) practised in Canada. All of these types of culture have their own particularities and occur in a wide range of marine environments, varying in flushing time, depth, temperature and sediment type that determine the potential for adverse habitat effects.
- Most of the information presented at the workshop was based on the suspended culture of mussels on the east coast of Canada, which accounts for approximately 80% of the value of the Canadian shellfish culture industry.
- In natural systems, bivalves can play a number of important roles affecting diversity, abundance and productivity of organisms at other trophic levels. Bivalves affect ecosystem energy flow and nutrient cycling and may affect benthic and pelagic community dynamics and structure.
- Interactions in the coastal zone between farmed bivalves, nutrient loading and dynamics are highly complex and all aspects need to be balanced objectively and integrated quantitatively before conclusions can be reached with regard to net habitat effects of bivalve aquaculture and other anthropogenic activities.
- Most effects of bivalve aquaculture seem to be related to the scale (intensity and extent) of aquaculture rather than the type of infrastructure.
- Different modeling techniques are available to predict the potential environmental effects of bivalve culture. They may be used to test scenarios of site suitability or to direct monitoring strategies and provide information within a decision-making framework.
- It is important for monitoring programs to maintain some flexibility for adding or removing specific habitat indicators in order to address different culture and ecosystem situations. The robustness of the sampling design is also a key element for implementing a monitoring program.
- Current management practices for regulation of bivalve aquaculture in Canada are focused on site-by-site assessments. New observation methods and management approaches are required to quantify cumulative effects from all anthropogenic influences in coastal areas where intensive bivalve aquaculture has the potential to cause broad-scale, ecosystem-level changes.

INTRODUCTION

Section 35 of the *Fisheries Act* prohibits the harmful alteration, disruption or destruction (HADD) of fish habitat unless authorized by the Minister or regulations. DFO Habitat Management's policy framework related to application of section 35 of the *Fisheries Act* is based on principles such as the conservation of productive capacity of fish habitat, the avoidance and mitigation of fish habitat effects wherever possible, and the application of a Risk Management Framework.

Habitat Management has been managing aquaculture impacts to fish habitat on a site-by-site basis by applying Section 35 of the *Fisheries Act* to fish habitat reviews and through various other regulatory mechanisms. Assessment of environmental baseline conditions and monitoring is important to determine habitat effects and to guide the adaptive management of bivalve aquaculture sites. Habitat Management may also have responsibilities under the *Canadian Environmental Assessment Act* for conducting environmental assessments of proposed projects, or for providing expert advice on fish and fish habitat for the purposes of environmental assessments conducted by other federal departments.

Habitat Management has sought science advice to support defensible assessments of the risk to fish habitat posed by bivalve culture, thereby supporting the management decisions that flow from that risk assessment. Tools are needed by Habitat Management to support decisions regarding bivalve aquaculture in order to: identify all potential environmental effects; predict and assess the risk to fish habitat posed by bivalve culture, both in terms of scale of potential negative effects and the sensitivity of fish and fish habitat; to mitigate those risk factors; and, to monitor habitat changes as part of an adaptive management regime.

Priority areas for science advice were summarized in a series of 5 groups of questions:

1. What are the positive and the negative effects (benthic and/or water column) of marine shellfish aquaculture on fish habitat? How do shellfish aquaculture effects on fish habitat differ from the natural effects of wild shellfish? What are the effects of the physical structures used in shellfish aquaculture on fish habitat (including lines, socks, bags, predator control devices, etc.)? How can these effects be assessed or measured?
2. What chemical, biological or physical indicators developed and in use for monitoring the farm-scale fish-habitat effects of marine finfish aquaculture are applicable to monitoring shellfish aquaculture effects? Describe the thresholds that apply. What other indicators are available specifically to measure these shellfish aquaculture effects? What are the thresholds for these potential indicators?
3. What modeling methodologies or techniques are available to provide predictions of the potential effects of shellfish aquaculture operations on the marine environment? What are the advantages and disadvantages of these methodologies or techniques?
4. What are the cumulative and far-field effects of shellfish aquaculture in fish habitat? How can the cumulative fish habitat effects of shellfish aquaculture (e.g. marine eutrophication, oxygen or phytoplankton depletion, community shifts, exceeding carrying capacity) be quantified? What tools or indicators are useful for quantifying the far-field or ecosystem-scale fish habitat effects of shellfish aquaculture? What are the advantages and disadvantages of these tools or indicators?
5. What types of fish habitat are likely to be affected by shellfish aquaculture? How sensitive (in relative or absolute terms) are these habitats to shellfish aquaculture effects?

