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THE EFFECTS OF MARICULTURE ON BIODIVERSITY

Background document prepared by World Fisheries Trust

INTRODUCTION

1. The present review paper was written as a background document for the Ad Hoc Technical Expert Group on Mariculture. The Group, established by the Conference of the Parties in its decision V/5 to assist the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) in its work on marine and coastal biological diversity, works specifically to implement programme element 4 (Mariculture). The present paper is intended to help the Expert Group to:

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

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

2. 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 explosively and its practices have important implications for marine biodiversity, especially in light of a trend toward the culture of high-value carnivorous species.

3. Mariculture practices have many effects on biodiversity, ranging from the immediate and obvious (such as the genetic effects of large-scale deliberate release of farmed fish into the wild) to the subtle and secondary (like effects on primary productivity that filter down through the food chain). Whether mariculture has the potential ultimately to reduce the pressure on wild fisheries is the subject of fierce debate, and will depend greatly on the policies and economies associated with both activities.[133] The outcome is not at all clear; increased farmed production of salmon, for example, has *not* resulted in reduced wild harvest despite lowered prices, a situation that may reflect fisheries subsidies and inflexible policies more than simple supply and demand.

4. Like all aquaculture, the culture of marine species displays boom and bust tendencies that attract investors keen to cash in on a new species. A species or an entire culture technique can thus enjoy wild popularity followed by a sudden disappearance from the radar screens of agencies that monitor production. New species command high prices but markets can rapidly be saturated, and, in notorious cases like shrimp culture, production can evaporate nearly overnight due to fundamentally flawed environmental practices (see Case Study, *Shrimp Farming: Boom, Bust and the Beginnings of Change*).

5. There are two economic production modes in mariculture. The first is for economically significant export species such as salmon or shrimp, whose impact on the environment draws the attention of special interest (and policy-forming) groups. The second form of production is for generally local consumption. This group remains largely unaffected by regulations that attempt to control the sourcing of broodstock, crossbreeding, or the introduction of alien species to waterbodies.[189] Biodiversity effects are more likely to emerge in the first group.

6. Mariculture is very technology-dependent and, in large-scale farming at least, constantly intensifying. State-sponsored research concentrates on feeds, seed supply (artificial reproduction) and culture systems. Within the past two decades the impetus for research has gradually shifted from the purely economic to at least the partially environmental, and technical advances like hatchery methods or new kinds of genetic manipulation are less likely to be wholeheartedly embraced by society and more likely to be debated for their effects on biodiversity. The lively controversy on ocean ranching is evidence of this new sensibility, and an encouraging background for the work of the Expert Committee for whom this paper has been prepared (see Case Study, *Enhancement and Sea Ranching: Damn the Torpedoes*).

7. This report is divided into four main chapters. The first is a brief "who's who" of mariculture. This section presents the major cultured species and collapses them into five **mariculture methods**. Its purpose is simply to provide a snapshot of the most important culture methods. In Chapter 2, we summarize the most common biodiversity effects of these five methods ("review of the current state of scientific and technological knowledge on the effects of mariculture on marine and coastal biodiversity"). Because the same biodiversity effect frequently arises from more than one of the main culture methods, this chapter is organized by biodiversity effect. The third chapter lists ways in which some of these biodiversity effects can be minimized ("review of criteria, methods and techniques that avoid the adverse effects of mariculture and stock enhancement"), and briefly addresses the question of whether marine productivity can actually be enhanced through mariculture ("review of criteria, methods and techniques that enhance the positive effects of mariculture on marine and coastal productivity"). The final chapter looks briefly at the issue of criteria for describing the biodiversity effects of mariculture.

