Environmental Interactions with Sea Cage Culture of Atlantic Salmon

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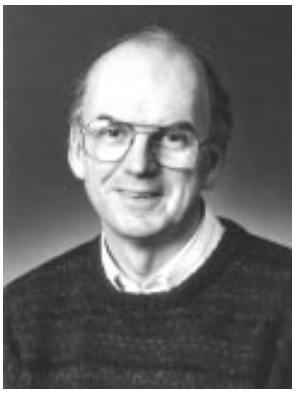

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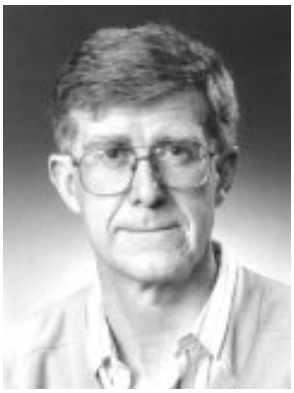

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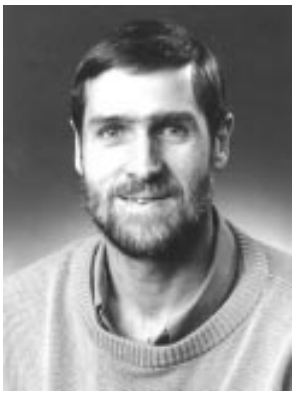
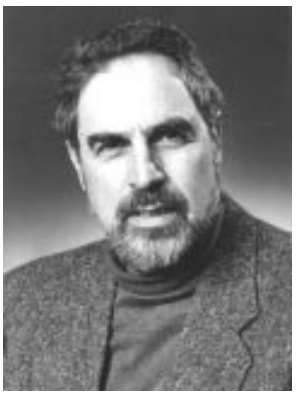


T. Milligan



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Background

Mariculture of fish such as Atlantic salmon offers the promise of increasing supplies of food from marine ecosystems, but scientific studies and industrial experience have shown that coastal areas have only a finite ability to support sustained aquaculture yield. There is a risk of excessive nutrient enrichment through release of uneaten food and fish wastes when this occurs in enclosed coastal embayments. Optimal siting of aquaculture operations and decisions concerning industry expansion require environmental information. Physical conditions such as maximum and minimum water temperature, water depth and current speed, and biological factors such as potential for the spread of pathogens, impacts of escapees on wild stocks, and occurrence of toxic plankton blooms, are now recognized as important factors that can limit aquaculture activities in coastal waters.

For the past five years, Department of Fisheries and Oceans (DFO) staff at the Bedford Institute of Oceanography (BIO), the St. Andrews Biological Station, and in the Newfoundland Region have conducted research to evaluate environmental interactions of salmon aquaculture (Wildish *et al.*, 1990). Field observations and modelling studies in the Bay of Fundy and Baie d'Espoir, Newfoundland, have been combined to determine environmental and operational factors that could limit site selection and expansion of finfish cage aquaculture in coastal regions. The overall aim is to develop sampling methods, modelling tools, data bases and knowledge useful for management advice on cumulative impacts of finfish cage aquaculture in the context of coastal zone management. Advice has been provided to DFO Habitat Management concerning methods for surveillance, calculation of site holding capacity, and data requirements for modelling environmental interactions. Draft guidelines have been prepared for assessment of benthic carbon loading and spatial scales of mariculture impacts.

Field and Modelling Studies - Water Column

A project was initiated in Newfoundland at a salmon aquaculture site in Baie d'Espoir to obtain data on water column variables to test empirical models that predict carrying capacity for finfish production based on nutrient loading and oxygen demand. The availability of sheltered sites to avoid ice rafting in the spring was identified as an overall limiting factor in coastal fjord systems. Symptoms of oxygen stress observed during summer months indicated that models predicting oxygen availability and demand from currents, depth and water column structure are important for predicting carrying capacity of suitable sites.

Studies have also been carried out in the Western Isles Region in the Bay of Fundy where salmon aquaculture has grown rapidly over the last ten years. A hydrodynamic finite difference model was developed by ASA Consultants Ltd. to predict principal oceanographic features, including tidal currents, circulation, distribution of temperature and salinity in space and time, and diffusion characteristics (Trites and

Petrie, 1995). Output from the model illustrates where impacts of increased nitrogen release and biological oxygen demand (BOD) from both fish farms and fish processing plants in the area might occur. Fish pens have to be located in areas of sufficient water exchange to avoid oxygen depletion and possible ammonia accumulation associated with large numbers of fish held in enclosures. Water column observations of dissolved oxygen and nutrients and flushing experiments at selected cage sites carried out over short (tidal) time periods have shown that variable flushing rates occur under different hydrographic conditions (Wildish *et al.* 1993).

