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The role of ICES in supporting research in mariculture

Harald Rosenthal

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The paper describes the historic development of the Mariculture Committee within ICES and highlights the areas of research in which ICES scientists were involved. These include: environmental issues within mariculture systems, introductions of exotic species, impact of mariculture on the environment, rearing and culture technology developments in Member Countries, overriding problems in diseases, their diagnosis and control, and finally, the area of interaction with other resource users in the coastal zone. Prior to the mid-1970s, mariculture subjects were covered by the Fisheries Improvement, ANACAT, and Shellfish and Benthos Committees. Extensive discussions over several years by various ICES bodies led finally to recommendations in 1974 to form a Mariculture Working Group and, three years later, to the recommendation to establish the Mariculture Committee. At that time, the development of marine shellfish farming had already reached an impressive production level, and finfish culture in ICES Member Countries began to increase rapidly, although initial attempts at finfish cage culture date back to the early 1960s. The Mariculture Committee and its working groups have, over the years, provided extensive advice to the Council and its customers on research priorities, environmental issues, and biotechnological needs. The proactive role of this Committee peaked in the late 1980s and 1990s. Unfortunately, ICES has, in recent years, lost competence in some areas of mariculture research to other organizations. Several of the options to regain momentum are discussed.

Keywords: coastal aquaculture, coastal zone management, disease control and exotics, environmental interactions, mariculture history in ICES.

Harald Rosenthal: Institut für Meereskunde an der Universität Kiel, Düsternbrooker Weg 20, 24105 Kiel, Germany, and Schifferstrasse 48, 21629 Neu Wulmstorf, Germany; tel: +49 40 700 6514; fax: +49 40 7010 2676.

Introduction

ICES involvement in research and development of modern mariculture dates back to the early years of its emergence in Europe. Although initially seen as a sideline activity, some aspects of this form of aquatic resource use were always addressed in the Anadromous and Catadromous Fish Committee (ANACAT), which dealt with salmonid issues relevant to mariculture, such as ranching, hatchery operation, life-cycle requirements, and diseases. Similarly, the Shellfish Committee considered many aspects of extensive mariculture dealing with mussel and oyster growth, diseases, and quality issues (harmful algal blooms, etc.).

With the principal focus on fisheries (rather than cultivation), ICES also accommodated issues on coastal aquaculture production under the umbrella of the Fisheries Improvement Committee during the 1970s. The Committee initially dealt with all aspects that somehow had to be addressed, but which were not really the domain of the fisheries science community. Pollution issues were, at the time, of central importance to the Committee. However, topics on mariculture surfaced at an increasing rate. In the following sections, a few of the mariculture issues will be briefly highlighted where ICES has been instrumental and proactive in assisting both the development of the industry and the safeguarding of the environment.

Mariculture development in ICES Member Countries

Traditional fish farming has been practised in freshwater systems for many centuries in most of the ICES Member Countries. Shellfish farming has also been practised for a long time, while marine finfish culture started with a few local trials (mainly with Atlantic

salmon) during the late 1960s and early 1970s in some countries, including Norway, Scotland, Denmark, Ireland, and Canada. Besides these attempts, hatchery operations for the ranching of salmonids has been a long-standing tradition in several northern countries not only for salmonids, but also for other marine species. The most famous such case was undertaken by G. M. Dannevig in 1903–1905 at the Flødevigen hatchery in southern Norway to hatch large quantities of cod eggs for release in coastal waters (Solemdal *et al.*, 1984). Although destined to fail, these early studies on ranching marine species initiated numerous experimental research studies of marine fish recruitment mechanisms. Ranching for salmonids developed in particular in Sweden with programmes aimed at compensating for the lost access of Baltic salmon to upstream spawning grounds caused by hydro-dam construction. The scientific studies associated with this development in Sweden and the basic work by J. R. Brett on the reproductive physiology and rearing of Pacific salmon species at the Pacific Biological Station in Nanaimo, British Columbia (Brett, 1965, 1971, 1976) were of great importance. These papers have become classic citations and laid the groundwork for the success of marine aquaculture of salmonids in the second half of the 20th century.

While marine finfish farming is a relatively new activity which emerged mainly during the second half of the past century, shellfish farming has already had a long-standing tradition in most countries. Production trends in finfish and shellfish farming vary greatly among ICES Member Countries. For example, Norway started with a few Atlantic salmon farms in the early 1970s and gradually increased production to over 350 000 t in 1998. Sweden, although a country which did have the technology to mass produce salmon fry and smolts, did not embark on large-scale coastal aquaculture development mainly because of a lack of appropriate sites. Atlantic salmon was the successful species to be raised in coastal waters of most northern countries, while the production level for rainbow trout remained insignificant despite the long-standing tradition of culturing this species in inland waters of most countries. A less pronounced but still significant upward trend in Atlantic salmon farming in cages was observed in the United Kingdom, followed by Ireland at a much lower rate. Canada, however, has experienced a slower initial growth rate compared with all other northern ICES Member Countries, with Atlantic salmon taking the lead during the 1990s (even along the Pacific coast), while the production of Pacific salmon (e.g., sockeye, chinook, and coho) declined despite the initial promise of these species for mariculture in the late 1980s. While Atlantic salmon production continued to grow in these countries, brackish water and marine finfish culture in others levelled off, particularly in Sweden and Germany, at a relatively low overall amount not exceeding a few hundred tonnes.