I. THE MAIN MARICULTURE SPECIES AND METHODS

8. Given the short time available to prepare this report, we made the assumption that the severity of biodiversity effects will roughly mirror production tonnage, so we concentrated on the genera and species responsible for most global mariculture production, using the most recent summary data available (FAO Fishstat Plus 2000).[61] FAO's compilation shows a rather marked drop in tonnage for individual genera at about the 20,000 ton mark, so we cut our list at that point, limiting our survey to 32 genera from 25 different genera (approximately 130 marine species were cultured in 2000). The volatility of aquaculture production means that this list is significantly different from that of, say, two years earlier, and is certain to change again. The list does not include marine species, such as milkfish and mullet, when they are cultured in brackish inland waters, nor does it include freshwater species, such as tilapia, grass carp and

European eel, when they are grown in brackish or marine waters. We eliminated FAO's "not elsewhere included" (NEI) designation, which groups species not listed individually. Most of the English names are those used by FAO, with alternates occasionally given. Our arbitrary cut-off at 32 species means that many familiar ones, like barramundi, grouper, red drum, giant clam or mud crab, are not included. Some of these species are of great local importance, and will undoubtedly rise in the tonnage rankings. It also means that we had to ignore the potentially very important local effects of small scale culture, for example seahorse culture.

9. Species are listed in order of tonnage produced. Brackish water aquaculture production is dominated by shrimp but also includes finfish such as milkfish, and molluscs. Marine aquaculture is dominated by seaweed, notably Japanese kelp, and molluscs, mainly the Pacific cupped oyster, but also includes high value finfish such as salmon.[59]

Table 1. Top mariculture species in 2000

Species	**Annual Production (tonnes)**	**Culture Environment**	**Top Two Countries**
Japanese kelp (*Laminaria japonica*)	4,580,056	m	China, Japan
Pacific cupped oyster (*Crassostrea gigas*)	3,944,042	m, b	China, Japan
Japanese carpet shell (*Ruditapes philippinarum*)	1,693,012	m, b	China, Italy
Yesso scallop (*Patinopecten yessoensis*)	1,132,866	m	China, Japan
Laver / Nori (*Porphyra* spp.)	1,010,963	m	China, Japan
Atlantic salmon (*Salmo salar*)	883,448	m	Norway, Chile
Tambalang / Elkhorn / Spinosum (*Eucheuma cottonii*)	604,600	m	Philippines
Giant tiger prawn (*Penaeus monodon*)	571,497	b, m	Thailand, Indonesia
Blue mussel (*Mytilus edulis*)	458,558	m	Spain, Netherlands
Blood cockle (*Anadara granosa*)	319,382	m	China, Malaysia
Wakame (*Undaria pinnatifida*)	311,105	m	Rep. of Korea, Japan
Fleshy prawn (*Penaeus chinensis*)	219,152	b, m	China & Rep. of Korea
Red seaweeds (*Kappaphycus* spp. & *Eucheuma* spp.)	205,277	m	Indonesia
Rainbow trout (*Oncorhynchus mykiss*)	153,340	m, b	Chile, Norway
Whiteleg shrimp (*Penaeus vannamei*)	143,737	b, m	Ecuador, Mexico
Japanese amberjack / Yellowtail (*Seriola quinqueradiata*)	137,328	m	Japan, Rep. of Korea
Mediterranean mussel (*Mytilus galloprovincialis*)	117,271	m, b	Italy, France
Coho salmon (*Oncorhynchus kisutch*)	108,626	m	Chile, Japan
Green mussel (*Perna viridis*)	87,533	m	Thailand, Philippines
Gilthead seabream (*Sparus aurata*)	87,106	m, b	Greece, Turkey
Silver / Red seabream (*Pagrus major*)	82,811	m	Japan, Rep. of Korea
New Zealand / Green shelled mussel (*Pena canaliculus*)	76,000	m	New Zealand
European seabass (*Dicentrarchus labrax*)	52,817	m, b	Greece, Egypt
Gracilaria seaweeds (*Gracilaria* spp.)	52,674	m, b	Chile, Viet Nam

Species	Annual Production (tonnes)	Culture Environment	Top Two Countries
Northern quahog / Hard clam (*Mercenaria mercenaria*)	50,685	m, b	Taiwan Province & USA
Banana Prawn (*Fenneropenaeus indicus* & *F. merguiensis*)	45,717	b, m	Indonesia, Viet Nam
Caulerpa seaweeds (*Caulerpa* spp.)	28,055	m	Philippines
Flathead gray mullet (*Mugil cephalus*)	27,737	b, m	Egypt & Italy
Milkfish (*Chanos chanos*)	25,723	b, m	Taiwan Province, Philippines
Chilean mussel (*Mytilus chilensis*)	23,477	m	Chile
Peruvian calico scallop (*Argopecten purpuratus*)	21,295	m	Chile & Peru
Japanese flounder / Bastard Haibut (*Paralichthys olivaceus*)	21,202	m	Rep. of Korea, Japan

m= marine, b= brackishwater

10. 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), we have grouped the mariculture methods in a common-sense way that makes it easy to identify and visualize their biodiversity effects. Our culture categories are:

(a) Bivalve;

(b) Shrimp/prawn;

(c) Aquatic plant;

(d) Finfish in net pens and cages;

(e) Finfish in ponds.

