ICES Journal of Marine Science, 58: 363–368. 2001
doi:10.1006/jmsc.2000.1044, available online at http://www.idealibrary.com on IDEAL®

ICES Symposium on Environmental Effects of Mariculture

Introduction

M. Holmer, P. Lassus, J. E. Stewart, and D. J. Wildish

Holmer, M., Lassus, P., Stewart, J. E., and Wildish, D. J. 2001. ICES Symposium on Environmental Effects of Mariculture: Introduction. – ICES Journal of Marine Science, 58: 363–368.

M. Holmer: Institute of Biology, Odense University, DK-5230 Odense M, Denmark; P. Lassus: Departement Microbiologie et Phycotoxines, IFREMER BP 21105, 44311 Nantes Cedex 03 France; J. E. Stewart: Fisheries and Oceans Canada, Bedford Institute of Oceanography, P O Box 1006, Dartmouth, NS, Canada B2Y 4A2; D. J. Wildish (corresponding author): Fisheries and Oceans Canada, Biological Station, 531 Brandy Cove Road, St Andrews, NB, Canada E5B 2L9; tel: 506 529 8854; fax: 506 529 5862; e-mail: wildishd@dfo-mpo.gc.ca

The Symposium on Environmental Effects of Mariculture (SEEM) took place in St Andrews, New Brunswick, on Canada's east coast, near the heart of the Bay of Fundy salmonid culture industry. The Symposium dates were 13–17 September 1999 and the meeting was co-convened by David Wildish of Canada and Maurice Héral of France. A scientific steering committee for SEEM was drawn from the ICES WG on Environmental Interactions of Mariculture and besides the conveners included Hans Ackefors, Ian Davies, Arne Ervik, and Harald Rosenthal.

Two major questions were addressed during the Symposium:

- what are the environmental effects of finfish and bivalve farming in the coastal zone, and
- how does the local environment affect carrying and holding capacity?

These proceedings include selected papers from the different sessions addressing the first question. Each paper was reviewed by a minimum of two research scientists (List of Referees, p. 529) and selection made by Dr D. J. Wildish, as Guest Editor, based on their advice. The latter question comprised one session and dealt with how environmental variables influence the carrying capacity of bivalve culture and the holding capacity of finfish mariculture. This issue is of particular importance when new mariculture sites are being selected. Following review, some of the presentations at this session have been selected (Table 1) for a separate publication in the *Canadian Journal of Fisheries and Aquatic Sciences,* with Professor J. Grant as Guest Editor.

The question concerned with environmental effects of mariculture was addressed in the following sessions (Chairs are indicated within parentheses):

Table 1. List of papers from the session "Mariculture and production/carrying capacity or holding capacity" that will be published in the *Canadian Journal of Fisheries and Aquatic Sciences.*

J. Stenton-Dozey, T. Probyn, and A. Busby – Impact of mussel raft-culture (*Mytilus galloprovincialis*) on macrofauna and *in situ* benthic oxygen uptake and nutrient fluxes in Saldanha Bay, South Africa
A. Smaal, M. van Stralen, and E. Schuiling – The interaction between shellfish culture and ecosystem processes
A. Gangnery, C. Bacher, and D. Buestel – Assessing the production and the impact of cultivated oysters in the Thau lagoon (France) with a population dynamics model
J. Grant and C. Bacher – A numerical model of flow modification by suspended aquaculture in a Chinese bay

- Disease/environmental factors in mariculture (J. E. Stewart)
- Harmful algal blooms and mariculture (P. Lassus)
- Sediment biogeochemistry and mariculture (M. Holmer)
- Environmental monitoring in mariculture (D. J. Wildish)
- Other ecological issues in relation to mariculture (D. J. Wildish)

These five topics were thought to cover most of the demonstrated environmental effects of mariculture that might be of concern to other users of the coastal zone.