In the Mediterranean ICES Member Countries, sea bass (*Dicentrarchus labrax*) and sea bream (*Sparus aurata*) culture emerged as a new activity in finfish cage farming as well as in land-based pond (raceway) systems. Marine finfish farming in Spain emerged mainly during the last decade of the past century, with sea bream, sea bass, turbot (*Scophthalmus maximus*), eel (*Anguilla anguilla*), and even salmon (*Salmo salar*) as the main species. In Portugal, sea bass and sea bream have been the main species in a relatively small finfish farming industry, while shellfish farming has clearly dominated for many years, with oysters (*Crassostrea gigas*) and mussels (*Mytilus edulis*) as the main species being cultured and clams and cockles playing a minor role.

While finfish production saw a rapid growth for a few key species, shellfish culture in major producing countries in the ICES Area had already levelled off over the past two decades. Blue mussel production in The Netherlands fluctuated between 50 000 and 100 000 t over the past two decades, indicating that most of the production capacity of the extensive bottom-culture plots in the Wadden Sea had already been effectively utilized. In Spain, mussel farming has reached a constantly high level in the coastal rias (the inlets along the coast), benefiting from the coastal nutrient upwelling. Mussel farming along the Dutch coast, however, underwent several drastic changes after World War II owing mainly to interacting and conflicting coastal-zone use issues not necessarily related to the productivity of the area. In Spain, there was even a gradual decline in mussel production, with a marked low in the early 1990s and a slow recovery towards the end of the century.

Statistics on mariculture production were fragmentary and hard to obtain in the 1970s and early 1980s. In subsequent years, the situation improved greatly. The ICES Mariculture Committee was the early promoter for developing reasonable statistical formats for reporting production in Member Countries. This was found to be essential in order to monitor the development and to assess the importance of various sectors of the industry, thereby enabling the identification of research and development priorities for consideration by governments and industry.

The early days of mariculture research considerations in ICES

ICES involvement in mariculture-related research dates back to the early 1960s, although no special programme was identified at that time. Research on marine cultivation of species at any trophic level received little attention, even if addressed by highly reputable scientific institutions or teams, as there was initially no specific institutional arrangement within ICES that would provide a forum for appropriate recognition of these activ-

Table 1. Number (in bold) of mariculture-related papers in selected subject areas submitted to the Fisheries Improvement and Mariculture Committees for presentation at the annual ICES Statutory Meetings between 1975 and 1990. During the period 1975–1977, mariculture papers were primarily allotted code numbers associated with the Fisheries Improvement Committee (FIC). In 1978, the Mariculture Committee met for the first time. Numbers and letters in parentheses refer to papers cross-referenced or primarily submitted to other standing committees: D = Statistics Committee, E = Marine Environmental Quality Committee, H = Pelagic Fish Committee, J = Baltic Fish Committee, K = Shellfish and Benthos Committee, L = Biological Oceanography Committee, M = Anadromous and Catadromous Fish Committee, and N = Marine Mammals Committee.

Depth	Pollution (general) and FIC (total)	Technology	Mariculture (nutrition, feed, growth, behaviour)	Brood stock, larvae, reproduction, fish/shellfish hatchery	Micro-macro-algae	Genetic	Diseases/parasites, shellfish toxins, vaccination	Finfish culture (general)	Finfish ranching	Shellfish culture (general)	Environment/ Monitoring	Introduction	Review statistic
1975	**33**	**4** (4K)	**2** (1H)	**1** (G1, H1, K1)	**1**	**0**	**2** (K6)	**1** (6M)	**0**	**1** (2K)	**0**	**0**	**0** (13K, 6M)
1976	**29** (1B, 2C, 2K, 3N)	**3**	**3** (1K, 1M)	**4** (2M)	**0**	**1** (3K)	**0** (1P, 3K)	**1**	**0**	**0** (4K)	**0**	**0**	**2**
1977	**33** (B13, C1, M1)	**9** (1B, 1C, 1L)	**6**	**2** (1J, 1M)	**0**	**0**	**4** (2M)	**2** (2L)	**0** (7M)	**2** (1K)	**5**	**1**	**2**
1978	-	**7** (1J)	**8** (2M)	**0** (3G, 1H)	**0**	**0** (1K)	**6** (1K)	**0**	**0** (4M)	**2**	**0**	**1**	**3**
1979	-	**5**	**8** (1M)	**3** (1M)	**3**	**13**	**4** (4E, 1G, 1K)	**4** (1M)	**0**	**10** (2K)	**1**	**3**	**6**
1980	-	**3**	**4**	**12**	**0**	**1**	**2** (1E)	**2** "	**0**	**2** (1K)	**1**	**1**	**2** (1D)
1981	-	**5**	**8** (2M)	**9**	**1**	**8**	**2** (1K)	**7**	**4**	**4**	**3**	**5**	**4**
1982	-	**3**	**5**	**9** (1M)	**1**	**2**	**4**	**3**	**3** (2M)	**5**	**2**	**5**	**2**
1983	-	**2**	**1**	**9**	**0**	**4**	**2**	**1**	**0**	**2**	**3**	**2**	**3**
1984	-	**3**	**4**	**8**	**0**	**2**	**6**	**1**	**1**	**0**	**2**	**1**	**3**
1985	-	**9**	**11**	**12**	**1**	**1**	**3**	**2**	**2**	**5**	**5**	**1**	**2**
1986	-	**2**	**8** (1L)	**15** (1H)	**0**	**0**	**7**	**4**	**0**	**4** (1E, 1K)	**4**	**1**	**1**
1987	-	**4**	**7**	**8**	**0**	**1**	**5**	**4**	**3**	**2**	**2**	**5** (Mini-Symp.)	**1**
1988	-	**4**	**7**	**6** (3K)	**1**	**0**	**5**	**7**	**0** (3G)	**5**	**2** (1L)	**1**	**1**
1989	-	**2**	**1**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**3** (1K)	**1**	**2**
1990	-	**8**	**12**	**19**	**1**	**3**	**9**	**5**	**0** (2K)	**1**	**7** (2E, 1K)	**3**	**5** (1L)

