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MARINE AND COASTAL BIODIVERSITY: REVIEW, FURTHER ELABORATION AND REFINEMENT OF THE PROGRAMME OF WORK

Summary report of the Ad Hoc Technical Expert Group on Mariculture

Note by the Executive Secretary

EXECUTIVE SUMMARY

The Ad Hoc Technical Expert Group on Mariculture was established by the Conference of the Parties in adopting the programme of work on marine and coastal biological diversity at its fourth meeting (decision IV/5, annex). The expert group was established to assist the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) in its work on the topic of mariculture. The terms of reference instructed the expert group to

(a) Evaluate the current state of scientific and technological knowledge on the effects of mariculture on marine and coastal biodiversity.

(b) Provide guidance on criteria, methods, techniques and best practices that avoid the adverse effects of mariculture, and also subsequent stock enhancement, on marine and coastal biological diversity and enhance the positive effects of mariculture on marine and coastal productivity.

In evaluating the current state of knowledge on the effects of mariculture on marine and coastal biodiversity, the group identified the main mariculture species and methods, and the biodiversity effects of those methods (section II). The group agreed that all forms of mariculture affect biodiversity at the genetic, species and ecosystem level, but that under certain circumstances mariculture could also enhance biodiversity locally (section IV). The main effects include habitat degradation, disruption of trophic systems, depletion of natural seedstock, transmission of diseases, and reduction of genetic variability. The biodiversity-effects of pollutants, such as chemicals and drugs, are not very well studied, though are generally assumed to be negative.

* UNEP/CBD/SBSTTA/8/1.

There are many available methods and techniques for avoiding the adverse effects of mariculture on biodiversity, and they are summarized in section III of this document. They include, most importantly, proper site selection, as well as optimal management including proper feeding. Other mitigation measures include culturing different species together (polyculture), and the use of enclosed, and especially re-circulating, systems. Many of the other impacts can be avoided with better management practices and other technological improvements. A number of aquaculture-specific international and regional principles, standards and certification processes exist, and are described in section V of this document.

SUGGESTED RECOMMENDATIONS

The Subsidiary Body on Scientific, Technical and Technological Advice may wish to:

(a) *Welcome* the summary report of the Ad Hoc Technical Expert Group on Mariculture and the full report of the Group as presented as an information document;

(b) *Express its appreciation* to the Food and Agriculture Organization of the United Nations (FAO) for the technical support and meeting facilities provided for the meeting of the ad hoc technical expert group on mariculture;

(c) *Take note* of the negative biodiversity effects of mariculture, as described in section II of the present document, and of the methods and techniques available for their mitigation, as described in section III below;

(d) *Note also* that mariculture may have some positive effects on biodiversity, as described in section IV below;

(e) *Urge* Parties and other Governments to adopt the use of relevant methods and techniques for avoiding the adverse effects of mariculture on marine and coastal biological diversity, and incorporate them into their national biodiversity strategies and action plans;

(f) *Recognize* the complexity of mariculture activities, the highly variable circumstances of different geographical areas, mariculture practices and cultured species, and as well as social, cultural and economic conditions, which will influence mitigation options, and, accordingly, *recommend* that Parties and other Governments adopt the use of following specific methods, techniques or practices for avoiding the adverse biodiversity-related effects of mariculture:

(i) The mandatory application of environmental impact assessments, or similar assessment and monitoring procedures, for mariculture developments, with due consideration paid to the scale and nature of the operation, as well as carrying capacities of the ecosystem, taking into account the guidelines on the integration of biodiversity considerations in environmental impact assessment legislation and/or processes and in strategic impact assessment, endorsed by the Conference of the Parties in its decision VI/7 A. There is a need to address the likely immediate, intermediate and long-term impacts on all levels of biodiversity;

(ii) Development of effective site-selection methods, in the framework of integrated marine and coastal area management;

(iii) Development of effective methods for effluent control;

(iv) Development of appropriate genetic resource management plans at the hatchery level and in the breeding areas, including cryo-preservation techniques, aimed at biodiversity conservation;

(v) Development of controlled low-cost hatchery and genetically sound reproduction methods, made available for widespread use, in order to avoid seed collection from nature;

(vi) Use of selective fishing gear in order to avoid/minimize by-catch in cases where seed are collected from nature;

(vii) Use of local species in mariculture;

(viii) Implementation of effective measures to prevent the inadvertent release of mariculture species and fertile polyploids;

(ix) Avoiding the use of antibiotics through better husbandry techniques;

(g) *Urge* Parties and other Governments to adopt best management practices and legal and institutional arrangements for sustainable mariculture, in particular through implementing Article 9 of Code of Conduct on Responsible Fisheries, as well as other provisions in the Code dealing with aquaculture, recognizing that it provides necessary guidance to develop legislative and policy frameworks at the national, regional and international levels;

(h) *Request* the Executive Secretary to undertake a comprehensive review of relevant documents on best practices relevant to mariculture, and to disseminate the results, as well as relevant case studies, through the clearing-house mechanism prior to the seventh meeting of the Conference of the Parties;

(i) *Approve* the research and monitoring priorities identified by the ad hoc technical expert group on mariculture as outlined in annex I below, and *recommend* their implementation as part of the programme of work on marine and coastal biological diversity;

(j) *Recommend* that the Executive Secretary, in collaboration with the Food and Agriculture Organization of the United Nations and other relevant organizations, explore ways and means for implementing these research and monitoring priorities, including an evaluation of means through which mariculture can be used to restore or maintain biodiversity;

(k) *Recommend* that the Executive Secretary, in collaboration with the Food and Agriculture Organization of the United Nations and other relevant organizations, harmonize the use of terms in regards to mariculture by further developing and adopting the glossary of the Food and Agriculture Organization of the United Nations;

(l) *Express its support* for regional and international collaboration to address transboundary biodiversity impacts of mariculture, such as spread of disease and invasive alien species;

(m) *Decide to promote* technical exchange and training programmes, and transfer of tools and technology;

(n) *Recommend* that the Conference of the Parties examine the need for support through the financial mechanism to developing country Parties for country-driven activities aimed at enhancing capabilities to mitigate the adverse effects of mariculture on biological diversity.

