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Monitoring for benthic impacts in the southwest New Brunswick salmon aquaculture industry

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Salmon aquaculture has been undertaken in southwest New Brunswick since the late 1970s. By 1986, there were 28 salmon farms, the industry was expanding rapidly, and researchers had started proposing methodologies for tracking benthic impacts. As a result of a number of projects conducted to determine a cost-effective monitoring protocol, and in consultation with aquaculture industry representatives, an Environmental Monitoring Program (EMP) was adopted in 1995. This programme is a requirement of the aquaculture site licence and is conducted annually at each farmed site. The programme is now under review with the aim of refining the scientific information that is used in assigning an annual site impact rating. The development of the current Environmental Monitoring Program and the Federal and Provincial responsibilities with respect to environmental protection under which the monitoring programme was developed are discussed. A description of the scientific rationale and the industry requirements with respect to production that has led to the proposed changes to the current programme is included.

Key words: monitoring, benthic impacts, aquaculture.

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Introduction

Early in the development of the salmon mariculture industry in southwest New Brunswick, a number of incidents alerted the industry, the developing agencies, and the regulators that the relationship between aquaculture and the marine environment was an issue that needed to be better understood. Super chill and poor growth challenged theories of site placement. Disease challenged ideas of production levels and timetables for growth. Microalgal blooms challenged our knowledge of harmful algal blooms and their impact on oxygen levels. These factors led to the development of projects to monitor impacts at cage sites, first from a scientific perspective (Wildish *et al.*, 1990a,b), and later from the perspective of refining management practices for better economic and sustainable outcomes.

Other jurisdictions throughout the world where aquaculture is pursued have experienced the same types of challenge and responded by developing a monitoring programme. However, in each jurisdiction there are differences in regulatory framework, local benthic and hydrographic characteristics, or politics that are reflected in the form monitoring takes. In New Brunswick, there has been the recognition that the Environmental Monitoring Program (EMP) initiated in 1995 had shortcomings. This paper attempts to identify those shortcomings and the method in which they will be addressed through the revised EMP. The New Brunswick experience may provide useful lessons for those embarking on a monitoring programme.

Brief history

The New Brunswick salmon aquaculture industry has grown from one farm in 1977 to 90 sites in 1999 (Table 1). The estimated value of the marketed product reached a high of $139 million in 1997. Because of the infectious salmon anaemia (ISA) virus and subsequent eradication of fish on about 20 sites in 1998, the annual crop value dropped to $106 million in 1998. This compares with the 1979 value of $40 000. Salmon aquaculture in New Brunswick is concentrated in the southwest part of the province in the Bay of Fundy between the Maine, USA, border and Saint John. At

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Table 1. Production statistics for the New Brunswick salmon aquaculture industry, 1979–1998. *Source:* New Brunswick Department of Fisheries and Aquaculture.

Year	N smolts	N market fish (estimate)	N farms	Production (t)	Price/kg ($Can.)	Value ($Can.)
1979	4 000	1 540	1	6	7.27	40 286
1980	7 200	3 600	2	13	7.27	94 176
1981	13 300	6 480	2	24	7.51	175 219
1982	22 000	11 970	4	44	8.33	359 100
1983	78 000	19 800	4	72	10.00	712 800
1984	122 000	70 200	5	255	11.67	2 948 400
1985	222 000	109 800	18	399	12.11	4 787 280
1986	477 000	199 800	28	727	12.82	9 222 768
1987	880 000	429 300	33	1 561	14.11	21 808 440
1988	1 220 000	792 000	36	2 880	13.33	38 016 000
1989	2 220 000	1 098 000	49	3 993	9.44	37 332 000
1990	2 600 000	1 998 000	52	7 265	10.00	71 928 000
1991	2 700 000	2 340 000	57	8 509	10.00	84 240 000
1992	3 100 000	2 430 000	60	8 836	9.47	82 738 584
1993	3 500 000	2 883 000	67	10 484	8.89	92 256 000
1994	4 300 000	3 499 965	67	12 727	7.78	97 999 020
1995	4 731 500	4 140 040	71	14 490	7.78	111 574 078
1996	4 860 845	4 680 021	74	16 380	7.55	122 522 957
1997	5 515 164	5 310 000	76	18 585	7.55	139 015 800
1998	4 029 913	3 880 000	78	14 232	7.55	106 678 400

present, it is the single largest food commodity in New Brunswick, based on the annual value of salmon sold.