ities. Instead, research issues related to mariculture were dealt with over the years by several standing committees such as the Shellfish Committee, the ANACAT Committee, and the Fisheries Improvement Committee. During the 1970s, the number of contributions on cultivation issues increased in all of these committees, sometimes with considerable overlap and little cross-linking. It was obvious that, with the growing importance of marine cultivation, ICES would have to respond soon to provide overviews and guidance on scientific issues related to the development of this coastal activity.

The key individuals in the struggle by several ICES Delegates and committee members to establish a Mariculture Committee were Klaus Tiews (Bundesforschungsanstalt für Fischerei, Hamburg) and Dag Møller (Institute for Marine Research, Bergen), who vigorously supported the proposal of the Norwegian Delegate to form a Working Group on Mariculture as an initial step to explore the needs for research activities in this subject area within ICES. It was the time during which marine finfish culture began as a novel idea in coastal areas in Norway and some other countries. Cage-farming trials were conducted on a relatively small scale and, at the time, biotechnological issues dominated the discussion among scientists. In 1974, the Consultative Committee decided to establish a Working Group on Mariculture with Tiews as Chair to explore the developmental trends in ICES Member Countries and to identify potential science areas where research would be needed to safeguard this development. The very active Working Group clearly demonstrated the growing interest among Member Country scientists in this emerging industry and identified – to the great surprise of conventional fisheries science groups – the significant scientific expertise in aquatic cultivation which already existed at that time in ICES Member Countries (Tiews, 1975). Based on the outcome of this initial survey, the Working Group made clear and significant recommendations on a number of research issues (Korringa *et al.*, 1976), while also identifying several research priorities. Today, it is fair to state that the overview provided by the Working Group was instrumental in guiding ICES in the right direction.

Scientific contributions to the Working Group had to find a "home" and, therefore, the papers were submitted to the Fisheries Improvement Committee (FIC) for the first time in 1975, and – because of the growing importance and volume of mariculture contributions – were soon presented in subsections of the FIC, co-shared by the Committee Chair and the Working Group Chair (Tiews, 1975). A total of 14 papers related to mariculture issues were dealt with, and an additional 11 papers were referred from other committees (e.g., ANACAT, Shellfish and Benthos, Demersal Fish, and Pelagic Fish). Table 1 depicts the increasing contributions to mariculture topics dealt with by the FIC during the early 1970s. Some of the initial needs for research were identified, including the optimization of feed formulations for salmonids (ICES, 1976), a subject that has so far received little attention. At that time, ICES had no clear policy in place when screening submitted Council Meeting papers to assign all papers related to mariculture issues to one specific standing committee such as the FIC. It was left to the respective committee chairs to decide whether a particular paper had relevance to mariculture and should be cross-referenced to FIC. Because of the established cultivation of molluscs, it comes as no surprise that the Shellfish Committee was assigned additional papers of relevance to the subject, such as mussel and oyster farming, and continued to accept submissions to the subject under its umbrella. Therefore, until the mid-1970s, mariculture issues had no "home" in the ICES organization.

Fisheries Improvement Committee members repeatedly addressed the need to separate subjects dealing with pollution and mariculture in order to attract scientists interested in one or the other subject area. During Committee business meetings at ICES Statutory Meetings, it became obvious that the FIC was becoming increasingly divided into two interest groups: mariculture and marine pollution.

It was also during 1975 that the first report was presented on the outcome of the deliberations of the Working Group on Mariculture. This was an historic meeting in the sense that it provided the basis for the arguments intensely discussed in subsequent years on the need to establish a standing committee on the subject.