We are aware that the coverage of each session does not provide a fully comprehensive view of that topic. This resulted because the only attempt to pre-select presentations was in providing each participant with a list of topic sessions as shown above. Consequently, the papers presented are a random

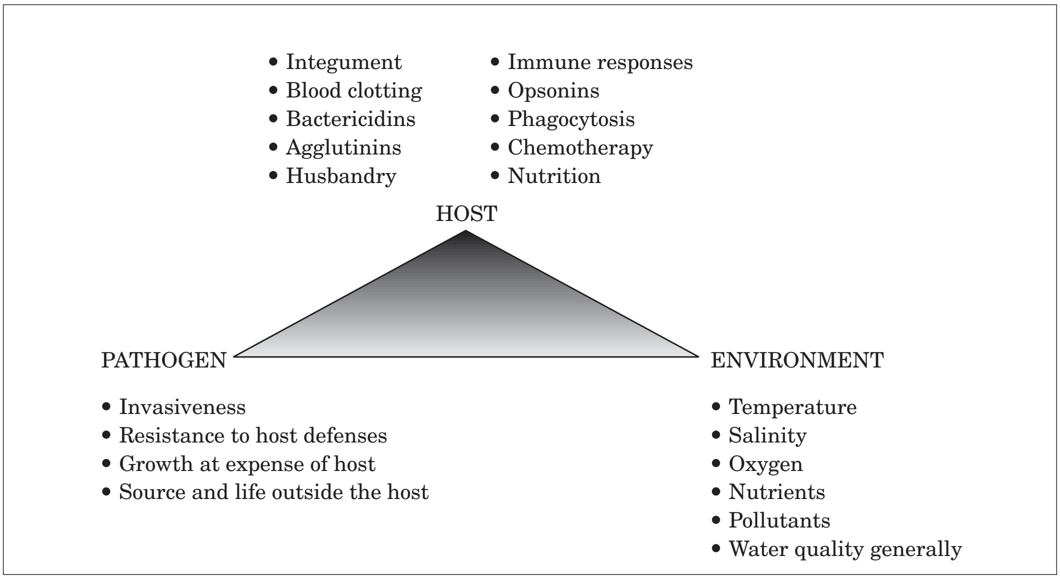

Figure 1. Host/pathogen/environmental characteristics and interactions affecting infectious diseases.

selection of environmental research or monitoring related to mariculture that was ongoing or completed just before the beginning of the new millennium.

An introduction to each session was prepared by the responsible Chair, and the sessions are considered in the same order as they were presented during the Symposium. Each session is briefly summarized below.

Disease/environmental factors in mariculture

Mariculture production in ICES Member Countries has increased significantly over the last 30 years. In 1970, it consisted of several hundred thousand tonnes of molluscan shellfish and ~1000 tonnes of salmonids. By 1999, production was close to one million tonnes, with most of the increase coming from salmonid mariculture, plus smaller amounts of marine fish.

In some cases, such rapid expansion has been accompanied by serious problems. Many of these involve diseases and the often-recognized interactions with the environment to which the cultured species are subject. The important elements of these interactions are shown in Figure 1, which emphasizes that the healthy or diseased states are a direct result of balances, or imbalances, among hosts, pathogens, and environmental conditions.

The important factors in infectious diseases of fish and shellfish are that the host will remain healthy as long as the optimum environmental factors are sustained and the host is able to maintain its defenses against virulent and invasive pathogens. If environmental conditions deteriorate or the host is in an inappropriate environment, opportunistic, non-specific pathogens can prevail and be just as effective in causing mortalities as the specific pathogens.

One of the reasons for the limited participation in this session was the coincidental Fish Disease Symposium, organized by the Association of Fish Pathologists, held in Rhodes, Greece. Presentations included the use of sentinel fish, risk assessment, and a review of innate defense factors in protecting fish from disease.

St Hilaire *et al.* (pp. 369–373) used sentinel fish, surveys, and survey approaches to develop databases for disease occurrences among wild fish occupying the same areas as those used in mariculture. The databases included information on innate resistance factors, such as lectins, which have merits for the protection of cultured fish, and on the interrelationship between parasites of wild and cultured fish. They also revealed the merits and problems associated with risk assessments. The use of sentinel fish proved to be straightforward and useful. In addition, the authors showed that a fallowing period of two months was sufficient to reduce the concentrations of the infective agent below levels needed to initiate infectious hematopoietic necrosis.

Stephen (pp. 374–379) considered that risk assessment should be regarded as an essential element in any culture management scheme. The author was concerned that in many instances the databases were inadequate to carry out a realistic assessment. He argues that the databases upon which the assessments rely need to be dramatically improved.

In the review by Ewart *et al.*, (pp. 380–385) the potential of innate defense factors was compared and contrasted with the development of specific immunity in response to particular immunogens. They concluded that, because of their widespread occurrences and their efficacy at lower temperatures, innate resistance factors such as soluble lectins could be of value in protecting cultured fish against infectious diseases.