ASSESSMENT

1. Positive and negative impacts of marine bivalve aquaculture on fish habitat

In natural systems, bivalves play a number of important roles that can affect the diversity, abundance and productivity of organisms at different trophic levels. Bivalves affect ecosystem energy flow and nutrient cycling and when present in high abundance may alter benthic and pelagic community dynamics and structure. Bivalves in culture appear to fill many of the same ecological roles as natural bivalve communities.

Suspended mussel culture is the best studied of several types of bivalve aquaculture but generalities from these studies and extrapolation to other types of systems may not be warranted. Localized bio-deposition due to enhanced sedimentation of feces and pseudofeces from suspended or off-bottom bivalve culture may focus organic loading, potentially leading to hypoxic and anoxic sediments that alter local infaunal communities. Because the absolute and relative scales of lease and inlet or bay area are important, scaling analysis is required for inter-system comparisons.

The abundance, biomass and diversity of species growing on or directly associated with bivalve culture are usually considerable. Numbers of large invertebrates like sea urchins, starfish, crabs and lobster, and fishes can be enhanced in bivalve culture areas; however, it is not known if net productivity is increased. Physical structures, such as rafts, blocks, ropes and buoys, and shell deposits on the bottom related to culture operations may add hard substrate and three-dimensional habitat that further enhance the diversity and abundance of biota.

2. Chemical, biological or physical indicators available to measure these effects

There are many potential indicators (Table 1) but few threshold values that define significant changes to fish habitat. Methods and thresholds are available for bio-geochemical indicators, such as total free sulfides and redox potentials in soft sediments, to assess the degree of organic enrichment in the immediate vicinity of bivalve operations and to be applied in operational monitoring programs. Sediment imaging techniques have also been used successfully to assess physical and biological habitat structure and provide qualitative and some semi-quantitative information on potential bio-geochemical changes.

Table 1. Recommended indicators of bivalve aquaculture habitat effects with the associated spatial scale of impact that each can address.

Indicators	**Spatial Scale**
1) Benthic Habitat	
• Geochemical (total free sulfides, redox potential, organic content, porosity)	Lease
• Imaging (sediment profiling, video)	Lease
• Benthic community biotic indices (indicator species, trophic indices, indices of biological integrity)	Lease
2) Pelagic Habitat	
• Secchi depth	Lease
• Chlorophyll depletion	Lease-bay
• Bacteria/Chlorophyll ratio	Bay
• Picoplankton/Chlorophyll ratio	Bay
• Performance of caged and cultured bivalves (condition indices, shell/meat weight and growth, biochemical indicators)	Lease-bay
• Farm inventory (production, stocking density/biomass, mean yield per cultured unit)	Lease-bay

Monitoring programs should maintain flexibility to add or remove indicators and to address different types of culture and ecosystem situations. Monitoring programs should also be based on robust sampling designs that include lease and reference sites and replicates and controls to account for potentially confounding factors. It is also important to have well-defined protocols for data quality and access. Industry information on site-specific farm husbandry and production data would greatly improve environmental assessments of bivalve aquaculture for both near and far-field effects.

Near-field habitat assessments are focused primarily on benthic habitats in the immediate vicinity of each shellfish aquaculture lease. Ecosystem-level interactions with shellfish aquaculture populations are more complex than for finfish culture. Effects on fish habitat can extend beyond site-specific footprints and lease monitoring does not allow broad-scale, ecosystem-level effects to be understood or measured. Measurements of variables in far-field benthic and pelagic habitats are needed because deductions from existing ecological knowledge indicate possibilities for altered system states. Monitoring and modeling approaches using mass balance models and indices (ratios) of critical variables were identified with a potential for quantifying broad-scale, ecosystem-level changes associated with intensive bivalve aquaculture.