11. **Seed suppl**y and **growout** are considered separately for each, as these very different activities have fundamentally different effects on biodiversity. The methods are now described briefly.

A. Bivalve culture

1. Seed supply

12. Bivalve mollusc larvae or “spat” are either collected from natural grounds using suitable materials to which the larvae adhere or “set”, or produced by artificial fertilization in hatcheries. The latter technique allows much greater control over the genetic makeup of the stock, as well as transport of the larvae to distant grow-out facilities (“remote setting”). Hatchery production of bivalve seed has been primarily driven by the North American production of Pacific or Japanese oyster, for which abundant natural spat is lacking in North America.

2. Growout

13. Larvae that have attached or “set” to their substrate are grown in **hanging culture** (suspended from floating rafts or long lines on strings, racks, trays, stacks or mesh bags), **vertical or rack culture**

(sticks or posts are staked on the bottom and act directly as a growing medium or support racks, or platforms), or in **bottom culture** (shells, stones, rocks, cement slabs etc. added to the bottom provide attachment sites).

14. Hanging culture is the most common method of oyster culture in Japan. In France, oysters are cultured on the bottom to produce the regularly shaped shells preferred by raw half shell consumers.[16] Commercial clam growers in Japan and quahog culture operations in the US still depend largely on bottom culture.[16] Mussel farming makes extensive use of bamboo either as stakes or as floating rafts. The stake method is the most commonly used.[15] Seed scallops are most commonly suspended in the water from rafts, frames or longlines, sandwiched in metal mesh frames, hung in fine mesh lantern nets (shallow water cages) or pearl nets (deep water cages) or hung individually from strings (ear hanging).[16]

B. Shrimp/prawn culture

1. Seed supply

15. Until the last decade, the global shrimp and prawn farming industry relied on wild-caught larvae or larvae produced by wild-caught females carrying fertilized eggs ("berried females"). With the expansion of shrimp farming and especially the need to ensure the supply of disease-free post-larvae (the stage at which artificial feeding and growout in tanks starts), the trend is toward maintenance of broodstock in hatcheries and the complete closing of the life cycle in captivity using induced spawning techniques. Such controlled reproduction of farmed crustaceans has greatly reduced dependence on natural supplies of seed.

2. Growout

16. Shrimp are grown in coastal and brackishwater ponds whose salinity may be adjusted by the addition of fresh or salt water. In the early days of shrimp farming, for example in China, shrimp culture was done in "trap ponds" where juveniles were allowed to enter and grow to marketable size.[54] However, this method is no longer responsible for large scale production (although it persists in many countries). Now, most shrimp are grown in semi-intensive and intensive culture ponds where they are given supplementary or full artificial feeds, respectively. The former augments the natural production of the pond, while the latter totally replaces the natural organisms in the water as a source of nutrition.[15] In many countries, shrimp ponds began their existence as rice fields, mangrove forests, or fish ponds (for example, milkfish ponds in the Philippines).[185]

C. Aquatic plant culture

1. Seed supply

17. Cultured aquatic plants generally have complicated life cycles with several intermediate stages. Most culture of aquatic plants is now dependent on hatchery production of the early life stages (monospores, zoospores or gametophytes) which are attached to growing media and transferred to marine sites.