Harmful algal blooms and mariculture

Phytoplankton specialists interested in Harmful Algal Blooms (HABs) throughout the world are well connected through biennial international symposia held on this topic (in February 2000 in Sydney, Australia) and through the ICES/IOC Working Group on Harmful Algal Bloom Dynamics, which meets annually. This may explain why only three papers are included here, despite the recognized importance of this topic in mariculture. Cultured bivalves may feed on HABs and carry the toxins to vertebrate consumers, thus becoming a human health hazard. For finfish, some HABs may be directly toxic, while others may be indirectly harmful after the microalgae die and decompose, thereby reducing local dissolved oxygen concentrations in bottom waters.

On the basis of a ten-year seasonal survey of phytoplankton, Smith *et al.* (pp. 391–397) followed changes in the spatial distribution of a non-toxic diatom, *Thalassiosira nordenskioeldii*, at four sites in the Bay of Fundy, Canada, where an intensive salmon mariculture industry has developed. The data were used to determine whether significant differences existed between salmon farm and reference sites. The results suggested a positive trend in the relative abundance of this cold-water diatom at salmon farm sites, concurrently with a negative trend in salinity. Because of the observational nature of the study, it was not possible to pinpoint the cause.

In vitro experiments presented by Arzul *et al.* (pp. 386–390) demonstrate the potential effects of excretory products from farmed shellfish or fish on the growth of different microalgal populations. These effects could be inhibiting or stimulating, depending on the microalgal species and the excretory products considered. Oyster and mussel excreta were stimulating, whereas fish excreta were generally inhibitory, with one exception. The stimulatory effects were due mainly to ammonium compounds, whereas the inhibitory effects of fish urine were caused by other organic compounds.

Rhodes *et al.* (pp. 398–403) deal with practical monitoring in New Zealand. This country has a particularly broad spectrum of microalgal HABs, including the genera *Gymnodinium, Alexandrium, Pseudo-nitzschia, Dinophysis,* and *Protoceratium*, and hence with the related phycotoxins: NSP, PSP, ASP, and DSP. New methods, such as the use of DNA probes for the rapid detection of ASP-producing microalgae, have recently been introduced into the New Zealand monitoring network.

An important question raised by Arzul *et al.*, (pp. 386–390) as well as in unpublished Symposium presentations, concerned whether HABs could be stimulated directly by hypernutrification originating from mariculture. This issue was addressed at a round-table discussion held one evening during the Symposium to establish future research directions and priorities. Recommendations resulting from this discussion are available at http://www.ices.dk/symposia/eem/habseesl.htm.

Sediment biogeochemistry and mariculture

Mariculture produces particulate wastes that are difficult to quantify, and the effects of such wastes on the environment are difficult to assess. The particulate loss occurs during finfish feeding and faeces production, and wastes are usually found directly under the net cages, with relatively local impacts. The underlying sediments become enriched with organic matter that degrades more easily than the natural particulates in coastal areas. This may have important consequences for sediment biogeochemistry, especially when microbial activity is enhanced. In the marine environment, sulphate reduction is among the most important mineralization processes, and is stimulated by enrichment with organic matter. This leads to an increase in the production of sulphides, and sulphides may accumulate to toxic levels for the benthic fauna. In moderately enriched sediments, opportunistic species may survive, but if enrichment is increased further, the fauna may disappear completely. This leaves the degradation of waste products to microbes only, and such a change is usually followed by increased burial rates of organic matter. It may then become very difficult for a climax benthic community to re-establish itself.

Although particulate organic waste is recognized as an important environmental problem in mariculture, only a few studies have investigated the dynamics of sedimentation in detail. The vertical and horizontal dispersion of particulates during a feeding cycle was investigated in British Columbia by Sutherland *et al.*, (pp. 404–410) who achieved an improved understanding of the temporal and spatial changes in particulate loading. The study showed high rates of sedimentation under the net cages during feeding, and the dispersion of feed pellets was strongly related to their size. Such intensive studies are the first step in the development of detailed dispersion models to be used at mariculture sites in general.

Sedimentation fluxes in a Japanese estuary were measured by Hayakawa *et al.*, (pp. 435–444). They included both natural inputs, e.g. after phytoplankton die-off, as well as biodeposits from cultured oysters. Biodeposition rates were estimated with a physiological model based on key input variables that had been measured in seawater and gave predicted values in the range of 5–390 g m^{-2} d^{-1}. This range was scaled by the ratio of oyster raft area to the whole estuary and the difference with observed values explained by dispersion factors.