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Annexes

I. BACKGROUND

1. The Ad Hoc Technical Expert Group on Mariculture was established by the Conference of the Parties in adopting the programme of work on marine and coastal biological diversity at its fourth meeting (decision IV/5, annex). The Expert Group was established to assist SBSTTA in its work on the topic of mariculture. The terms of reference for the group were approved by the Conference of the Parties at its fifth meeting, in decision V/3. The work of the Group is intended to help implement programme element 4 (Mariculture) of the programme of work on marine and coastal biological diversity. The operational objective of this programme element is as follows:

> "To assess the consequences of mariculture for marine and coastal biological diversity and promote techniques which minimize adverse impact."

2. In its terms of reference the Group was requested to:

(a) Evaluate the current state of scientific and technological knowledge on the effects of mariculture on marine and coastal biodiversity;

(b) Provide guidance on criteria, methods and techniques that avoid the adverse effects of mariculture, and also subsequent stock enhancement, on marine and coastal biological diversity and enhance the positive effects of mariculture on marine and coastal productivity.

3. In decision V/3 paragraph 15, the group was also asked to identify best practices in mariculture.

4. The Expert Group met from 1 to 5 July 2002, at FAO headquarters in Rome. The complete list of members of the Group is contained in its full report, which is being circulated as an information document for the eighth meeting of SBSTTA. The staff of the FAO Fishery Resources Division provided logistical and technical support for the meeting.

5. Section II of the present note presents an evaluation of the current state of scientific and technological knowledge on the effects of mariculture on marine and coastal biological diversity. This section corresponds to part (a) of the terms of reference, and reviews the main mariculture species, methods and their impacts. Section III presents criteria, methods, best practices and technology for avoiding the adverse effects of mariculture on marine and coastal biodiversity, while section IV discusses enhancing its positive effects. These sections correspond to part (b) of the terms of reference. Additionally, a summary of existing international and regional guidance on mariculture is provided in this section V of the report.

II. EVALUATION OF THE CURRENT STATE OF KNOWLEDGE ON EFFECTS OF MARICULTURE ON MARINE AND COASTAL BIODIVERSITY

A. Volume and main species

6. Mariculture is the farming and husbandry of marine plants and animals in brackish water or marine environments. While mariculture output is still dwarfed by the tonnage of farmed freshwater organisms, it is growing worldwide. FAO statistics shows an increase from roughly 9 million tonnes in 1990 to more than 23 million tonnes in 1999. However, this increase is the result of the higher production of only few species. The full report of the Expert Group lists the top mariculture species based on the 2000 FAO statistics.

B. Methods

7. Despite the huge variety of marine organisms cultured, the methods used can be reduced to a few basic strategies. While there are numerous schemes for grouping kinds of aquaculture (e.g. autotropic vs heterotrophic), the mariculture methods presented here are grouped in a common-sense way that makes it easy to identify and visualize their biodiversity effects. Detailed information about each culture method is provided in the full report of Expert Group. The culture categories are:

(a) For *molluscs*:

(i) Vertical or rack culture;

(ii) Hanging culture;

(iii) Bottom culture;

(iv) Land-based tank culture;

(v) Sea ranching;

(b) For *echinoderms*:

(i) Tank culture;

(ii) Cage culture;

(iii) Sea ranching;

(c) For *crustaceans*:

(i) Pond culture;

(ii) Raceway culture;

(iii) Cage culture;

(iv) Sea ranching;

(d) For *marine aquatic plants*:

(i) Suspended culture (longline, raft, net) ;

(ii) Bottom culture;

(iii) Tank culture;

(e) For *finfish*:

(i) Cage culture (inshore and offshore);

(ii) Pen culture;

(iii) Pond and raceway culture (flow-through and recirculation systems);

(iv) Sea ranching.

8. Polyculture, the growing of two or more species belonging to different trophic levels in the same system, has a long history in freshwater aquaculture, especially in China. Some marine examples include grouper and mudcrab in ponds; milkfish and siganids in marine net cage; sea scallops suspended from salmon net pens; shrimp and scallop; and ezo scallop, Japanese kelp and sea cucumber are cultured in combination with open-water maricultural structures like net cages for finfish.

C. Biodiversity effects of the main types of mariculture

9. All forms of mariculture, regardless of physical structure or economic motivation, affect biodiversity at genetic, species and ecosystem levels. Mariculture can modify, degrade or destroy habitat, disrupt trophic systems, deplete natural seedstock, transmit diseases and reduce genetic variability. For example, coastal mangroves have been converted into shrimp ponds, enclosed or semi-enclosed waters have been affected by nutrient loading (or stripping), and benthic habitats affected by bivalve bottom culture practices as well as by sedimentation. This section presents a summary of the main biodiversity effects of mariculture. A comprehensive discussion of this topic can be found in the full report of the Expert Group.