2. Growout

18. In bottom culture, large rocks or artificial substrate such as various shapes of concrete are placed on the seabed and either seeded with zoospores (an early life stage) or have sporophytes (young plants) anchored to them using rope. Bottom culture, now often used in conjunction with raft culture, is the earliest know form of kelp culture but is still employed in China, as well as in Japan and Korea.[16]

19. In off-bottom culture, monospores (another early life stage) or young plants are either suspended from weighted rope lines or attached directly to lines or culture nets. These lines and nets are attached to floating rafts, bouyed longlines, fixed longlines or fixed pole structures and frames. *Nori* (laver) monospores are attached to culture nets in the laboratory and the nets are suspended from wooden or bamboo frames anchored to the bottom in shallow coastal areas or inland seas.[16] *Wakame* is cultured in open water on longlines that can reach depths of up to 6 meters depending on water clarity. [16] The fixed, off-bottom monoline method is the most common method used in the culture of eucheuma. Raft or long-line methods are also used.[67]

D. Finfish: net pens and cages

1. Seed supply

20. Most of the important finfish species are grown from larvae or "fry" produced by controlled reproduction in hatcheries. Induced breeding technology has progressed through the application of crude pituitary homogenates to the development of highly active gonadotropin-releasing hormone analogues that can stimulate spawning in recalcitrant species that would otherwise need careful and expensive manipulation of their holding conditions.[88] [198] Of all the major marine finfish species cultured, salmonids are the main group from which gametes can be removed in the wild and combined later in the hatchery, the technique most commonly used for enhancement. For most tropical species, and for salmonids held in captivity before breeding, spawning is initiated by hormone application. In some species, for example milkfish, whether fry are produced in a hatchery or collected from the wild is determined by the budget of the farmer.

2. Growout

21. For most of the major species of finfish, fertilized eggs are incubated until hatching (a very short process in tropical species, but several months in salmonids) and then conditioned to artificial feed in large tanks before transfer to growout pens or cages. Salmonid culture makes the further demand of freshwater tank culture followed by growout in the ocean, because the species move between fresh and salt water in their life cycle. In some very intensive systems, such as Japanese flounder, fry produced from artificial spawning can be grown not only in sea cages but also in outdoor land-based tanks or indoor re-circulating systems.

22. **Enhancement** or ranching is most developed with marine finfish. In enhancement, fry are not grown out in cages or pens; instead they are released directly to the environment and harvested later as part of the "wild" fishery.

23. Pen and cage culture involve the rearing of fish within fixed or floating net enclosures supported by frameworks made of bamboo, wood, or metal, and placed in sheltered, shallow portions of estuaries and bays or in deeper marine environments. A fish pen does not have a net bottom; the edges of its net are anchored to the bottom/substrate. A fish cage has a bottom made of the same netting material used for its four sides, and so can be either fixed or floating. Cage-reared fish may or may not be fed supplemental or artificial diets depending on the stocking density and the level of technology in the country.[15] In the Philippines, for example, milkfish pens generally have a nursery compartment within the grow-out pen/enclosure and are not generally given supplemental feeding except for occasional rations of bread crumbs, rice bran, broken ice cream cones, fish meal, and *ipil-ipil* leaf mill.[15]

24. Species that are cultured in brackish water pens and cages include mullets, seabreams, seabasses, groupers, snappers, threadfins, rabbitfish and scads. Species cultured in marine net pens include salmonids, amberjack (yellowtail), seabreams, seabasses, tuna, groupers, snappers, scads and pomfret.

E. Finfish: ponds

1. Seed supply

25. The same trend toward controlled reproduction is evident as for finfish cultured in nets and cages, although the extent depends on the region and the level of operation. Milkfish and mullet are more commonly cultured in coastal and brackish water ponds than in sea cages, the technology probably reflecting their status as a locally consumed species rather than a "high-end" export species. Many low intensity operations still depend on unreliable natural supplies of fry with no opportunities for domestication or selective breeding. In Egypt, for example, fry of mullets, sea bream and sea bass are still derived primarily from the wild.[56]

2. Growout

26. A typical fish pond system consists of the following basic components: pond compartments enclosed by dikes, canals for supply and drainage of water to and from the pond compartments, and gates or water control structures to regulate entry and exit of water into and from the pond compartments.[15] Most mullet farms use shallow ponds and low stocking densities (less than 1 fish per square metre). Milkfish culture in the Philippines follows the progressive culture scheme, with separate nursery, transition, and rearing ponds.[15] Fish grown in semi-intensive and intensive culture ponds are given supplementary and full artificial feeds, respectively.[15]

F. A note on polyculture

27. Polyculture, the growing of two or more species in the same system, has a long history in freshwater aquaculture, especially in China. Polyculture can mitigate some of the biodiversity effects of aquaculture and make better use of available resources. Some marine examples include grouper and mudcrab in ponds; milkfish and siganids in marine net cage; sea scallops suspended from salmon net pens; and ezo scallop, Japanese kelp and sea cucumber in shallow bay and open-water maricultural structures.