Memorandum of understanding

In April of 1989, the government of Canada, through the Minister of Fisheries and Oceans (DFO), and the government of New Brunswick, through the Minister of Fisheries and Aquaculture (NBDFA), signed a Memorandum of Understanding (MOU) that identified their respective regulatory roles. The intent of the agreement was to establish a mutual regime for the orderly development and growth of aquaculture. The agreement covers any aquatic flora or fauna that may be husbanded or cultured in New Brunswick.

The institutional arrangements required the establishment of a management committee composed of the Regional Director General of DFO and the Deputy Minister and Assistant Deputy Minister of NBDFA. They have the power under the MOU to establish sub-committees.

Under the MOU, the federal government, through DFO, is to continue to carry out and sponsor scientific research and development, including research on aquaculture ecology and the optimization of biological systems. The province of New Brunswick, through NBDFA, is responsible for applied aquaculture research, such as disease diagnosis and prevention. Both parties are to give priority to research and development programmes. New Brunswick is responsible for education, licensing, and leasing, and the administration of licensing and leasing. Both parties "shall conduct periodic inspections of aquaculture facilities to determine compliance with their respective acts, regulations and guidelines, and will provide the other with the results of those inspections" (MOU, 1989).

One of the sub-committees that has been established through the MOU is the Aquaculture Environmental Coordinating Committee (AECC), which is co-chaired by the two signatories of the MOU. Membership includes industry, representing both grow-out and hatchery operations, NBDFA, DFO, Environment Canada and the New Brunswick Department of the Environment and Local Government (NBDELG). This committee establishes the annual research agenda required to obtain more knowledge about aquaculture/environmental interaction so that this information can contribute to policy and management decisions. In addition, the committee reviews all activities and projects relating to aquaculture environmental interaction (AECC, 1993). The AECC is currently developing a revised Environmental Monitoring Program for salmon aquaculture.

Site development and management process

While this paper focuses on the EMP, the programme is only one of the components in the development and management of the industry. When a farmer expresses an interest in a site through an application (Application Guide; New Brunswick Regulation 91-158), the site is subjected to a pre-site assessment. This involves a depth

profile, recording current speed and direction, a 100-m transect line with grab samples to determine bottom characteristics and redox readings, an assessment of flora and fauna, and a video along the transect line. The information provided must conform to the Site Allocation Policy (DFA, 1992). The proposal is reviewed by various member agencies in the Aquaculture Site Allocation Committee, which is composed of provincial and federal regulators. That group, which is an advisory body to the Minister of Fisheries and Aquaculture, makes a recommendation to the Minister. A site is approved by the Minister and a production level for the site is identified (NBDFA, 1993). The production number is incorporated into the licence and lease issued by DFA to the fish farmer. Licence conditions state that each site must be monitored on an annual basis following the protocol identified in the EMP. The site rating must be submitted to the DFA Registrar of Aquaculture.

Just as the EMP is in the process of being revised, so too is the pre-site assessment and the Site Allocation Policy. In addition, responsibilities of provincial government agencies are changing so that NBDELG will be issuing an Approval to Operate which requires compliance with the EMP and reporting of raw data. This intensive update of policies and guidelines is representative of the evolution of the industry from one of development to one of a mature industry requiring more rigorous attention to management and environmental factors. Much of the push for these revisions comes from the industry itself as a result of the experience gained over the years, and the recognition of the need for both an environmentally and economically sustainable industry.

Development of the original EMP

Government-led environmental monitoring at salmon aquaculture cage sites began in 1991. For the first two years the programme was carried out by the New Brunswick Department of Environment. The programme protocol was developed by divers and biologists working for the Department of Environment at the time, after reviewing recent literature and programmes elsewhere. Results of the overall programme were made available to the public.

In 1993, NBDFA commissioned a consulting firm, Washburn & Gillis Associates Ltd., through funds from the New Brunswick Environmental Trust Fund, to develop a monitoring programme that would be conducted annually at each salmon aquaculture lease site (Washburn & Gillis Associates Ltd, 1995). The consultant was to: review aquaculture monitoring programmes previously used, or in use, in the region in order to identify the responsibilities of all parties, the essential parameters, the schedule, costs, mechanisms for implementation and reporting, and consult with industry and NBDFA to develop a consensus on the procedures and the process of transfer of financial support from government to industry.

The intention was to develop an industry-led finfish aquaculture environmental management plan. At the time, it was believed that industry compliance with the programme would be greater if its development was an active consultative process. Also, industry was very concerned that individual site information not be released to the public and, to achieve this, the best method at the time was to have only the basic information on site ratings submitted to the Provincial Registrar of Aquaculture, in fulfillment of the license requirements. The other data requirements of the EMP were not considered crucial to compliance. Consequently, as is evident by Table 3, industry frequency did not provide the information to the contractor.