10. Mariculture could also provide local biodiversity enhancement under certain circumstances, for example birds could be attracted to mariculture sites and artificial reefs acting as species aggregating devices may result in enhanced biodiversity. *In situ* coral-replanting programmes have also proved to have a positive effect on reef biodiversity. 1/

11. Depending on energy sources used to produce biomass, mariculture could be divided into

(a) Autochthonous organic-based or "natural" trophic systems, such as kelp culture, and raft culture of mussels or oysters. Such culture practices derive their energy from solar radiation or nutrient sources already available in natural ecosystems, and tend to have fewer negative effects on biodiversity. In some cases, their impact on biodiversity may even be positive;

(b) Allochthonous organic-based or "artificial" trophic systems, such as net and pond culture of fish and shrimps, derive energy mainly from feeds supplied by growers and are more likely to disrupt the natural ecosystems.

12. All the environmental effects are strongly dependent on the sensitivity of a particular ecosystem, or its type. Thus, some wetland habitats and ecosystems are particularly vulnerable, such as those that have been identified as threatened or sensitive, either due to their rarity or their vulnerability to change. Such ecosystems include mangroves, estuaries, seagrass beds, coral reefs as well as specific benthic communities. Specific impacts will depend on different carrying capacity requirements for various culture practices in any given ecosystem, which however are poorly known.

13. Considering the fate of by-products of culture practices, particulate matter including organic forms of nitrogen and phosphorous and sulphates typically move downward into the benthos, while carbon dioxide, dissolved organic carbon, and various nutrients (e.g., ammonia and phosphate) frequently move into the water column. Benthic communities (e.g., microbes and suspension feeders) modulate their transport pathways, as does the structure of pelagic communities. The structure and function of these communities are in turn modified by these processes.

14. The potential dangers to biodiversity in areas that receive discharges of pollutants such as chemicals, drugs and other additives used in mariculture have not been adequately studied. Such discharges result from excessive use of these pollutants. Lack of access to information on appropriate use has led some aquaculturists to misapply some chemicals (e.g., antibiotics). Salesmen or pharmaceutical companies may also encourage misapplication. Commonly used chemicals include antibiotics, pesticides, disinfectants, antifoulants and hormones.

15. Many pesticides used to control parasites and fungi are biologically potent even at quantities below chemical detection limits. Effects on the marine environment are not well studied, though are usually assumed to be negative.

1/ Ekaratne, personal communication.

16. Chemicals are also used as antifouling agents and as disinfectants. Antifoulants such as TBT are banned in developed countries for aquaculture purposes, but are still used in some other countries, where they continue to impact on biodiversity.

17. Hormones are used to induce or prevent reproductive maturation, for sex reversal and to promote growth. Bath and feed-incorporated applications of hormones are obviously more of a concern than controlled injection into individual broodstock animals because they become readily released into surrounding waters where they can persist in the environment or in aquaculture products. Hormone use is not well documented and is sometimes carried out without adequate understanding of the quantities needed.

18. Parasites in cultured stock pose problems not only for aquaculturists but also for other organisms in the environment. In British Columbia, for example, one theory for the rise of *Parvicapsula* infection in migrating Pacific salmon is acquisition from a fish farm. The parasite is suspected to be linked to profound changes in migratory behaviour of salmon that leads to massive pre-spawning mortality and may be responsible for decimation of diversity at the population level. 2/

19. The high value marine carnivorous species that are farmed require feeds incorporating animal sources of proteins. The most obvious effect of farming these carnivorous species such as salmon, trout, and sea bream is that more protein is fed to the fish than is later harvested for human consumption. Most of this feed comes from marine sources in the form of fish meal and fish oils, and the percentage of fish meal incorporated into fish feed has been increasing from 10% in 1988, to 17% in 1994 to 33% in 1997. 3/ Although plant proteins are being developed for inclusion as protein sources in fish feeds, complete replacement of fish oils in fish meals may not be possible since they have a beneficial effect on in resistance against fish diseases.

20. Harvesting small fish for conversion to fish meal leaves less in the food web for other commercially valuable predatory fish, such as cod, and for other marine predators, such as seabirds and seals. Pauly *et al.* (1998) have identified a significant trend in aquaculture of "farming up the food chain" that they consider in combination with the global problem of "fishing down the food chain". However, this statement continues to attract debate. Increasing intensification of aquaculture, especially in Asia, and its concentration on higher value carnivorous species, is inexorably raising dependence on capture fisheries through increased feed production. The competitive nature imposed on marine fisheries by capture and culture fisheries merit further investigation.

21. Bivalve culture takes nutrients away from the marine food web. However, it only affects biodiversity adversely if the carbon and nitrogen removed from the water column becomes excessive, leaving less for other herbivores and phytoplankton, thereby affecting the growth and reproduction of zooplankton and other herbivorous marine animals. Bivalves do take particulate matter suspended in water and change it into denser particles that fall to the bottom. Permanent extensive bivalve culture may bring about changes in the coastal food web, altering the eutrophication process.