II BIODIVERSITY EFFECTS OF THE MAIN TYPES OF MARICULTURE

28. All forms of mariculture, regardless of physical structure or economic motivation, affect biodiversity. Mariculture can degrade habitat, disrupt trophic systems, deplete natural seedstock, transmit diseases and reduce genetic variability.

29. Some broad divisions of effect are possible. **Autotrophic** or "natural" trophic systems, such as kelp culture and raft culture for scallops, take their energy from solar radiation and their nutrients from naturally occurring organisms in the water body, and tend to have fewer negative effects. **Heterotrophic** or "artificial" trophic systems, such as net and pond culture of fish and shrimps, derive energy mainly from feeds supplied by growers[160] and are more likely to disrupt the natural ecosystems.

30. In the discussion that follows, we group the biodiversity effects of mariculture as **indirect** (pollution, effects on habitat, and trophic effects) and **direct** (disease transmission, depletion of natural seedstock, and genetic effects).

A. Indirect biodiversity effects

1. Pollution

31. Heterotrophic culture systems produce organic and chemical wastes that affect biodiversity by causing shifts in abundance at various levels in the food chain. The net effect of these changes is disturbance of ecosystem balance. Such effects are a reminder that aquatic ecosystems must be considered as a whole, not as separate parts that can be altered without affecting any of the other components.

Organic pollution

32. Culture systems in open waters discharge their untreated wastes (faeces and uneaten feed) directly into the water and often at levels higher than the environment can absorb. In sheltered bays the overloading of carbon-based nitrogen and phosphorous compounds may lead to blooms of phytoplankton, whose subsequent degradation can drastically reduce oxygen levels. If the algae are toxic, fish are killed and shellfish contaminated. Algal blooms can also cause severe shading to seafloor vegetation that serves as nursery habitat and refuge for finfishes and benthic invertebrates.[34]

33. Intensive culture of high-value marine finfish has notorious waste problems that have led to the beginnings of reform in industry practices (e.g. salmonids in British Columbia and most high-value finfish species in Japan).[35 126] Mollusc culture can also produce high quantities of effluent. Scallops and oysters, for example, individually produce up to 50~60g and 120g faeces in dry weight respectively each year.[180] Some of this waste will decompose and be carried away, but most will settle under the beds. During storms, the sediment can be drawn up into water columns and cause heavy mortality by blocking the gills of the bivalves. This overlay of sediment can also shift the composition of benthic communities towards pollution-tolerant species,[105 123] a clear biodiversity effect.

34. In sheltered bays the effects of such waste sedimentation on the sea bottom tend to be confined within 50 or 100 meters of the site and may take years to severely degrade the area. However, in bays swept by strong currents the nutrients may spread widely and spark algae blooms within days,[161] although Beveridge[26] and Gowen and Bradbury[78] report that strong tidal currents tend to dilute wastes before they can cause hypernutrification or eutrophication. Both effects are culture density-dependent.[78 194]

35. Organic carbon (particulate form) and oxygen, nitrate, sulphate typically move downward into the benthos, while carbon dioxide, dissolved organic carbon, and various nutrients (e.g., ammonia and phosphate) frequently move up from the sediments into the water column.[164] Sea-floor biota (e.g., microbes and suspension feeders) modulate these movements, as does the structure of pelagic communities.[166]

Chemical pollution

36. The potential dangers to biodiversity in areas that receive discharges of chemicals, drugs and other additives used in mariculture have not been adequately studied. Commonly used chemicals include antibiotics, pesticides, disinfectants, antifoulants and hormones.