The consulting firm developed the current EMP through a consultative process with industry, NBDFA, DFO, and the AECC. The final draft of the EMP was accepted in October 1995. The scientific basis was contained in numerous DFO reports from the 1980s (not cited in Washburn & Gillis Associates Ltd, 1995), (Thonney and Garnier (1994)), and is based on monitoring carried out for the Department of Environment and the criteria established by NBDFA (1993) for determining the size of sites and production levels of aquaculture operations in the Bay of Fundy. Although reference is made in Thonney and Garnier (1994) to the need for sediment redox measurements, this requirement was dropped after discussions with industry.

The EMP developed contained the following requirements (Washburn & Gillis Associates Ltd, 1995):

Structure, implementation, and responsibilities

- Licence-holders are responsible to have the programme conducted at their sites. This has later become a condition of their licence.
- Each licence-holder receives a report from the contractor identifying conditions at the site.
- DFA receives a letter from the grower indicating the site rating.
- An annual report giving industry-wide, but no site-specific data, is available to the public.

Site production information required

- site diagram, cage numbers, and raft configurations;
- site operational age and age of operations at specific rafts;
- fallowing or cage rotation schedules;
- feed types, rates, and techniques; locations of age classes of fish;
- surface and bottom current speeds and directions over a tidal cycle;

Table 2. Observed or measured under-cage benthic conditions that determine the rating categories.

Rating	Observed/measured conditions
Low (a)	Erosional sea floor (silt/clay <30%). Bacterial coverage <25%. Wide diversity of epibenthic macrofauna, occurrence of strong current and/or hard bottom species. Conditions under cages similar to control sites.
Moderate (b)	Moderately depositional sea floor (silt/clay between 25 and 90%). Bacterial coverage 25 to 100%. No gas bubbles released from the sediment. Less diversity but higher biomass than control sites. Occurrence of low oxygen-tolerant species, but absence of strong current and/or hard-bottom species.
High (c)	Depositional sea floor (silt/clay >90%). Bacterial coverage grey or absent. Gas bubbles freely released from sediments. No epibenthic macrofauna or benthic in-fauna.

- harvesting schedules, fish health information, including information on superchill, parasites, and net conditions and changing;
- water quality data such as temperature, salinity, and dissolved oxygen.

Environmental information required

- video transects under cage rafts;
- sediment samples to be analysed for grain size and total organic carbon;
- depths relative to mean low water of video and sediment sample locations;
- qualitative assessments including: sediment colour, sediment consistency, sediment odour, outgassing, bacterial mat coverage, macrofaunal abundance, feed and faeces distribution, current speed direction and tidal slack period, general site aesthetics. This includes also water quality.

Video transects must begin at the centre of the cage configuration in a downstream direction of the prevailing current ending 50 m beyond the cage edge. The section on sediment sampling and analysis describes where the sediments are to be taken: directly under the cage raft, at the cage edge, and downstream 30 m. The monitoring is to take place annually between August and November. If a site receives a poor rating, it is to be monitored again in March of the following year.

There were three ratings [Table 2(a), (b) and (c)]. The observed conditions that identify the degree of impact were developed mainly during the initial environmental monitoring programme conducted by the Department of Environment.

Although the information collected was qualitative, the report by Washburn & Gillis Associates Ltd (1995) emphasized the need for consistency. In an attempt to introduce consistency, they suggested that only one contractor complete all the work, although a team of divers could be used. General instructions on how to obtain consistency were provided, but the judgement of the consultant has been relied upon almost exclusively. In 1998, there was an independent audit conducted using the same qualitative parameters. Results correlated quite closely with those of the contractor.

Table 3 presents a brief description of the requirements of the current EMP and the degree of compliance. One of the main benefits has been that licence-holders obtain annual information about their site and the contractor provides advice to the licence-holder on measures to improve environmental conditions.

Proposed revised EMP

A requirement of the current EMP is that it be reviewed and revised as required on a regular basis. AECC is the group whose mandate is to undertake that review. The Canadian Environmental Assessment Act (CEAA) recognizes the value of this approach and is incorporating it in the development of its revised EMP to the extent of its mandate. This means that any such programme must meet the needs of both regulators and operators and be cost-effective.

As a result of the deficiencies identified previously, it was felt, by both the regulatory agencies and industry, that more scientifically defensible data were required in a revised EMP. Scientifically defensible data would facilitate management strategies by providing a rationale for the implementation of new management practices, such as the use of Bay Management Areas, and provide a basis for the evolution and improvement of these strategies.