Mussel farming is also constrained by high rates of sedimentation, although the organic matter is more difficult to degrade compared with finfish wastes. Enhanced pools of organic matter have been found in the sediments surrounding mussel farms. Sediment biogeochemistry measures show negative trends and the benthic macrofauna is often impoverished. In a study of mussel farms on the west coast of Scotland and the southwest coast of Ireland, Chamberlain *et al.* (pp. 411–416) tested a model developed to predict both the sedimentation and the benthic effects. The model is a modification of the fish-farm impact model DEPOMOD, and provided important information on the impacts at the locations. Again, this is only the first step on the road in the use of models in mariculture, and has to be tested at supplementary sites before it can be widely implemented.

It can be very difficult to determine changes in the benthic macrofauna that are caused by mariculture activity. One problem is to find a suitable reference site that can be compared to the mariculture site. Another is the large year-to-year variation that was found at all stations in an investigation in Canada by Pohle *et al.*, (pp. 417–426). It was also difficult to assess the effects of fallowing, a practice whereby a finfish lease is left without fish for up to two years. Only by the use of indicator species and measurements of organic pools in the sediments was it possible to conclude that the sediments had improved, although they had not fully recovered after three years of fallowing.

There are relatively few studies that have examined the effects of mariculture on benthic fauna. It has been observed that the burial of organic matter is reduced significantly, if macrofauna are present in the sediments, and macrofauna are often used to monitor mariculture operations. The significance of a change in community structure from a climax community, with a diverse fauna inclusive of large animals that cause strong bioturbation, to an opportunistic community with many, but small, organisms has not been considered. An experimental study by Heilskov and Holmer (pp. 427–434) at a mariculture site in Denmark showed that mineralization of organic matter was significantly higher in sediments if fauna were present. There were important differences between the climax and the opportunistic communities. In the former, the organic matter was primarily consumed by the fauna, whereas the higher activity in the opportunistic community was due to enhanced microbial activity. This may have significant consequences for the macrofauna, because sulphate reduction is an important process in these sediments, and if they are unable to oxidize the sediments, sulphides may accumulate and poison them. Because results from Pohle *et al.* (pp. 417–426) suggest that it takes a long time before a climax community can be re-established, it is imperative that such conditions not be allowed to develop at fish farms.

Environmental monitoring in mariculture

A succinct definition of environmental monitoring proved to be difficult, because there may be many purposes, e.g. to protect humans from ingesting harmful bacteria or HABs which could cause illness or disease, protecting the coastal zone from organic enrichment in sediments (Crawford *et al.* pp. 445–452; Wildish *et al.* pp. 469–476) or in the water column (Butler *et al.* pp. 460–468), or from chemical contamination which may result in impairment of ecological functioning (Davies *et al.* pp. 477–485; Zitko pp. 486–490; Haya *et al.* pp. 491–495). Also presented was a paper by Janowicz and Ross pp. 453–459 describing an existing environmental monitoring programme of the Atlantic Canadian salmon mariculture industry in the Bay of Fundy.

It is possible to design and use an environmental monitoring programme only where the basic knowledge of the subject is adequately researched and the problem fully understood. Such knowledge permits the use of proxy variables that are cost effective to measure and directly relate to the variables of concern.

If we concentrate on a single purpose for environmental monitoring, e.g. organic enrichment in sediments, four types of goals might be considered (Table 2). Although the goal commonly targeted is practical monitoring, the comparison of sites objective is needed in case of a dispute. Temporal and spatial monitoring are much more technically demanding, and consequently expensive, and virtually limited to basic research projects.

Many different proxy methods, applicable to practical monitoring, indicate changes in structure or functioning of ecosystems. It must be shown that the changes are decoupled from seasonal variations where these are present. Monitoring may involve physiological or behavioural bioassays, tissue surveys of keystone fauna for chemical burdens, sentinel monitoring with live animals, and measures of biological community structure, as well as oceanographic and sediment geochemical techniques. To protect human seafood consumers, various chemical and biological (e.g. mouse bioassay) methods may be employed.

Because of the variety of methods available, operational criteria have been developed to aid in choosing the best one (Table 3). Scientific defensibility implies that the monitoring is referable to an accepted scientific

Table 2. Measures of benthic community structure to meet divergent environmental monitoring goals for detecting organic enrichment effects in sediments.