37. Norway is one of the few countries that have extensive records of the amounts of **antibiotics** used in mariculture. In 1987, one gram of antibiotic was used per kilogram of salmon produced, for a total of 49 tonnes of antibiotics in Norwegian coastal waters.[27] By 1993, antibiotic use in Norway had dropped to about 10 tonnes.[164]

38. In much of the world, antibiotic use in mariculture is little restricted, and the temptation to apply large and repeated doses has always been great, a reflection of the essentially stressful nature of most fish culture conditions (high stocking rates, poor water quality, handling, inadequate feed). In regions such as Southeast Asia, huge quantities of antibiotics have been used in aquaculture, both prophylactically in the food and to treat disease.[144 147 154 94] Most antibiotics applied to mariculture systems end up in the sediment[144], though some can accumulate in wild fish and shellfish.[155] Drugs accumulated in underlying sediments can over the long-term impose antibiotic stress on the sediment microflora and increase resistance in pathogens[27], thus selecting for antibiotic-resistant strains and changing the genetic diversity of sedimentary microbes.[164] Lack of access to information on appropriate use has led some aquafarmers to misapply some chemicals (e.g. antibiotics). Salesmen or pharmaceutical companies may also encourage misapplication.[58]

39. Parasites 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 (C.Wood, pers. comm. 2002). Many **pesticides** used to control parasites and fungi are biologically potent even at quantities below chemical detection limits.[144] The organophosphate class of chemicals like dichlorvos and trichlorphon used outside the USA to control sea lice (parasites that feed on salmonid mucus) includes nerve gases and many insecticides. Effects on the marine environment are not well studied; however, dichlorvos is toxic to some crustaceans and molluscs.[48] Effects of residues are usually assumed to be negative, although supporters of the use of the carbamate insecticide Sevin to kill burrowing shrimp (which undermine intertidal zone sediments used for oyster beds) believe that by stabilizing sediments the insecticide promotes greater biological diversity.[145]

40. Chemicals are also used for **antifouling** and as disinfectants. Sandnes reports[156] that as salmon production in Norway has increased the relative usage of antifoulants has declined, with the exception of copper, which rose from 119 tonnes in 1991 to 174 tonnes in 1995.

41. Finally, **hormones** are used to induce or prevent reproductive maturation, for sex reversal and to promote growth. Dip applications are obviously more of a concern than controlled injection into individual broodstock animals. Hormone use is not well documented and is sometimes carried out without adequate understanding of the quantities needed and of their persistence in the environment or in aquaculture products.[58]

2. *Effects on trophic systems*

42. While there is a marked and welcome trend in fisheries management to consider harvested species as part of an ecosystem rather than "stand-alone" targets, the effects of mariculture on aquatic ecosystems have been little studied. However, given the scale of culture of some of the major species, the effects can be far-reaching.

43. Unlike freshwater cultured species, the high value marine finfish that are farmed do not use plant-based proteins and lipids efficiently, and require animal sources of these nutrients. The most obvious effect of farming 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, though the percentage is dropping as the industry, partly driven by global deficits in fish oils,[156] is actively seeking plant protein replacements. Fish protein and lipids presently

came from the huge fisheries for small pelagic fish like anchoveta, Chilean jack mackerel and Atlantic herring. These fisheries comprise four of the five top global fisheries.

44. 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.* [142] have identified a significant trend in aquaculture that they consider analogous to the global problem of "fishing down the food chain".[141] They point out that increasing intensification of aquaculture, especially in Asia, and its concentration on higher value carnivorous species, is inexorably raising dependence on capture fisheries.

45. Even bivalve culture takes nutrients away from the marine food web: the bivalves remove carbon and nitrogen from the water column, leaving less for other herbivores. If the biomass of bivalves is too great and absorbs too many nutrients, the quantity of phytoplankton falls rapidly and primary production of the waterbody decreases, affecting the growth and reproduction of zooplankton and other herbivorous marine animals.[180] Since bivalves feed on material carried in the water column, there is no net addition of organic matter to the environment (contrasting with the culture of fish such as salmon). However, bivalves do take suspended seston (particulate matter suspended in water) and change it into denser particles that fall to the bottom.[80] Permanent extensive bivalve culture may bring about changes in the coastal food web [97] or in benthic communities.[183]

3. Habitat degradation

46. The loss or alteration of habitat becomes a biodiversity effect when it changes living conditions for other species. All kinds of mariculture take up space, often very large amounts of it, not only in bays and oceans but also on nearby foreshores. The sheer occupying of acres of water can affect migratory routes and feeding patterns of a wide variety of non-target species. Salmon farms, for example, are believed by some to interrupt the free movement of wild migrating salmon and feeding killer whales.[128] Underwater exploders and other acoustic devices intended to deter predators may also increase the stress on non-target animals.