Descriptions of physical processes that dominate water exchange were used to predict the impact of nutrient inputs on inlet-wide scales and to develop a carrying capacity model based on the potential for nutrient enrichment from estimated numbers and sizes of salmon held in cages in the Western Isles Region (Strain *et al.* 1995). The input from the aquaculture industry could then be evaluated in the context of other man-made and natural inputs. When making a comparison between inputs from different sources, it is important to consider both the nature of the inputs and their interaction with water movements. Figure 1 compares the magnitudes of inputs of nitrogen and BOD from various sources to the Letang Inlet.

Although organic enrichment of coastal embayments through discharges of domestic sewage, agriculture and industrial wastes is generally more wide-spread than the release of waste products from aquaculture facilities, the latter may be a significant source in small less-populated areas. The largest single input to the Letang region is from aquaculture (Fig. 1). Despite this, the local impact from the fish plant is as severe (or much more severe, for pre-1991 conditions) as the worst impact from aquaculture. To restate this comparison, aquaculture changes existing nutrient concentrations by moderate amounts over a large area; the fish plant causes larger changes over a smaller area.

Field and Modelling Studies - Sediments

Of several possible negative effects, deposition of particulate matter as unconsumed food and faecal matter from finfish aquaculture has been identified as one having potential long-term negative environmental impacts (Hargrave 1994). Studies have shown that sediments and the organisms in them (the benthos) change in response to organic enrichment. However, enhanced sedimentation from salmon net-pen aquaculture is site specific, spatially limited, and highly dependent on physical factors such as water current speed and seasonal storm-related resuspension. Organic matter accumulated under fish pens can lead to localized anoxic conditions which result in depletion of macrofauna and increased fluxes of oxygen and dissolved inorganic nutrients between sediments and overlying water (Hargrave *et al.* 1993). A survey of 11 farm and 11 reference sites in the Western Isles Region in 1994 showed that benthic variables which are correlated with organic matter sedimentation (gas and nutrient fluxes, sulfide, organic carbon and oxidation-reduction potentials) can be used to scale the degree of organic enrichment (Hargrave *et al.* 1995). However, biological processes are not always sufficient to limit organic matter accumulation especially in areas where hydrographic conditions and/or low current speeds result in low rates of oxygen supply to the sediment surface.

Model Development and Application

Although effects of organic enrichment in the water column and sediments arising from aquaculture activities have been identified in these site specific studies, there have been few attempts to derive general models linking numerous physical, chemical and biological factors that are altered by increased organic matter supply. Silvert (1992, 1994a) formulated a general approach of this type and Sowles *et al*. (1994) used data from different finfish aquaculture sites to calibrate these conceptual models. These models describe and predict impacts of organic loading under various operating and environmental conditions and provide a basis for decisions concerning the suitability of a coastal site for new or expanded aquaculture development.

The modelling approach used to assess environmental impacts of salmon aquaculture in the Western Isles Region is based on a nested set of hierarchical submodels as shown in Figure 2 and described by Silvert (1994b). The central submodel is FISH, which is an input-output representation of the feeding physiology of farmed fish. Using environmental variables such as water temperature and photoperiod, this submodel calculates the amount of feed consumed and the resulting growth and excretion rates as a function of the size and age of the fish. The POINT submodel integrates the FISH submodel over the size and age distribution of all the fish in the farm, calculating a total point source strength for loadings from the site.

The POINT submodel can be used to derive several different models dealing with various types of environmental impact. The one that has received the greatest emphasis so far is SETTLE, which describes the deposition of waste feed and faecal pellets on the seabed under and near the site (Silvert, 1994a, Gowen *et al.* 1994). Another is the Water Quality Model (WQM), which describes the transport of dissolved and suspended material. This is being integrated with the ASA hydrodynamic model described earlier. The FARM model is used to calculate near-field effects, such as the tidal variation of benthic oxygen levels at a site.

A major problem in the analysis of data relating to the environmental impacts of fish farms is the difficulty of making complete sets of quantitative observations. The nets and mooring systems often preclude the use of traditional benthic sampling equipment, and observations may be made by divers using only video equipment and simple sampling devices. Because of this, there is concern about how to use qualitative descriptive data to characterize benthic conditions without compromising scientific objectivity. Fuzzy logic is ideally suited to the processing of this kind of data. Results from observations in diver logs taken under a net pen fish farm have been analyzed using this new technique. Preliminary results show a strong correspondence between highly enriched sedimentary conditions and high levels of sediment organic