Regulators always need to have a monitoring programme that provides assurances that their regulatory responsibilities are being met. The Habitat Management Division (HMD) of DFO administers Section 35.1 of the Fisheries Act, which states that "No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat" as the result of the siting, expansion, or operation of an

Table 3. Record of compliance to the elements of the current EMP.

EMP requirement	Degree of compliance
EMP continually reviewed and updated between NBDFA and NBSGA	Inconsistent. Some changes were agreed to. Some were made by contractor owing to lack of information provided by growers.
Growers have annual monitoring conducted at their sites.	Excellent.
Letter with results submittted to DFA	Inconsistent. Timetable for submission inappropriate for any government response.
Annual report submitted to DFA by contractor	Excellent.
Site diagram	Provided by contractor rather than grower.
Cage numbers, raft configuration, etc.	Provided by contractor rather than grower.
Operational age of site and raft locations	Known to contractor – not recorded in site reports.
Age class of fish per location	Not available.
Feed types, rates, and techniques	Not available.
On-site fallowing or cage rotation schedule	Not available.
Surface and bottom current and directions over tidal cycle	Rough estimate provided by contractor.
Harvesting schedules	Not available.
Fish health information	Not available.
Water quality data: temperature, dissolved oxygen, salinity	Temperature and salinity not available to contractor though growers often have this. Dissolved oxygen available through EMP.
Video transects under cages	Done. No assurance that transects represent same location from year to year.
Grain-size samples and TOC	Available through EMP.
Depths of video and sample locations	Available in report to each grower; not available to government except on request.
Qualitative assessments: sediment colour, consistency, odour, outgassing, bacterial mat coverage, macrofaunal abundance, feed and faeces distribution, current speed and direction and tidal slack period, general site aesthetics	Available to grower, but not to government except by special request made to individual grower.

aquaculture facility either at the cage site or as the result of far-field (cumulative) effects.

For the purposes of salmonid aquaculture, unacceptable habitat conditions occur when the sediment becomes anoxic. This is defined by the absence of macrofauna and a change from aerobic to anaerobic microflora, as indicated by geochemical measurements of sulphide and redox potential (Eh).

Hypoxic conditions, as defined by the presence/absence of macrofauna or microflora, as indicated by geochemical measurements of sulphide and redox potential (Eh), would be of concern to DFO. In cases where hypoxia is demonstrated, remediation measures would be indicated to mitigate the situation and to prevent further progression to anoxia (Wildish *et al.*, 1999).

In extraordinary circumstances, where it may be impossible to protect fish habitat by changes in the project design or by other mitigation to lessen harmful effects, the Minister of Fisheries and Oceans may issue an authorization under Section 35.2 of the Fisheries Act to undertake a project that will cause a harmful alteration, disruption, or destruction of fish habitat. Fisheries Act authorizations are contained in the Law List Regulation of the Canadian Environmental Assessment Act (CEAA) and a federal environmental assessment would be required. Authorizations cannot be issued retroactively; they apply only to new proposals.

An authorization would require the proponent to incorporate mitigation into the development plan and to provide compensation for any lost habitat that cannot be mitigated. This requirement is the result of DFO's Policy for the Management of Fish Habitat, which has as a guiding principle the "no net loss" of productive capacity of fish habitat and a "net gain" of fish habitat as a policy objective. This is fundamental to the policy's habitat conservation goal of maintaining "the current productive capacity of fish habitats supporting Canada's fisheries resources, such that fish suitable for human consumption may be produced".

The NBDELG has responsibility under the Water Quality Regulations – Clean Environment Act and the Clean Water Act to ensure the health of the marine environment. The New Brunswick Water Quality Regulation identifies that approvals are required where direct or indirect water pollution is caused to the waters of the Province. The NBDFA is concerned with maintaining an environmentally and economically sustainable marine ecosystem. This Department views healthy habitat as the cornerstone to sustainable development in the marine environment.

Industry also requires accurate, repeatable, and appropriate measures of the environmental condition of the benthos in the area of their lease to have assurance that their management practices and stocking plans are providing for optimum growing conditions. In addition, the appropriate measurements, such as sulphide and redox potential (Eh), provide major input in the determination of the estimated site potential for models like those developed by SEPA (1998), and any that may be considered for application to the aquaculture industry in southwest New Brunswick.