47. Three main habitats are affected by mariculture: **coastal reefs or mangroves, pelagic waters,** and the **benthos**. Coastal mangroves are often converted into shrimp ponds, pelagic waters are affected by nutrient loading (or stripping), and the benthos is affected by sedimentation.

48. Converting tidal wetlands for shrimp ponds and building roads, dikes, and canals threatens benthic habitat diversity in the tropics, particularly in Latin America and Southeast Asia.[164] Tidal marshes and mangroves that serve as nursery grounds for wild shrimp and fish populations are lost, and less mangrove and marshgrass detritus enters coastal food webs.[133] The draining of 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. [164]

49. The best-known example of habitat alteration arising from mariculture is the effect of shrimp farming on mangrove ecosystems, which have very high species diversity both in the water and on land and contribute about one-third of yearly landings of wild fish in Southeast Asia (see also the case-study: *Shrimp Farming: Boom, Bust and the Beginnings of Change*).[133]

B. Direct biodiversity effects

1. Depletion of natural seed-stock

50. 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 growout can remove significant amounts of biomass. Milkfish provides a good example. Controlled reproduction is possible, and widely used in intensive culture.[197] However, in poorer areas where hormonal or environmental manipulation of broodstock is impossible, wild fry are still resorted to.

51. The local or more widespread effects of this removal on non-target species have not been well studied. However, if collection is intense enough the natural recruitment of local populations can suffer. Naylor *et al.* [133] review the effects of fry collection on natural seedstock, noting that 85% of the larvae collected for milkfish farming in the Philippines, for example, are from species other than milkfish, and are discarded – a huge bycatch.

2. Transmission of diseases from farmed to wild stocks

52. The crowded and stressful conditions of net pen culture 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. Salmon net-pen farming provides an example of the spread of exotic pathogens.[108] In 1985, a virulent strain of the bacterium *Aeromonas salmonicida*, which causes the disease furunculosis, was brought from Scotland to Norway[130], spreading to salmon farms and thence to wild salmon and killing large numbers of fish..[90] Bivalve and shrimp farming can also cause disease transmission. The Japanese oyster drill (*Ocenebra japonica*) and a predatory flatworm (*Pseudosylochus ostreophagus*) were brought to American waters along with the Pacific oyster, now the mainstay of bivalve farming in North America. However, these parasites have contributed to the decline of native West Coast oyster stocks.[39] Wild broodstock of Pacific white shrimp (*Penaeus vannamei*) infected with white spot disease (SEMBV) have been moved to previously disease-free regions[189] while Taura Syndrome, caused by the TSV virus, may have been spread through the shrimp cultures of Latin America by the transfer of diseased postlarvae and broodstock.[114] The impact of this introduced virus on its recipient environment is still unknown.[33] [65]

3. Genetic effects

53. 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 explode as new analytical techniques become available. For now, predicting the genetic effects of mariculture will remain difficult, and many prognostications may turn out to be wrong (see Case Study, *Enhancement and Sea Ranching: Damn the Torpedoes*). The genetic effects of cultured marine animals are either **inadvertent** (through escapes of cultured animals) or **deliberate** (enhancement or sea ranching).

54. In culture systems, genetic diversity is deliberately constricted and channeled. Because many aquatic species are highly fecund, numerous seed can be produced from a few parents, leading to a rapid contraction of the genetic base of the farmed stock.[165] Studies of hatchery populations suggest that such loss of genetic diversity is common ([188] [109] for fish and [47] [23] for invertebrates). 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.[153] [74] This situation occurs when the

species being farmed is a local one, and might be called "inadvertent enhancement". It is best studied in salmon aquaculture.