The year 1977 was the last during which mariculture issues were included in the Fisheries Improvement Committee, and a joint session on mariculture was held between the Fisheries Improvement, Shellfish and Benthos, and Anadromous and Catadromous Fish Committees. The report of the Mariculture Working Group presented at this meeting listed 82 participants and 13 observers from other countries, with total representation from 22 nations (Berge and Pawlak, 1978). It became obvious that the interest in mariculture research issues had gained sufficient momentum to justify the establishment of a standing committee on this subject.

Long discussions and controversial opinions led to detailed proposals to dissolve the Fisheries Improvement Committee and create two new committees: the Marine Environmental Quality Committee (MEQC) and the Mariculture Committee (MC). At the time, many ICES Delegates believed that in scientific terms, mariculture would remain a marginal activity and, therefore, the formation of a standing committee on the subject would not be justified. Norway and Germany (Tiews) were the true promoters, finally leading to the formation, by the Council, of the Mariculture Committee at the 1977 Statutory Meeting. Support for its formation was also met with reluctance from committees such as Shellfish and Benthos and ANACAT, which addressed related subjects, mainly because of the potential transfer of some of the subjects they commonly dealt with to the

Table 2. List of Chairs of the Mariculture Committee and key issues addressed during their periods in office.

Years	Chair	Country	Major activities
1974–1977 1978–1981	Klaus Tiews	Federal Republic of Germany	Chairing the Mariculture Study Group; establishing the Mariculture Committee; building linkages to EIFAC; fostering finfish culture methodologies; promoting finfish nutrition studies
1982–1984	Dag Møller	Norway	Supporting finfish cage culture and mariculture technology in general; supporting rearing methodologies
1985–1988	James Stewart	Canada	Initiating the Study Group on Environmental Impacts of Mariculture; promoting improved mariculture statistics in Member Countries; initiating discussions on appropriate terminology; exploring options for new candidate species
1989–1992	Harald Rosenthal	Federal Republic of Germany	Pursuing environmental issues; harmonization of methodologies; promoting water quality considerations in intensive systems; considering chemical usage in mariculture; promoting research on interactions of mariculture with other resource users
1992–1995	Hans Ackefors	Sweden	Stimulating discussions on integrated coastal zone management related to aquaculture; promoting studies on mariculture interactions with wildlife; addressing issues pertinent to the protection of mariculture from environmental pollution caused by other coastal resource users
1996–1997	Robert Cook	Canada	Promoting research on disease and genetic issues; considering new candidates and product quality; fostering early life history studies, including new species
1998–2000	Maurice Héral	France	Promoting modelling of shellfish culture systems, leading to specific workshops and the development of sets of models

Mariculture Committee. The Committee met for the first time at the 1978 Statutory Meeting. Already at that time, a 1977 Council Resolution (ICES, 1978a) supported the invitation of papers in response to the anticipated co-sponsorship of an international symposium on "Thermal Effluents of Industries and Power Plants for Mariculture Purposes", a conference which received worldwide recognition and was conducted in cooperation with EIFAC (European Inland Fisheries Advisory Commission of FAO) three years later (Tiews, 1981a, 1981b).

The first Chair of the Mariculture Committee was Tiews, who also initiated the intensive contacts with the respective EIFAC sub-commissions (Tiews and Mitchell, 1980). This was particularly useful as EIFAC had already established working parties on several aquaculture-related subjects such as finfish nutrition and fish-farm effluents. It was also through Prof. Tiews that the Working Group on Introductions and Transfers of Marine Organisms (WGITMO), which, since 1972, has provided advice to ICES Member Countries on the introduction of exotic marine and estuarine species and their associated parasites and diseases, found its home in the Mariculture Committee. The Working Group also became strongly linked with the respective EIFAC working party, leading at one time to a jointly agreed Code of Practice on introductions (a level of direct cooperation never seen again between the two intergovernmental organizations).

The future home of existing and partly independent working groups dealing with mariculture-related issues was a sensitive issue of debate within ICES. Because of the dominance of mariculture-related issues dealt with by the WGITMO and by the Working Group on Pathology of Molluscs and Crustaceans of Economic Importance, it was decided that they should report to the Mariculture Committee. The Pathology Working Group had to expand its remit to include broader issues on diseases of all species, which led, in 1977, to a name change (Working Group on Pathology and Diseases of Marine Organisms – WGPDMO; ICES, 1978b).

Subsequent Chairs of the Mariculture Committee and the major issues dealt with during their terms of office are briefly summarized in Table 2. The highlights mentioned therein certainly reflect a very subjective view on priorities being chosen during each period. There are

many more issues that were embraced by the Mariculture Committee and its respective working groups. Over more than two decades of its existence, the gradual move from basic biological to technological, physiological, and environmental issues is obvious, and changes in emphasis on specific issues continue. Some of these priority changes are highlighted in subsequent chapters.