22. The loss or alteration of habitat becomes a biodiversity effect when it changes living conditions for other species. Seed collection from habitats such as lagoon bottom habitats using destructive gear results in habitat destruction or/and alteration. Mariculture takes up space, often very large amounts of it, not only in bays and oceans but also on nearby foreshores. Converting tidal wetlands for shrimp ponds and building roads, dikes, and canals threatens benthic habitat diversity in the tropics, particularly in Latin America and Asia. Tidal marshes and mangroves that serve as nursery grounds for wild shrimp and fish populations are lost, and less mangrove and marsh grass detritus enters coastal food webs. The draining of

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2/ C.Wood, personal communication 2002.

3/ Davenport *et al,* in press.

ponds for harvest releases diseases, antibiotics, and nutrients into estuarine and coastal waters. Despite the possibly large-scale implications, the effects in the coastal zone remain poorly studied.

23. The local or more widespread effects on non-target species such as the by-catch of seed collection from the wild have not been well studied. In culture systems where there are no methods for artificial control of reproduction, or where such methods exist but are beyond the means of local farmers, manual collection of fry for grow-out can remove significant amounts of biomass and biodiversity. For example, collection of one tiger shrimp larvae involves the removal of 1400 other macrozooplankton individuals.

24. In net-pen culture, crowded and stressful conditions frequently lead to outbreaks of infection. Sometimes the infections result from organisms naturally present in wild fish; in other cases, the disease organism is an exotic one.

25. The genetic effects of mariculture are varied and highly significant for biodiversity. Unlike many of the other effects discussed so far, understanding genetic effects demands a high level of understanding of the genetic structure of both the farmed and wild populations, something we do not have for any species. The field of fish molecular genetics is just starting to expand rapidly as new analytical techniques become available. The genetic effects of cultured marine animals are either inadvertent (through escapes of cultured animals) or deliberate (enhancement or sea ranching), and may result in the loss of genetic diversity. Such reduced interpopulation variation is not necessarily bad for cultured populations, but can have a long-term impact on species survival if the farmed stocks intermingle with wild neighbours.

26. The production of sterile fish is often advanced as a mitigating technology. However, although sterile fish cannot establish wild populations or interbreed with wild fish, they can still compete with wild fish for food, spread disease, and disturb wild nesting sites. Escaped or released fertile tetraploids may attempt to breed with wild fish and disrupt overall spawning success. Gene transfer (not yet used in commercial mariculture) may have ecological effects if the introduced DNA causes major change in the ecological role of the transgenic fish (by, for example, increasing its size or its ability to use new food sources). Transgenic fish given a gene to speed growth, for example, could out-compete wild fish for food or spawning sites, while fish engineered for cold-tolerance might intrude on the ranges of more northerly species. Unanticipated pleiotropic (multiple) effects may also appear.

27. Because much of the world's aquaculture relies on species outside their native range, escapes are a constant biodiversity concern. Many alien marine species resulting from escaped cultured stocks have become firmly established far from their native ranges. When self-sustaining populations of escapes become established, they could interact with native communities in a number of ways, including predation, competition and even elimination of native species. The risk is probably greater with escape of species occupying similar niches to local ones, because they are more likely to interact with native populations and affect their survival. The ability of natural populations to recover from introgression of farmed genes has been very little studied.

III. AVOIDING THE ADVERSE EFFECTS OF MARICULTURE ON MARINE AND COASTAL BIODIVERSITY

28. While mariculture has a variety of adverse effects on biodiversity, many of these effects can be mitigated or eliminated. In some cases, it is even possible to produce some positive biodiversity-related effects. It is important to mention that mariculture based on alochthonous feed (most finfish and crustaceans) could have larger and more significant adverse effects than mariculture based on authochtonous feed (filter feeders, macroalgae, deposit feeders). The areas offering the most promise for avoiding adverse biodiversity effects of mariculture include reducing waste by better management, changes in nutrition (reformulation of feeds, reduction in use of animal protein, improving utilization) and technological improvements such as "enclosed systems". In such enclosed tanks or ponds, it is possible

to treat the effluent in order to avoid outflow of chemicals, antibiotics, diseases, as well as excess nutrients. A description of problems, impacts, main mitigation tools, and the results of mitigation is provided in the full report of the Expert Group.

A. Best-site selection and better management to reduce nutrient input effects

29. Proper site selection is usually the best tool for management and mitigation of nutrient inputs to the environment. In some cases such nutrient inputs could have positive effects on local productivity and biodiversity. The key issue is not to allow nutrients to be lost to bacterial degradation but to enter natural food webs or artificial food webs in the case of polycultures.

30. Mathematical modelling can help estimate the relative impacts of a mariculture operation. For such modelling however, basic information, such as estimates of other nutrient inputs to bodies of water, is often hard to find. Cooperation with other sectors is needed. Types of mathematical models include mass balance models and hydrological models for siting, as well as the use of geographic information systems (GIS) tools. In addition, the application of integrated marine and coastal area management (IMCAM) can help optimize spatial distribution and help mitigate the effects of mariculture.