Baseline assessment and operational monitoring of bivalve aquaculture sites could be based on a tiered approach that includes different levels of monitoring effort and associated indicators that are proportional to the perceived risk. A comprehensive monitoring program could be based on models and understanding of habitat sensitivity, the nature of the operation, such as size, species and husbandry, and previous measurement and verification of environmental impacts.

3. Modeling methodologies available to predict the impacts of bivalve aquaculture

There are a number of models available to assess the effects of bivalve aquaculture on the marine environment. In general, these are prognostic and able to synthesize information and develop scenarios of potential effects that can be transferred to other areas. The most effective models for indicating habitat changes due to intensive bivalve aquaculture are simple, calculating interactions between important processes rather than simulating all interactions within an entire ecosystem.

The choice of a model to assess potential habitat effects due to bivalve culture should be tailored specifically to the question of interest. All model output should be interpreted with caution and used in concert with other site information. Three types of models, near-field waste-sedimentation models, lower-trophic box models, and simple index models, were examined. The first one addresses near-field concerns while the latter two examine far-field effects.

Near-field models such as DEPOMOD simulate the trajectory of particles from farm sites to assess the degree and extent of particulate sedimentation and associated changes in the benthos. The model is applicable only to suspended culture. The case study of a mussel farm in the Magdalen Islands showed that the model proved to be a reasonable predictor of particulate sedimentation when compared to observed fluxes. The model has promise in terms of understanding near-field benthic effects of shellfish aquaculture, particularly testing scenarios on the degree and extent of increased flux with changes in site conditions such as depth, stocking density and hydrodynamic regime. This type of model could also be used to identify situations where there is little risk to the benthic environment. Further work at additional sites is needed to increase confidence in the model's predictive capability.

Lower-trophic box models are well established and readily adapted to include bivalve aquaculture. Box models are useful for understanding the coupling and the dominant processes between nutrients, phytoplankton, detritus, and bivalves. However, these models are not predictive and are still primarily research tools with the aim of understanding dominant ecological processes.

Index models are available to predict bay-wide outcomes of waste production and removal under different scenarios of aquaculture production. A feature of these models is that they are interactive, allowing scientists, managers and aquaculturists to work together and decide on appropriate input parameters and their variances, which can be applied to questions related to an entire bay. These models can provide guidance for management considerations but cannot be used for forensic evidence. One limitation of index models is that they are focused on the biogeochemistry and processes that occur at lower trophic levels. Index models do not partition alternative sources of nutrient mobilization, which is important in bays that are eutrophic. Because they assume that everything is spread throughout the bay simultaneously, these models are unable to describe local inputs and effects.

All the models examined are constantly evolving. They are useful to identify realistic indicators of ecosystem health and for building a decision-making process among regulators, developers and stakeholders, from large-scale to small-scale: 1) What bays are suitable for aquaculture and how much aquaculture? 2) What information is needed to define potential sites and impacts? 3) Where and what should be monitored?

4. Cumulative and far-field effects of bivalve aquaculture

The distinction between “near-field” and “far-field” effects is arbitrary. In the context of shellfish aquaculture, the term “far-field” effects can simply be defined as the influence of the shellfish on ecosystem processes and structure at some distance from the farm. Research into the influence of bivalve aquaculture on the environment is a relatively new field of study. Up to now, most research has focused on near-field effects on the benthic environment. Limited research has documented far-field, for example bay-scale, effects of various types of bivalve culture on lower trophic levels (nutrients, phytoplankton, zooplankton) and demonstrated or suggested some higher-level and other ecosystem-scale and cumulative effects.

Because the absolute and relative scales of lease and inlet or bay area are important, scaling analysis is required for inter-system comparisons. Ecological processes operate within a hierarchy of scales, and small-scale studies or patterns do not necessarily scale up to larger areas. The potential for far-field effects of a bivalve farm or farms in a given system becomes a question of understanding the scale of lease area and production relative to the inlet or bay where culture occurs, modulated by the oceanographic characteristics of the system. Synergistic effects, antagonistic effects, threshold effects and non-linear effects have all been documented but do not provide clear direction. Thus, ecosystem-scale studies are required to understand and predict far-field effects of shellfish aquaculture.