Hargrave *et al.* (1997) investigated the potential measurements of organic enrichment in sediments under aquaculture sites, showing that total sulphide, Eh, sediment O_2, and CO_2 release were the most sensitive. Wildish *et al.* (2001) demonstrated that sulphide and Eh of surface sediments were also the most cost-effective measurements in comparison with conventional macrofaunal sampling. These geochemical measurements should also fulfil the requirements of the Fisheries Act with respect to defining habitat destruction. Final pilot studies are underway that will incorporate the use of sulphide and Eh potential into this year's monitoring programme. It is expected that this will have a twofold result. It will provide data to refine the SEPA (1998) matrix-based approach to determine a level of site potential that is suitable for the southwest New Brunswick environment. This tool has been recommended for application to the New Brunswick aquaculture industry (Washburn & Gillis Associates Ltd, 1999). It will also provide a comparison with the results of the current EMP to determine if a historically consistent record of results can be maintained when a revised EMP is adopted. DFO's habitat protection mandate would also likely be met by an EMP that included Eh and sulphide measurements as the cornerstone, provided that adequate quality assurance measures were implemented and an audit procedure was in place to provide assurance that the objectives were being met.

The individual operators bear the cost of the annual environmental monitoring as a condition of their lease agreements. The incorporation of the additional tests is not expected to increase the costs from those incurred by the current EMP.

The eventual outcome will be a revised EMP that will incorporate the scientifically based measurements of the current programme with the additions of sulphide and Eh measurements, together with the video transects and observational records of the consultant conducting the monitoring (Table 4). What has been outlined here as the proposal is still in the development stages. The process of development is an interactive one, with the AECC taking the lead role of identifying parameters that meet the scientific criteria and reflect the agency and industry responsibilities. The proposal for the revised EMP must have a consensus from the AECC members. It is then submitted to NBDFA as the leasing and licensing authority and to the New Brunswick Salmon Growers' Association to confirm their support. Implementation is expected in 2001.

Table 4. Major environmental parameters for current and proposed EMP (visual assessment includes % bacteria cover, % waste feed cover).

Parameters	Current EMP	Proposed EMP
Video transects	×	×
% Volatile solids	×	×
Silt/clay ratio	×	
Qualitative assessment	×	×
Redox potential (Eh)		×
Sulphides		×

Discussion

The aquaculture industry in southwest New Brunswick has now matured beyond the initial development stages. Ensuring that policies and management practices lead to long-term sustainability is now key to industry, government, and the public. For sustainability to be ensured, a cooperative approach is required between industry and government.

There is increased recognition by industry that government mandates must have a respected place in a monitoring programme. This requires that the monitoring provide more scientifically justifiable data. It also requires that a mechanism be developed to fulfill the industry requirement for confidentiality of information, while allowing the agencies regulating and developing the legislated and the researchers involved in activities critical to the sustainability of the industry to have access to the data. This is one of the unresolved challenges for the revised EMP.

The revised EMP will not give a complete picture of all the environmental effects that are attributable to aquaculture. For instance, it will not address water quality, nor does it consider biodiversity. As discussed, it uses proxy measures designed to address the regulatory mandates of the government agencies involved and to provide indications to the operators of environmental conditions about which they should be concerned.

Industry has been reluctant to provide information on other factors that could provide more accurate predictions of the effects of aquaculture on the environment and vice versa. Information such as stocking density and biomass, and other requirements listed in Table 3 as unavailable, is absent because of industry's concern that these data may become available to the public under

access to information legislation. At the same time, regulators have been reluctant to use existing legislation to obtain it.

A different attitude appears to be emerging now as a new professionalism begins to take hold in the industry. The industry in southwest New Brunswick is now leading the implementation of the new EMP. The British Columbia Salmon Farmers' Association (BCSFA, 2000) has recently announced that monitoring data gathered on the environmental performance of salmon farms will become accessible to the public.

The proposed revised EMP will rely heavily on geochemical parameters, while in other jurisdictions benthic communities are monitored. The justification for the New Brunswick approach is reduced cost to growers and simplicity of sample analysis. Wildish *et al.* (2001) show how the four classical organic enrichment categories, based on macrofaunal sampling, could also be determined by sediment geochemistry. This will be reflected in the new EMP, which will also have four categories: Oxic 1, Oxic 2, Hypoxic and Anoxic.

A revised EMP such as discussed would be fully supported by DFO, NBDFA and NBDELG if it could provide assurances that their mandates with respect to fish habitat and sustainable development are being respected. It would also provide more reliable information to operators on the potential for adverse interactions between the environment and their operations.

Finally, the most important change between the revised and original versions is that DELG is now requiring Approvals to Operate which will reinforce the requirements of the EMP under the legislation of the Clean Environment Act.

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