B. Reducing waste by better management

31. The degree of impact from effluent wastes is dependent on husbandry parameters, including species, culture method and feed type, as well as on the nature of the receiving environment in terms of physics, chemistry and biology. 4/ Waste from marine fish farms can contain high concentrations of organic and inorganic nutrients. It is clear that in the case of culture methods which involve the use of fishmeal-based feeds, there will be a transfer of nutrients into the receiving waters (as well as original nutrient ratios) that may have the potential to lead to increases in nutrient concentrations and ultimately to eutrophication. Euthrophication is defined as "an increase in rate of supply organic matter to an ecosystem". Whether euthrophication will occur as a consequence nutrient addition will depend on the state of the receiving environment which may vary spatially, over short time-scales or seasonally, depending on which factors limit primary production. 5/

Improving efficiency of feeding process

32. Minimizing the input of nutrients can be achieved by improving the efficiency of food conversion. This can be done through improving feed formulations, resulting in better palatability and uptake and by reduction in food wastage. Minimizing effects could also be achieved by using some efficient strains of fish, shellfish etc.

33. Reduction in the input of waste feed can be achieved through a variety of methods including: use of acoustic detectors in marine cages to reduce loss of feed pellets, use of sensors that detect when fish reduce feeding activity, linked to input controllers as well as through the use of systems for collection and recovery of waste feed.

34. When automated and controlled feeding systems are not available, raising the awareness of farm workers to the effects, both environmental and economic, of feed wastage and training in efficient hand feeding can contribute to a reduction in feed usage.

4/ Wu, 1995.

5/ Black, 2001.

Reduction of nitrogen and phosphorus in diets

35. Nitrogen is generally assumed to be the nutrient limiting phytoplankton growth in marine waters. Minimizing the direct input of nitrogenous wastes to the environment from finfish farms can thus minimize potential eutrophication effects. The level of nitrogen in feeds has decreased as feed formulation becomes closely aligned with the dietary requirements of the fish. In particular, modern diets tend to contain more lipid and less protein which has contributed to a general reduction of food conversion ratios and a reduction in inputs of nitrogenous waste.

36. Shrimp farming should consider the use of natural feed items in the pond, such as zooplankton and benthic organisms to supplement the formulated diets. This practice will reduce the allochthonous loading into the ponds. Pond management practices such as aeration, feeding rate and stocking rate should aim to enhance natural food in the ponds.

37. Formulated feed low in phosphorus and nitrogen should be used in shrimp culture to reduce the occurrence of eutrophication in pond water as well as in associated water bodies. However, the movement towards this end is very slow, perhaps because of the lack of environmental awareness among producers of shrimp feed.

Improved shrimp pond management

38. Shrimp farmers normally release enriched pond waters during water exchange and flushed organic matter from the pond bottom at the end of each harvest to the estuary causing serious eutrophication problems. A decrease the frequency of water exchange should alleviate problems of eutrophication in the estuary. In disease-prone or polluted areas, culture practices show a shift towards closed culture system where water from external sources is not required during the culture period.

39. Use of probiotics, preferably local ones, should improve the water quality of the ponds resulting in a better food conversion ratio, higher shrimp production and cleaner effluents. 6/

40. Removal of sludge from shrimp pond bottom after every harvest and extraction of nutrients from the sediments should not only prevent eutrophication in the estuary, but also the recovery of nutrients for mass culture algae in shrimp hatchery. 7/ In addition, pond management should ensure that all pond effluents should be treated in a reservoir containing macro-algae, bivalves and fish to decrease the turbidity and reduce nitrogen and phosphorus before being released into the sea or recycled to the ponds. In other cases there could be efficient coupling of filter feeders and shrimp.

C. Use of enclosed and re-circulating systems (both for finfish and shrimp culture)

41. Closed systems can contain domesticated species and keep them from mixing with wild populations, keeping most particulate nutrients from going to the environment and also reducing to a great extent the outputs of dissolved nutrients. 8/ Although such water-recycling facilities are expensive, they present greater opportunities for long-range planning at diminished risk for the culture itself and avoid excess nutrient export to natural coastal systems. Improvements in the design and engineering efficiencies of modern recycled-water plants allow for higher stocking densities, less disease, fewer breakdowns and lower operating costs as well as the reduction of eutrophication potential to coastal waters.

6/ Devarajah et al, 2002.

7/ Yusoff *et al* 2001.

8/ Ackefors 1999.

42. Most enclosed systems can incorporate mechanisms to reduce nutrient inputs to coastal zones. The simplest systems are settling tanks for particulate organic matter which can be cleaned periodically. Such systems are widely used for freshwater salmon smolt production where biofilters, aerated settling tanks, are commonly used. However most of these systems are not particularly efficient in removing dissolved nitrogen, which may cause eutrophication. More sophisticated re-circulating systems can recycle up to 80% of the water in the tanks.

D. Integrated mariculture (polyculture)

43. Polyculture has a long history in freshwater aquaculture (especially in China) and could be applied more in the marine environment. In marine polyculture, bivalves, seaweed, and marine finfish are produced together. By using such complementary species, the waste of one can be converted to protein by the others. In finfish production, for example, feed that is not consumed filters down to suspension-feeding bivalves, or mixes with fecal waste and is taken up by primary producers such as seaweed (harvested directly), or by phytoplankton, which is then consumed by bivalves.

44. Effluents rich in organic matter from shrimp culture can also be utilized by bivalves. Many species can filter out small particles and also utilize microalgae from the effluent. These can be commercially valuable species for harvest or non-valuable species for use as fish-meal. This form of culture shows much promise in increasing sustainability in many types of aquaculture since it maintains a balance of nutrients in the environment, and increases the efficiency of protein production.