Major developments and environmental issues in mariculture addressed by ICES

Culture technology and cultured species

Mariculture in cages was still in its infancy when ICES considered technological and biological issues. Numerous recommendations of the Mariculture Committee centred around 1) the improvement of culture technology (e.g., ICES, 1976); 2) husbandry techniques that befit species better, especially the rearing of the delicate larvae and fry of marine finfish (e.g., ICES, 1986a, 1990a); 3) water-quality management within farming systems; 4) risk assessment associated with the transfer of species under common commercial practice (e.g., ICES, 1986b), and studies on emerging diseases in mariculture and their diagnosis and control (e.g., ICES, 1990b); 5) genetics in mariculture (e.g., ICES, 1982), finfish nutrition, and standardization of research methodologies (including joint publication of reports with EIFAC; ICES, 1980); and 6) methods to reduce environmental and culture stress in finfish during their entire life cycle in captivity. With the growth of the industry, a critical mass was reached during the latter part of the 1980s that allowed an entire support industry to evolve, thereby providing opportunities for new stress-reducing operational approaches. Behavioural studies in finfish were addressed in relation to culture facility, stocking density, and metabolism and provided new insights on stress management and system design (e.g., Rosenthal, 1987).

Many of the studies undertaken by ICES Member Countries dealt with larval rearing and hatchery operation not only for salmonids, but increasingly for other species, particularly flatfishes such as sole, turbot, and halibut. Many years of effort in several countries (e.g., Norway, Canada, Germany, United Kingdom) passed before the first commercial production of turbot and halibut emerged. Milestones in directing research in this area were two ICES symposia on "The Early Life History of Fish" organized in 1979 in Woods Hole, Massachusetts, USA (Lasker and Sherman, 1981) and in 1988 in Bergen, Norway (Blaxter *et al.*, 1989).

Similarly, in the Mediterranean, sea bass and sea bream were the marine finfish species which evolved as lucrative candidates for commercial cultivation. Numerous studies by scientists from France, Portugal, and Spain focused on basic research ranging from brood-stock handling, larval rearing, feed composition, and ongrowing technologies. A special symposium on "Mass Rearing of Juvenile Fish" was held in 1993, evaluating the state of the art of our knowledge on reproductive physiology, larval feeding and nutritional requirements, and health considerations (Rosenthal *et al.*, 1993). The need for polyunsaturated fatty acids, the role of free amino acids in early development, the importance of pre-conditioning of parental stocks to survival success, and the quality of seed stocks were major issues addressed, while the possible use of pro-biotics in reducing the need for antimicrobials and strengthening health status was another area of central concern at that time.

Because of the limited number of species involved in successful mariculture, the Mariculture Committee, by means of questionnaires in 1990, evaluated the potential for new candidate species within the ICES Area (Stewart *et al.*, 1990). The results showed that 23 finfish and 13 invertebrate species were considered to be realistic candidates for culture, with seven each of the finfish and invertebrate species already in commercial culture at that time. With this analysis, preliminary insights were gained on which research priorities needed to be identified to achieve further diversification of species in mariculture production. Among those priorities were research issues on 1) improved knowledge on life cycle requirements and juvenile rearing, 2) improved nutrition, 3) understanding diseases and control measures, and 4) understanding brood-stock and spawning physiology (just to name a few without prioritization).

Issues relevant to shellfish farming pertained to disease outbreaks, disease control, introduction of exotic species for culture purposes as well as with live transport of species for common commercial practice, determination of regional and area-specific carrying-capacity limits, new technologies for depuration and rapid toxin analysis to safeguard the industry and consumers, and product quality control. Efforts to model system performance and environmental carrying capacity recently resulted in special issues of two journals (Bayne and Warwick, 1998; Smaal and Héral, 1998) that contained papers from a special workshop on "Shellfish Bivalve Cultivation, Growth, Modelling and Impact on the Ecosystem" held in 1996 which was organized by the Mariculture Committee.

Over the years, it was noted that scientists working on mariculture topics increasingly depended on the inputs from other disciplines. Terminology and reporting formats in these disciplines followed common standards. Because of the multidisciplinary nature of aquacultural science, the Mariculture Committee initiated an attempt to provide definitions of terms and some interpretations of their common use to facilitate better communications and avoid misunderstanding between scientists, planners, engineers, and regulatory authorities. This was particularly useful since ICES deals with a multilingual community. Inputs from several disciplines clearly showed that several definitions often existed for the

same term in neighbouring disciplines (fisheries, microbiology, veterinary sciences, engineering, etc.) and led to confusion. A preliminary glossary was presented, proposed, expanded, and harmonized with terminologies commonly employed in the ICES/EIFAC region to ensure compatibility. This initiative by the Mariculture Committee began in 1986 and – because of several shortcomings – saw subsequent issues (Rosenthal *et al.*, 1990). The concept was later picked up by EIFAC for preparation of a French version, and in 1994–1996, a project sponsored by the European Union (EU) under the LINGUA programme carried the work further to include over 2700 terms and definitions (available on CD-ROM) in four languages (Eleftheriou, 1997). The initial attempt was certainly fragmentary. However, ICES has been the lead organization in anticipating the need for establishing a "common language", and this proactive approach spawned subsequent initiatives now carried on by others to further improve communication between many disciplines.