Monitoring goal	Effects determined	Associated hypothesis
1. Practical	General impact	None – triggers improved husbandry practice
2. Site comparison	Differences between treatment/reference sites	H_0 reference = treatment site H_1 reference ≠ treatment site
3. Temporal	Before:after status	H_0 reference = treatment site in yr 1 H_1 reference ≠ treatment site in yr 2
4. Spatial	Geographical limits of impact	H_0 reference community present in entire study area H_1 reference and enriched communities delimited in study area

theory or model and could, or does, involve experimentation involving testing between the null and alternative hypotheses (see Table 2). In the benthic community example, the theory is supplied by Pearson and Rosenberg (1978), who showed that organic enrichment gradient responses are indicated by macrofaunal community changes. It is possible to supply a statistical confidence level about decisions made during field experiments when sites are compared. This type of test is needed in case of a legal dispute regarding whether or not organic enrichment has occurred. Practical monitoring, on the other hand, is designed for determining decision points that trigger farm management actions, such as fallowing or some other form of remediation. It is usually relatively simple to convert the practical to the comparison of sites method by adding sufficient reference observations. In searching for a suitable proxy variable or method to indicate ecosystem change, the operational criterion that usually decides the issue among the four is cost effectiveness (Table 3).

Other ecological issues in relation to mariculture

The purpose of the last session was to provide a focus for any research topic not covered in the other four sessions. As expected, we received a diverse range of presentations, which defies simple characterization. The subject range included a new method of cage mooring to minimize sedimentary impact, various aspects of impacts caused by finfish escapees in the natural environment, and methods to reduce the impact of diving duck predation on cultured blue mussels.

Table 3. Operational criteria to determine the value of environmental monitoring methods.

Category	Criteria
Scientific	1 – scientifical defensibility 2 – statistical weight of evidence
Resource management	3 – relevant decision points 4 – cost effectiveness in time and resources

In the single-point mooring approach advocated by Goudey *et al.* (pp. 496–502), each cage is allowed to move around a watch circle, depending on environmental forces (e.g. tidal currents and wind/wave activity). The potential environmental advantage of using single-point moored finfish cages was examined by modelling the fate of particulate cage discharges, assuming different anchoring and current regime scenarios. Taking this approach to its logical conclusion, using drifting cages would further minimize any direct impacts to sediments, although it might have other disadvantages, such as posing navigational hazards.

Three presentations dealt with the problem of salmonid finfish escapees and their ecological and genetic effects on native salmonid populations. The ecological effects of salmon escapees in the Magaguadavic River (Bay of Fundy) were presented by Whoriskey and Carr (pp. 503–508). The effects found included: escaped adult farmed salmon breeding with wild fish, wild smolt runs being swamped by escaped smolts from hatcheries located in the river catchment, and movement of escaped farm fish to the Magaguadavic River. In a study of cultured steelhead trout in Newfoundland, Bridger *et al.* (pp. 509–515) showed that the fish demonstrated homing behaviour to their rearing sites. Fish movements were monitored by a combined acoustic and radio telemetry system after simulating escapes by tagged steelhead trout.

One way to overcome the problem of escaped farmed fish breeding with wild fish, hence diluting the gene pool, is to use sterile salmon during seawater grow-out. Benfey (pp. 524–528) showed that this is possible by producing all triploid stock, by high temperature or pressure shock on eggs shortly after fertilization. He goes on to consider why the salmonid culture industry has not adopted sterile triploids, and shows that it is because of the inferior culture potential of the triploid in comparison with diploid stock. He suggests that further research on the nutritional and environmental requirements of triploid salmon could rapidly overcome this difference.

Where eider ducks are present near blue mussel farms, they are persistent predators of the cultured stock. Ross *et al.* (pp. 516–523) experimentally investigated the use of underwater sound recordings of engine noise to deter eider predation on mussels. They were able to show that reductions of 50-80% in eider numbers were achieved with the use of underwater engine noises. The long-term habituation of ducks to underwater sound was negligible, as long as the response was occasionally reinforced by boat chasing.

Conclusions

Of the 32 papers presented during the Symposium, excluding those dealing with mariculture and production carrying capacity, 23 were accepted for publication (72%) after independent reviews. It is these papers that occupy the following pages.

We felt that the Symposium succeeded in bringing together a multidisciplinary group of individuals: scientists and resource managers, as well as some from the mariculture industry. The selection of papers that follows provides a non-comprehensive representation of the diverse types of research or types of practical monitoring that are currently being undertaken in connection with the effects of mariculture.

Reference

Pearson, T. H., and Rosenberg, R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology: An Annual Review, 16: 229–311.