45. It should be noted, that mitigation of the effects of mariculture nutrient input on marine ecosystems requires knowledge of local and regional carrying capacity to receive nutrients as well as knowledge of food webs and ecosystem processes. Such studies are usually lacking from most environmental impact assessment and licensing of permits. There is also the need of articulate and couple mariculture with artisanal fisheries and sport fishing as a way of helping nutrients to cycle and produce additional positive effects or neutralize potential negative effects.

E. Production of larvae in aquaculture facilities rather than from the wild

46. In culture systems, where there are no methods for artificial control of reproduction, or where they are beyond the means of local farmers, manual collection of fry for growout can remove significant amounts of biomass. This should be correlated to the impact of fishing juveniles before any reproductive contribution. Although under-documented, intense collection of juveniles can lead to disruption of natural recruitment of local populations, therefore affecting species sustainability. Moreover, a shift in plankton biodiversity, food webs, and habitat destruction are expected. It should be emphasized that these impacts are highly dependant on the species reproductive strategy and ecosystem sensitivity. Harvesting wild seeds, followed by transfers might also lead to a loss of biodiversity through effects on genetic resources heterogeneity of native species. Although it may impact social activities, an efficient mitigation process is to produce larvae in aquaculture facilities so as to sustain aquaculture production. Implementation of such a plan can lead to recovery of affected biodiversity.

47. New technologies such as cryo-preservation could be considered as a mitigation process to limit pressure on wild populations and optimize brood stock management and seed supply at the hatchery level. Additionally, there is an critical need of genetic databases to assess genetic resources and forecast any change produced by cultured species.

F. Mitigating the effects of antibiotics

48. The overuse of antibiotics has caused a widespread concern about the emergence and selection of resistant bacteria. It is a generally accepted fact that antibiotic resistance is associated with the frequency of use in the environment. 9/

49. Training should be provided in the use and the harmful effects of antibiotics to ensure their proper administration. In many cases, the outbreak of disease is due to poor health management practices resulting in stress, and thus making the cultured animals more susceptible to diseases. Proactive monitoring and use of proper diagnostic tools are often best practices to avoid a disease outbreak.

50. Regulations to reduce the use of antibiotics must be drawn up and enforced. More attention should be paid to reduction of stress factors by improving health management practices. There has been a general move in some countries in the industry away from heavy use of man-made chemicals and toward lower stocking densities and the use of probiotics (to improve water quality).

51. This situation, combined with public resistance to antibiotic use in some countries, has led to intensive research on vaccines for infectious diseases of farmed marine animals. Vaccination can treat some infectious diseases highly effectively. Vaccines can be administered orally or by injection or through immersion or spraying. Major diseases for which vaccines have been developed include furunculosis, coldwater vibriosis, vibriosis, yersiniosis, and edwardsiellosis.

52. Further research should be encouraged in this area, and should include the close involvement of farming companies. Often there will be the need for economic assistance with such technological development, especially for developing countries.

G. Mitigating the effects of pesticides, piscicides and parasiticides

53. Pesticides and piscicides are used to remove pest species from the surrounding environment. Residues are often highly toxic and may persist for weeks in the water and sediment often killing non-target organisms. Lower stocking densities, large enough distances among farms, prophylactic methods and general management procedures (which includes proper training) should greatly help prevent the use of chemicals to control external parasites. Alternatively, totally self-contained systems should be used.

H. Reducing the use of hormones

54. Alternatives for the use of hormones include

(a) Proper genetic-selection programmws, which could provide better offspring and enhance certain traits otherwise achieved by using hormones;

(b) Use of photoperiod management in industrial production of salmon. This is probably one of the most promising mitigation tools for the use of hormones in the field of salmon production. Similar techniques could be developed for other species;

(c) Cryo-preservation could be considered as a mitigation process to optimize broodstock management and seed supply at the hatchery level.

9/ Hamilton-Miller 1990 and others.

I. Preventing disease transmission

55. Prevention should be encouraged as a mitigation process for disease transmission since no cures exist to several diseases in cultured species. Improved monitoring programmes for known and emerging diseases should be encouraged, as well as the use of biomolecular tools for diagnostics.

56. Mitigation should include contingency measurements such as quarantine stations and complete self-containment of infected organisms to be treated or to be transported for elimination. Effluent of contained systems should be treated with ultraviolet or ozone procedures.

57. To avoid diseases, protocols for quarantine and movement of animals should be in place to minimize transmission of diseases. International codes of practice, agreements and technical guidelines used to minimize the risk of diseases associated with movement of aquatic animals should be adopted. Examples of such are the OIE International Aquatic Animal Health Code and Diagnostic Manual for Aquatic Animals Diseases and Code of Practice on the Introductions and Transfers of Marine Organisms of the International Council for Exploration of the Seas (ICES). In addition, there is a need for regionally-orientated guidelines such as the most recent (2000) FAO/Network of Aquaculture Centres in Asia-Pacific (NACA) Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals and the Beijing Consensus and Implementation Strategy. Collaboration between regional and International agencies such as NACA, OIE, ICES and FAO should be further strengthened, and should include close collaboration on the issues related to transboundary movement of aquatic animals.

58. 57The use of indigenous species for culture should be encouraged. In addition, strengthening of aquatic animal health capacity, along with improved laboratory facilities, control protocols and therapeutic strategies should be put in place to minimize losses due to disease transmission.

59. In addition to the above, establishment and implementation of a harmonized regional certification system, establishment of regional reference laboratories for standardization and validation of diagnosis, and establishment of regional training programmes in aquatic animal health issues including trans-boundary movement, risk assessment and contingency plans, are vital for preventing disease transmission.