Environmental issues

Since the formation of the Study Group on Environmental Impacts of Mariculture in 1986 (ICES, 1986c, 1987a), ICES has been particularly proactive in providing advice to Member Countries and ICES clients.

The ICES Advisory Committee on Marine Pollution (ACMP) did not receive requests on mariculture issues from clients much before 1987. In anticipation, however, as early as 1986, this advisory body (which was reconstituted in 1992 as the Advisory Committee on the Marine Environment) considered in detail the report of the Working Group on Environmental Impacts of Mariculture (WGEIM), and it included an overall summary of the state of the art of our knowledge on environmental issues in each of its subsequent annual reports (ICES, 1987b, 1991, 1994a, 1995). ICES was, therefore, proactive and prepared to deal with the assessment of environmental problems that might arise from both water-based and land-based marine and brackish water farming systems for fish and shellfish. In subsequent years, ACMP repeatedly received requests from HELCOM (Helsinki Commission – Baltic Marine Environment Protection Commission) and others to provide advice on nutrient loads derived from mariculture and on the impacts of antimicrobials used in mariculture. Through the extensive work by the WGEIM and the Mariculture Committee, ICES was able to provide up-to-date information in areas where statistics were not readily available to assess the dimension of the potential problems (Rosenthal *et al.*, 1988). These assessments found their reflections in working group reports issued regularly (e.g., ICES, 1990c, 1994b, 1997, 1998) and were highlighted in a much-cited *ICES Cooperative Research Report* on "Chemicals Used in Mariculture" (Alderman *et al.*, 1994). One of the major outcomes of this report clearly showed that, while we have extensive knowledge on effective dosage and general chemistry of most of the antimicrobials used in mariculture, extremely little is known about the fate of these chemicals and their breakdown products in the environment. It was further noted that there are a very restricted number of antimicrobials licensed for use in mariculture in ICES Member Countries.

The Mariculture Committee and its working groups repeatedly considered the need for and the progress on vaccine development, particularly during years when the use of chemicals was unacceptably high. Norway took the lead in improving the situation through appropriate control and management schemes by reducing stocking densities, limiting production level per site, and most importantly through rapid development of vaccines and vaccination technologies. Consequently, the trend in the usage of antimicrobials in Norway over the past decades went from very high at times of low production levels in the mid-1980s to almost negligible volumes in recent years with steadily growing overall outputs. The progress made in past years serves now as a model for other countries with "Codes of Conduct" being prepared to protect the environment and safeguard the industry.

Diseases, parasites, and exotics

The Working Group on Pathology and Diseases of Marine Organisms (see Stewart and McVicar, 2002) dealt with diseases both in the marine environment and in culture systems. With this combination, ICES and its Mariculture Committee were well equipped to deal with the principal ecological problems related to diversity of diseases and their occurrence and were not restricted to "in-house" aquaculture diseases. This was fortunate as only very few organizations ever brought together the expertise in both fields. Forced to deal with a multitude of interacting factors, an ecosystem approach rather than a "veterinarian" approach was frequently taken, leading to numerous recommendations that dealt with interactions between the environment, diseases, and parasite occurrences both in mariculture systems and in wild populations. Besides these principal insights into the ecology of diseases and parasites, practical problems in coping with in-farm diseases were well addressed, while prophylactic approaches, rather than treatment procedures, were strongly recommended to derive sound management decisions. Again, the reader is referred to the detailed discussion by Stewart and McVicar (2002).

The Working Group on Introductions and Transfers of Marine Organisms (WGITMO) has repeatedly given advice on proposed introductions of exotic species for aquaculture purposes in ICES Member Countries. While some of the issues were controversial, the work

not only created awareness of the risks associated with these transfers, but also provided realistic and practical advice through the formulation and continued updating of the ICES Code of Practice and its accompanying guidelines and protocols (the latest version even including considerations on genetically modified organisms). One of the important issues also addressed by the WGITMO relates to the transfer of exotic species by other coastal-resource users most likely impacting on mariculture: the shipping industry and the transfer of species through ballast water and hull fouling. The ballast-water initiatives by the WGITMO during the early 1990s were not clearly recognized by the respective intergovernmental authorities. However, the International Maritime Organization is now heavily involved in studying ballast water effects and developing guidelines, often based on the ICES WGITMO experience and background. Additionally, ICES work in this area has initiated a landslide of studies sponsored by the EU and national authorities. Awareness is currently growing that this global issue must be addressed internationally to mitigate negative effects of these transmissions on renewable coastal and marine resource uses.