Interactions in the coastal zone between farmed bivalves and nutrient loading are highly complex (Figure 1) and all aspects need to be balanced objectively and integrated quantitatively before conclusions can be reached regarding the net habitat effects of bivalve culture and other anthropogenic stressors. Cumulative effects with other human activities in coastal ecosystems are recognized but generalizations and multi-system studies are lacking.

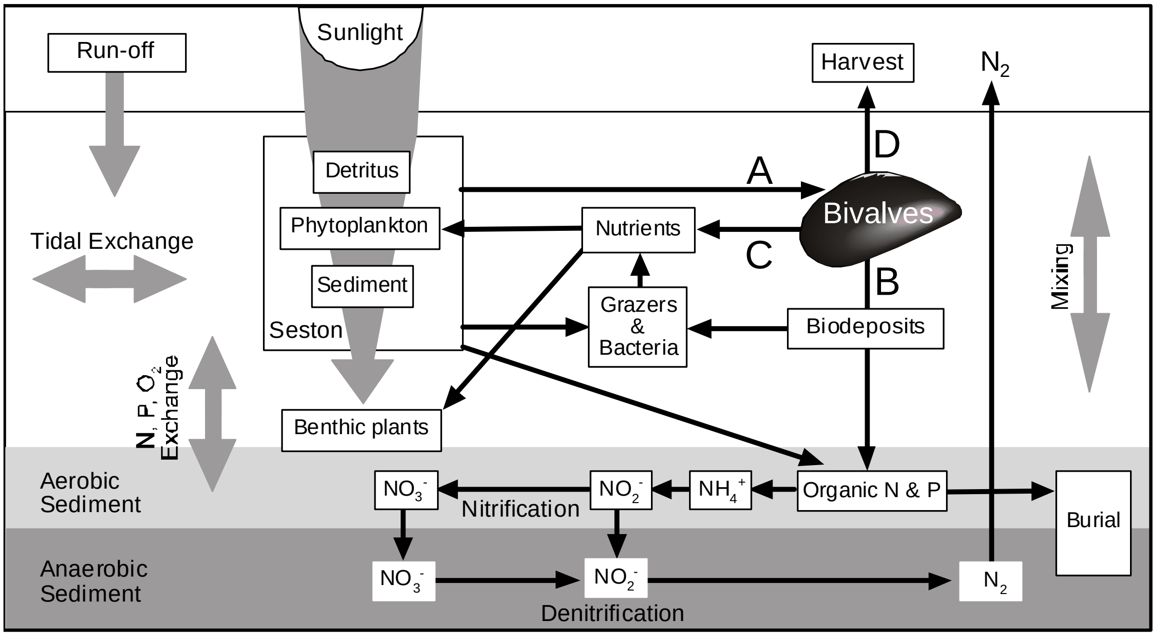


Figure 1. Conceptual diagram of bivalve aquaculture interactions in coastal ecosystems related to: (A) the removal of suspended particulate matter (seston) during filter feeding; (B) the bio-deposition of undigested organic matter in feces and pseudofeces; (C) the excretion of ammonia nitrogen; and (D) the removal of materials (nutrients) in the bivalve harvest.

When a preliminary qualitative risk assessment suggests that there may be a significant alteration of fish habitat and the ecosystem, the development of a quantitative approach could be considered for assessing the net changes in fish habitat as a result of human activities, including bivalve aquaculture. Bay-wide management offers: the selection of reference sites (or even protected sites) to gauge impacts and protect sensitive habitats; focusing monitoring methods at an appropriate scale to capture cumulative impacts; controlling the pace of aquaculture development and determine when the bay-wide carrying capacity has been reached; and, placing shellfish aquaculture within the context of other human activities that may affect the bay, including watershed activities.