J. Preventing escapes

Exotic species

60. Although geographic constraints may be difficult to address, especially in developing countries, mariculture of endemic species should be encouraged. Risk analysis can be carried out before any introduction so as to assess likely impacts. Improved management practices can limit the spread of escapes, including site selection outside their reproductive range to avoid reproduction. Use of sterile individuals can also be recommended when the risk to interact with native population is limited. Other contingency measurements should be mandatory in case of accidental escapes.

Native species

61. Farmed native species may cause a decrease in intra-specific genetic variability when released to the environment. Similarly, transferring seed within the geographical range of the species may affect genetic variability. Therefore, a proper broodstock-management plan is critical. An alternative mitigation approach is to limit the spread of the selected strains by supporting the production of sterile individuals.

IV. ENHANCING THE POSITIVE EFFECTS OF MARICULTURE ON MARINE AND COASTAL BIOLOGICAL DIVERSITY AND PRODUCTIVITY

62. Mariculture could help preserve biodiversity when, as a successful economic activity, it can provide a release to the predation pressure over commonly harvested aquatic species. Thus, it can provide a local relief, although globally and indirectly, aquaculture has been blamed for over-harvesting of aquatic resources to obtain fishmeal. 10/

63. Nutrient loads from mariculture can generate eutrophication and also cause biodiversity losses. However nutrient loads in oligotrophic to mesotrophic coastal zones could enhance productivity and increase biodiversity, although it can be argued that these are changes from natural conditions. One way to diminish the ecological footprint of salmon farming is to prevent nutrients from been lost to bacterial degradation. This can be achieved by finding alternative pathways (to direct bacterial degradation) that will need native species and ecosystem processes. Coupling these processes to the mariculture activity is still a challenge. Some ecological hypotheses have proposed that increased nutrient inputs could provide extended food webs and possibly increased biodiversity, at least within a certain range.

64. Best-site selection (including optimal flushing and dispersal of nutrients) could actually promote an increase of local and total productivity, specially in oligotrophic and mesotrophic systems, particularly when additional substrate heterogeneity, such as building of artificial reefs to soft bottom areas, is provided for. 11/ Angel *et al* (2002) showed a relevant improvement of environmental conditions around fin fish farms by using artificial reefs. Other possibilities include coupling with some forms of shellfish culture or natural shellfish beds. All these possibilities should be explored.

65. Additionally it should be mentioned that some forms of mariculture, such as shellfish and macro-algae production, could contribute to biodiversity enhancement by providing habitat structure and food. Such effect could enhance food web structure, fluxes, and interaction between mariculture and wild fish and invertebrates.

66. Although not directly connected to mariculture, overfishing and other activities affect biodiversity and produce depletion of wild stocks. Mariculture, under controlled reproductive activity, could be considered as a mitigation process for biodiversity recovery. However, this should be addressed through a genetically sound broodstock management plan in order to avoid reducing genetic variability.

V. MARICULTURE GUIDELINES RELATED TO BIODIVERSITY

A. Principles and standards

67. Although no set of internationally agreed-on criteria has yet been developed specifically for the environmental regulation of aquaculture operations, many national and regional regulations and laws, largely based on scientifically accepted environmental criteria, have been adopted. However, the ICES recently prepared draft guidelines for the preparation of environmental impact assessment documents related to shellfish mariculture 12/ and the European Union funded the MARAQUA project, which also presented scientific principles underlying the monitoring of the environmental impacts of aquaculture. A variety of principles and standards are voluntarily being applied to the industry in an attempt to decrease its environmental impact and improve its public image. In addition, in its decision VI/7 A, the

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10/ Soto and Jara 1999.

11/ Jara and Cespedes 1994.

12/ See http://www.ices.dk/reports/MCC/2002/WGEIM02.pdf.

Conference of the Parties adopted guidelines for incorporating biodiversity-related issues into environmental impact assessments.

68. Article 9 of the FAO Code of Conduct for Responsible Fisheries provides a set of voluntary principles and standards that, if applied, ensure that potential social and environmental problems associated with aquaculture development are duly addressed and that aquaculture develops in a sustainable manner. However, providing an enabling environment for sustainable development in mariculture is not only the responsibility of governments and aquaculture producers, but also the responsibility of scientists, media, financial institutions and special interest groups. Additional principles and standards include the ICES Code of Conduct, and NACA Code.

B. Certification

69. Aquaculture operations can be certified as: (i) producing cultured species to guidelines or codes of practice, (ii) producing cultured species to reputable and recognized standards, or (iii) through operational audits and assessments as producing species to defined criteria. The following section discusses these three methods of certification:

(a) Aquaculture operations are officially certified as producing cultured species to guidelines or codes of practice, sometimes followed by Eco-labeling of the product. For example, Global Aquaculture Alliance (GAA) is an international, non-profit trade association, which promotes environmentally responsible aquaculture through an eco-labeling programme called the "Responsible Aquaculture Program", which includes codes of conduct for responsible aquaculture and certification production standards. There are other schemes putting more emphasis on third-party certification;

(b) Aquaculture operations may be certified as producing cultured species to reputable and recognized organic standards. For example, the International Federation of Organic Agriculture Movements Basic Standards (IFOAM) provide organic production standards for agriculture and aquaculture that are used by certifying bodies and standard-setting organizations worldwide as a framework for development of certification criteria. IFOAM includes criteria for rearing of fish and servicing of cages; water quality; feeding; health; fish re-stocking, breeding and origin; propagation of fish stocks and breeding; and transport, killing and processing;

(c) Aquaculture operations may be certified, through operational audits and assessments, as producing cultured species to defined criteria. Certification is followed by eco-labelling of the product and often requires the implementation of a documented Environmental Management System (EMS). The International Organization for Standardization (ISO) has developed sets of generic management system standards, which provide general standards and criteria for the development of an EMS. The ISO 14001 Environmental Management System has been used by various organizations as a basis for environmental certification.