Likewise, the Working Group on Genetics (later renamed the Working Group on Application of Genetics in Fisheries and Mariculture) provided a similar forum for the discussion of modern approaches to mariculture and provided adequate advice whenever required (e.g., ICES, 1982). Here, expertise in both specific fields dealing with population genetics in wild stocks and breeding and selection programmes under culture conditions stimulated research beyond the single-discipline approach that is commonly found in animal husbandry disciplines. This has greatly assisted in dealing with controversial issues such as interactions of escaped fish with wild populations and has stimulated many studies in this area while also providing advice to the North Atlantic Salmon Conservation Organization.

Harmful algal blooms

During the late 1980s and early 1990s, the Working Group on Harmful Effects of Algal Blooms on Mariculture and Marine Fisheries specifically addressed the needs for better monitoring and warning systems to safeguard the aquaculture industry in coastal waters. While non-governmental organizations and environmental authorities were already concerned about the potential of mariculture for causing or contributing to the risk of harmful algal blooms, little attention had been given to the fact that mariculture itself can be greatly affected by recurring blooms. This holds true both for the finfish and shellfish fisheries and for mariculture. For example, the magnitude of economic losses in shellfish farming due to blooms is impressive, but has rarely been documented in monetary terms.

All mariculture and shellfish fisheries are located mainly in inshore waters, with many operations even in estuaries, rias, fjords, and embayments. Several ICES working groups and the Mariculture Committee as well as other standing committees have discussed these issues and drew attention, in the early 1990s, to specific research needs on exceptional blooms. This encouraged several Member Countries to initiate new or to enhance existing programmes. Most helpful in creating awareness was the initiation of an annual record of incidents in the ICES archival journal *Annales Biologiques*, which contributed to the initiatives for building databases elsewhere. At that time, mariculture management was in urgent need of better methodologies on bloom predictability, and the Mariculture Committee supported this need through recommendations and/or active participation in the respective working group activities. Recommendations repeatedly related to: 1) statistical validation of trends in historical toxicity data, 2) work on predictive modelling of occurrences of harmful algae on a regional scale, and 3) better toxin identification and toxicity testing.

Mitigation strategies during the presence of a harmful population were also frequently discussed by the Committee. This stimulated the development of quite a few management strategies in several countries, such as the cessation of feeding prior to and during bloom events, *in situ* shielding, moving, or lowering cages (or even longlines) to waters of lower algal cell density, dilution of surface water with pumped deeper water, and other methods.

Besides these post-siting management strategies, a major recommendation to aquaculture planning authorities and to the industry concerned proactive expansion of site-selection criteria and exploration of bloom occurrences prior to establishing a finfish or shellfish farm. In Canada (British Columbia), active participation by farmers in daily recording of either turbidity or phytoplankton sampling was encouraged through the development of a simple sampling and species identification guide.

Although ICES has been one of the initiators of proactive research in the area of exceptional algal blooms through its respective working groups, the Mariculture Committee and its working groups clearly assisted in directing and promoting research activities that suited an industry in need of strict resource protection. Furthermore, some elements of the EU Initiative on EUROHAB (Granelli *et al.*, 1999) reflect the basic work previously undertaken over many years within the ICES community.

Interactions with other resource users (coastal-zone management issues)

During the mid-1990s, many of the initial environmental problems were already addressed by the Mariculture Committee and the WGEIM, although these subjects

were still in need of further support and study. However, with the growth of the mariculture industry, it became obvious to those dealing with environmental issues that this could not be a one-way consideration. With the growing number of units in the coastal zone and with increasing activities of other coastal-resource users, the pressures on natural resources will increase and affect mariculture. It was at that time that this author decided to pursue a change in name of the Working Group as well as an adjustment in its terms of reference to accommodate the need of mariculture to be protected from adverse impacts stemming from the actions of other (adjacent) aquatic resource users. The name change was subtle, but significant at the same time. Therefore, the Working Group on Environmental Impacts of Mariculture became the Working Group on Environmental Interactions of Mariculture, emphasizing the dual influences exerted on each other and on the environment by all stakeholders in coastal and estuarine waters.

Only a few scientists and administrators within the ICES community clearly recognized the important change in emphasis leading to a broadened scope within the terms of reference. New and additional terms of reference were formulated to: 1) develop criteria and standard systems of monitoring and reporting, 2) delineate the scope and nature of environmental interactions between mariculture and other uses of the coastal marine resources, 3) provide advice on approaches in such areas as improved site selection through advances in husbandry to minimize conflicts between mariculture and other coastal-zone activities, and 4) review and evaluate national monitoring programmes relative to mariculture.

These additional terms of reference clearly reflect the dual approach on environmental impacts, considering all stakeholders in the coastal zone while also fostering environmental compatibility of mariculture.

It was only later that the need for quite different expertise than what is commonly present in ICES fisheries and mariculture circles was recognized in order to deal adequately with the multitude of issues. The level of interdisciplinarity required to deal with economic, socioeconomic, and cultural interactions as well as with true fisheries management and planning issues including economy–ecology costs and benefits (e.g., development of regulatory frameworks including modern decision-support systems) appeared to be a new scientific "playground" for which conventional fisheries biologists were not well equipped (Rosenthal and Burbridge, 1995; Rosenthal *et al.*, 2000).