5. Habitats likely affected by shellfish aquaculture

Bivalve species, indigenous and cultivated, are an integral component of marine ecosystems and, coupled with hydrodynamic processes, can have both direct and indirect effects on various other biotic communities. The type and intensity (scale) of the culture activities, the seasonal and physical characteristics of the aquaculture site and the state of the marine habitat being assessed, in relation to other anthropogenic activities, are all determining factors in terms of habitat sensitivity to shellfish aquaculture. For example, a shallow, protected, well stratified, soft-bottomed bay with warm summer-surface temperatures and abundant phytoplankton may not be able to maintain an oxygenated surface sediment layer (or even an oxygenated water column) when an additional particulate carbon supply is added to the sediments due to the presence of bivalve culture at high densities.

The literature on the effects of bivalve aquaculture on sensitive habitats is currently fragmented and not conclusive. Studies to quantify effects are presently ongoing. At this time, the relative sensitivity of different habitats to shellfish aquaculture has not been quantified. Nor is it possible to comment on any regional differences across the country.

Sensitive habitats, like eelgrass beds, play a structural and functional role in their ecosystem and are vulnerable to human activities. Where effects on sensitive habitats and species, such as eelgrass, are possible, enhanced assessment and monitoring of those effects should be considered.

CONCLUSIONS AND ADVICE

(Not in any order of priority)

1. Research is required to develop robust sampling designs for monitoring shellfish aquaculture effects in coastal regions. This includes identification of effective designs for regions where there are potential bay-wide effects and where traditional reference sites (located outside leased area) may also be affected. Particular attention should be paid to determinations of suitability of reference sites, cost-benefit of monitoring programs and suitability of various indices in terms of predictive capability, ease of calculation, sources of error, and data requirements.
2. Shellfish aquaculture often occurs in sheltered bays and estuaries because they offer suitable substrate. Such areas are often highly productive environments and key habitats for many migratory species. Work is required to study how potential impacts of bivalve culture (human activity, presence of structures on the seabed and in the water etc.) influence species in these ecosystems.
3. Research is needed to identify methodologies and a standard approach for assessing local and far-field effects on benthic organisms to determine the net effect of shellfish aquaculture on the productivity of benthic habitat.
4. A survey of various modeled indices and/or frameworks should be undertaken to designate the most robust options in terms of predictive capability, ease of calculation, sources of error, and data requirements.
5. Testing of DEPOMOD at additional sites in a range of environmental conditions is essential to define applicability and to provide confidence in model predictive capability. Research on the linkage between increased flux of shellfish bio-deposits and changes to the benthic status (benthic fauna/sediment chemistry) is required to improve model utility to habitat management.
6. Given the almost complete lack of knowledge on the types of habitat that may be negatively affected by shellfish aquaculture, more research on sensitive habitat is needed.
7. Acoustic remote sensing systems can be useful tools for collecting important layers of information such as bathymetry and general physical features of the substrate (hardness and roughness). However, more research is needed in the interpretation of acoustic seabed classification data before we can translate this information into biologically relevant habitats.
8. Observations of the dominant role of suspended mussel culture in controlling microplankton (bacteria and phytoplankton) structure and productivity and the nitrogen cycle in Tracadie Bay, PEI, warrant similar studies in other major aquaculture embayments in Canada. This work would help to determine if there are changes in pelagic food webs and would allow cumulative effects and broad-scale, ecosystem-level effects to be better understood and measured.

9. The role of bivalve culture in transfer and enhancement of exotic species needs to be better studied, including potential effects on indigenous fauna and their role in controlling coastal ecosystem structure and dynamics.
10. Research is required on far-field shellfish feeding effects on the size structure of the phytoplankton community (e.g. increased dominance of picoplankton and bacteria) in different regions in Canada to determine if far-field effects of shellfish feeding can be detected. Related research is needed on the consequences of potential changes in pelagic microbial food webs at shellfish aquaculture sites to consumer organisms including zooplankton, herbivorous fish and invasive species. The possibility of induced trophic cascades leading to ecosystem regime shifts cannot be discounted.
11. Work is needed to identify thresholds values that represent significant changes in fish habitat as indicators of shellfish aquaculture effects on pelagic communities.
12. Predator interactions associated with shellfish culture need to be assessed, including the implications of predator control, its necessity, and how benthic and pelagic food webs at higher trophic levels are affected. This study would include the effects of human activity and presence of structures in the water on migratory species, marine mammals and other predators.

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