70. Appropriate monitoring programmes are essential for achieving and maintaining an environmentally friendly mariculture industry. Monitoring and regulating the production process and the extent of the operation is also a prerequisite to integrating mariculture into coastal zone planning. It is only when adequate data are available that environmental, including biodiversity, and mariculture needs can be securely formulated. It therefore follows that integration will be successful when all participants (users of the coastal resource) are able to identify their environmental needs and impacts while demonstrating a high level of credibility in their assessments. To increase public confidence, it is recommended that the results of ongoing monitoring programmes are accessible to the public.

71. Setting threshold levels for environmental impacts or environmental quality standards (EQS) requires a close cooperation between authorities who can determine what impact is acceptable, and scientists who understand what this means in measurable parameters. In many countries, the task is

determined by environmental quality objectives (EQO) from which EQS values are derived. An EQO/EQS system is appropriate since it will contribute to transparent regulatory systems that are based on political decisions and public acceptance. This approach opens the possibility of defining zones with different allowable impacts and accordingly, different EQS values. 13/

72. Monitoring programmes must concentrate on the main impacts of mariculture. It has been suggested that following criteria should be used to select the impacts on which to place the main emphasis:

(a) The sum of the impacts must have relevance for both the environment and the mariculture operation;

(b) The impact must be convenient for monitoring e.g. routine analytical methods must be available and the signals must be distinguishable for background levels;

(c) Scientific information must be available to set adequate EQS;

(d) The monitoring must be cost efficient, as many mariculture operations are small enterprises.

13/ Henderson and Davies, 2000.

Annex I

RECOMMENDATIONS FOR FUTURE RESEARCH AND MONITORING PROJECTS

The Expert Group recognizes that at the present time, there is insufficient information available about the effects of mariculture on biodiversity and its mitigation. Therefore, additional efforts should be developed in the following areas:

(a) *General research needs*:

(i) Development of research programmes to support establishment of efficient monitoring programs to monitor impacts of mariculture on marine and coastal biological diversity;

(ii) Development of criteria for judging seriousness of biodiversity effects of mariculture;

(iii) Subsequent establishment of monitoring programmes to detect biodiversity effects of mariculture;

(iv) Improvement (and transfer) of integrated mariculture system including polyculture;

(v) Research on the impact of escaped mariculture species on biodiversity;

(vi) Development of criteria for when environmental impact assessments are required, and for the application of environmental impact assessments on all levels of biodiversity in the context of the guidelines endorsed by the Conference of the Parties in decision VI/7 A (genes, species, ecosystems);

(vii) Noting that the FAO glossary of terms is skewed towards marine capture fisheries, expansion of this glossary with regard to its terminology related to aquaculture;

(viii) Reinforcement of global assessments of marine and coastal biological diversity;

(b) *Research related to impacts of mariculture on genetic diversity*:

(i) Development of a genetic resource management plans for broodstock;

(ii) Research aimed at understanding genetic effects of biotechnology developments in aquaculture;

(iii) Research aimed at understanding genetic structure of both the farmed and wild populations, including:

(iv) Effects of genetic pollution from farmed populations on wild populations;

(v) Maintenance of genetic viability of farmed populations;

(vi) Studies of (genetics of) wild populations as potential new candidates for mariculture;

(c) *Research related to impacts of mariculture on species diversity*:

(i) Support for basic global-scale taxonomic studies, possibly in conjunction with the Global Taxonomy Initiative (GTI);

(ii) Support for studies aimed at development of responsible aquaculture using native species;

(iii) Development of methods and techniques for limiting by-catch of seed collection;

(d) *Research related to impacts of mariculture on ecosystem diversity*:

(i) Research on carrying capacity and carrying capacity models for planning aquaculture, specially stocking rates;

(ii) Comprehensive studies to quantitatively and qualitatively assess effects of mariculture on biodiversity for various aquatic ecosystems, selected by their sensitiveness degree;

(iii) Research on the competitive nature imposed on marine fisheries by capture and culture fisheries;

(iv) Studies aimed at improved understanding of the effects of inputs, such as chemicals, hormones, antibiotics and feeds on biodiversity;

(v) Research on impact of diseases in cultured and wild species on biodiversity;

(e) *Research related to socio-economics, culture, policy and legislation*:

(i) Comparative studies on legislation, economic and financial mechanisms for regulating mariculture activity;

(ii) Development of quantitative and qualitative criteria to assess mariculture impacts on the environment according to culture practices;

(f) *Monitoring programmes*:

(i) Support for mariculture-related disease monitoring programs at the global level;

(ii) Support for the transfer of biotechnological diagnostic tools for wide use;

(iii) Update of taxonomic database including genetic diversity at the intra-specific level.

Annex II

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14/ A more comprehensive list of references is available in the full report of the Ad Hoc Technical Expert Group on Mariculture.

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