Several reports of the WGEIM elaborated on these issues (ICES, 1997, 1998) and suggested a course of action that ICES could take to respond proactively and take the lead in the development of appropriate management tools, using mariculture as a model of a stakeholder which must operate in an environmentally safe way, but which is also in need of protection from other impacts (Rosenthal *et al.*, 2001). While most of the existing management schemes in the coastal zone are still sectorally structured, the major obstacle is the lack of capabilities to derive cross-sectoral approaches.

Among the many aspects of coastal-zone management discussed by the WGEIM and its parent committee, the following should be reiterated as I believe these issues will become even more important in the near future:

The coastal zone is unique, and special planning and management arrangements are required to achieve sustainable use of renewable natural resources: a) coastal-zone land and water uses must be jointly planned and managed to minimize conflicts; b) emphasis must be placed on multiple use of renewable resources to optimize economic and social benefits; and c) coastal-zone management should be structured for incremental implementation with emphasis on environmental assessment.

Unfortunately, the Mariculture Committee and WGEIM approaches were met with some reluctance within ICES. However, the proactive approach has been reflected in the EU demonstration projects on Integrated Coastal Zone Management carried out during the past few years.

Conclusions and outlook

Today, mariculture issues are still of high importance within the ICES community. However, the momentum has been lost to some extent in dealing proactively with key issues. There are several reasons for this loss:

1) International non-governmental organizations have developed powerful linkages with universities, the industry, and the public at large, linkages that ICES failed to develop convincingly and effectively in time. ICES still remains comfortably in the bureaucratic domain. National representation is usually limited to scientists from governmental agencies (with a few exceptions). Since many of these agencies are in transition and at least face severe budget cuts, the key players in science and business dealing with mariculture are often no longer found in these agencies.
2) In today's world, proactive approaches and strategic research objectives must be met by quick responses to rapid changes in both society and industry. Therefore, key issues must not only be addressed faster, but also in close cooperation with industry, planners, and managers and must allow for flexible responses. The rigid ICES system, through which recommendations are approved, is certainly adequate for most ICES clients who operate as intergovernmental agencies in similar modes, but this is not sufficiently flexible to respond to the dynamic activities evolving in globalized markets where scientific issues mainly related to environmental and resource-use-conflict problems require cross-sectoral approaches, including close linkages with management.

3) Several independent, international organizations (such as the World Aquaculture Society, the European Aquaculture Society, and other regional bodies) have developed powerful mechanisms and membership linkages with the science community, industry, regulatory authorities, planners, and managers to act as active and down-to-earth fora for all stakeholders. The ICES Annual Science Conferences, with only a relatively small commitment to mariculture, does not necessarily meet the needs of the scientific community dealing with this subject area.

What then are the future options for ICES to stay ahead in serving a wide range of interests in mariculture research?

Diseases will certainly continue to be an overriding problem that needs increasing attention. Modern genetics, with its evolving molecular tools, will also become a much more important scientific discipline in mariculture research. With genetically modified organisms at our doorstep, sound scientific criteria are still needed to address the current controversially debated issues on environmental interactions between wild and cultivated species.

Land-based marine farming systems will have to be developed and improved in their cost effectiveness as sites available for mariculture expansion in coastal waters become more and more limited. New products will have to be developed as mariculture for food is but one limited resource use with wastes now produced which will certainly become an environmental burden if not considered as a new resource that can be reused. Integrated farming systems will gain importance, and substantial research is required in this area to provide an optimum mix of resource-use options. Finally, offshore farming systems will emerge requiring a totally new set of assessment criteria to safeguard both the environment and the industry. Several organizations have begun to address this area seriously, but ICES has not.

With the present human population growth rate, finfish nutrition aspects will become a key problem as the fishmeal resources for culturing species high in the food chain are limited, are increasingly needed by other resource users, and are also becoming more and more contaminated (particularly in the northern hemisphere), thereby limiting their utility. Although replacement of protein sources in fish feed already takes place on a large scale, the implications for physiology, malnutrition, and general health aspects of the culture species and the human end-user of the products requires great efforts to guarantee safe development in this direction.

With further growth of the industry, co-management issues and interactions between all stakeholders in the coastal zone will become pressing issues to derive evaluation and planning tools that respond to various forms of renewable natural resource-use conflicts, including mariculture. With the growth of various user demands, conflicts will increase, and these are not necessarily being solved solely through natural science approaches. It has to be realized in mariculture, and fisheries as well, that the interaction between various interest groups must be recognized at an early date and scientific criteria must be developed that help to identify the optimum mix of coastal-resource uses rather than the independent maximization of exploitation of one specific resource. It is also worth noting that within the sustainability context, the multiple-resource-use approach provides a hedge against the failure of any single use of a resource in the face of uncertainty in the variability of the resource and the uncertainty of markets. It is here that the ICES Mariculture Committee could be a proactive future player by helping to define the scientific criteria for co-management options, while the industry and most of the scientific community are still heavily involved in solving day-to-day problems.

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