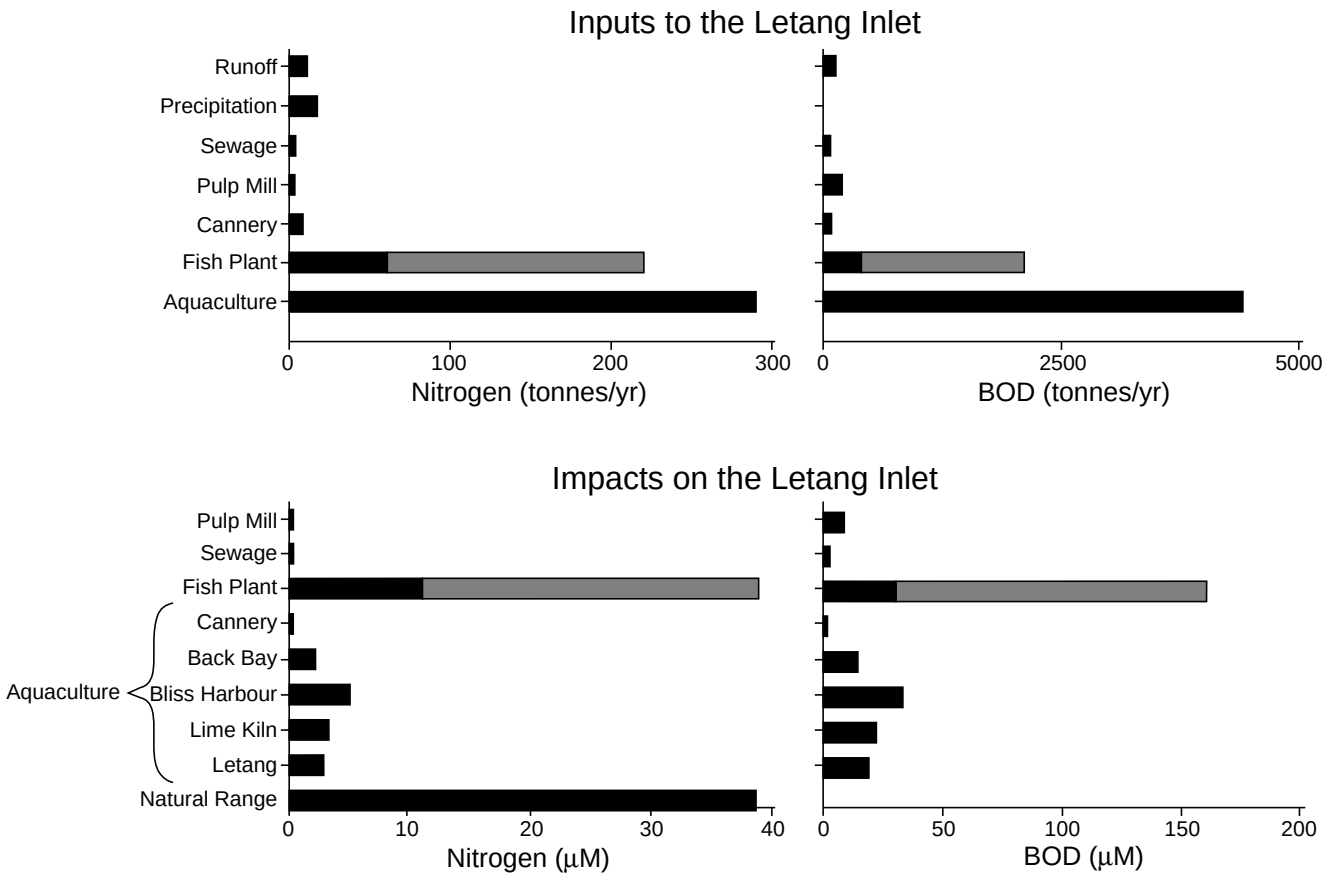

Figure 1: Inputs and impacts of discharges of nitrogen and biochemical oxygen demand (BOD) to the Letang Inlet. Inputs are the total discharge per year; impacts are the changes *in ambient concentration caused by these inputs in the waters they affect. The solid bars for the fish plant are for discharges after 1991, when improvements to the plant's waste management were made. The total length of these bars are discharges prior to 1991.*

matter, porewater nutrients and organic matter decay rates.

The next step in the utilization of these models is the development of a computer application to combine data, models and expert advice for input to the decision-making process (Silvert, 1994c, d). Work is currently underway to develop a Decision Support System (DSS) that will incorporate simplified versions of several models along with geo-referenced hydrographic and environmental information (Silvert 1994e). Model predictions of fish growth (farm yield) and environmental impacts will be made based on user-provided information about a specific site (such as area, depth, maximum-minimum current speeds, number of fish).

The different approaches used for modelling environmental interactions of finfish aquaculture were discussed at an international workshop held at BIO in September 1995. It was concluded that for model development an integrated approach is needed which must occur simultaneously with the implementation of advisory tools. Participants in the workshop felt that models are essential tools for practical management purposes to ensure that the future of finfish aquaculture in coastal regions is sustainable.

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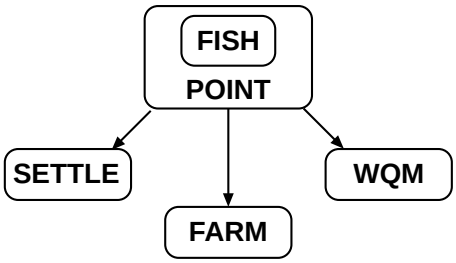

Figure 2: Configuration of hierarchical submodels used in simulation models of point source loadings from fish farms.

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