4. Escapes

55. Most animals farmed on land are highly domesticated, and without human protection they would likely fail to survive in the wild. Organisms used in aquaculture on the other hand are still relatively wild, and may easily survive and reproduce outside their natural ranges.[40] Because much of the world's aquaculture relies on species cultured outside their native range, escapes are a constant biodiversity concern. In the short term, escapes of hatchery fish may swamp wild fish populations through sheer weight of numbers. Skaala[163] stated that the number of Atlantic salmon (*Salmo salar*) escaping from fish farms in Norway exceeded the number of wild fish harvested in Norway.[143] A comparison of wild and farmed Atlantic salmon showed that farmed fish had higher growth rates and were more aggressive than wild fish, thus posing a threat to native populations that were already depleted by environmental factors.[49]

56. Many alien marine species have become firmly established far from their native ranges and are culturally accepted as "just more biodiversity". Japanese oyster and Manila clam, for example, are treasured by recreational fishermen on the Pacific coast of North America, and an environmental activist who might refuse a dinner of farmed salmon would likely not think twice about eating a fresh oyster or a plate of steamed clams even though they too are introduced species. In a time when ballast water is distributed around the globe it may even be unrealistic to attempt to prevent the spread of alien marine species. The greater risk is probably with escape of *local* ones, because they are more likely to interbreed with wild populations and affect their survival (again, however, the ability of natural populations to recover from introgression of farmed genes has been very little studied; see the enhancement case study).

57. 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.[76] Escaped or released triploid fish may attempt to breed with wild fish and disrupt overall spawning success. Gene transfer (not yet used in commercial aquaculture) 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.[76] Unanticipated pleiotropic (multiple) effects may also show up.[3]

C. Case-study—shrimp-farming: boom, bust and the beginnings of change

58. Nearly one-third of all shrimp landings are now farmed, despite the fact that shrimp farming is a relatively new industry. Half the landings are based on one species, *Penaeus monodon*, and Southeast Asia and the Americas account for three-quarters of world production.[196]

59. Development of the industry has been volatile. Chinese production, once the leader, failed catastrophically in 1993 and has been rebuilding since then. Taiwan was one of the top producers in the late 1980s but is now a net importer. The practice of intensive shrimp farming is also politically charged: an Indian Supreme Court ruling closing down coastal intensive farming in the mid-1990s because of environmental and social effects was superceded by subsequent legislation.

60. Present shrimp production technology has been strongly criticized as unsustainable, with high prices encouraging overloading of the environment's ability to provide clean water and absorb wastes.

Export-oriented shrimp culture was encouraged by many governments, often supported by external aid, and environmental planning took a back seat. Hence ponds were poorly sited, often in mangrove areas and altering the ecological functions; freshwater aquifers were overused; coastal areas, lagoons and creeks were overloaded with wastes; seed and broodstock were reduced by collection; and disease outbreaks became epidemic to the point where it became extremely difficult to find pathogen-free seed or broodstock.[17]

61. All of the foregoing impacts have direct or indirect relevance for biodiversity. What progress has been made in reducing them?

Mangrove-friendly culture

62. From an ecosystem perspective, the role of mangroves is especially important. Mangroves reduce erosion and serve as spawning and nursery habitat for many species of fish and shrimp.[104] Loss of mangroves became so serious, both biologically and economically, that world attention has focused on the issue within the past decade, and there are now strong signs of an emergent mangrove-friendly mariculture industry. This initiative, presently experimental and confined to ASEAN countries, involves the combination of silviculture (reforestation) with culture of fish, crabs or shrimp and is an attempt to develop and disseminate responsible culture technologies.[1] Mangroves are also being promoted as environments for culture of mud crabs in pens, a technique that eliminates the conversion of coastal areas to ponds. In the Philippines, crab farming in tidal ponds is already an established industry and crab farming in mangrove areas shows enormous potential. However, the seed crablets come from the wild. It is important to develop and refine breeding, hatchery, and grow-out technologies in order to realize their potential to become a cash crop and export industry in tropical Asia without adverse environmental impact.[157]

Controlled reproduction reduces the need for wild fry

63. The difficulty of collecting fry, especially disease-free ones, led to the rapid development of methods for controlled reproduction, a significant research investment. Now, in countries with well-developed shrimp farming industries, reproduction is largely controlled in the laboratory, using eyestalk ablation techniques to induce spawning in captive broodstock. There is even a research effort to develop gene banking technology for shrimp gametes and embryos, to ensure a steady supply of pathogen-free seed.

Better than the alternative?

64. The shrimp culture industry, with its spectacular successes and dismal environmental failures, provides a model for the intervention of states in developing codes of conduct for responsible practices. FAO in particular has been working hard in recent years to implement the principles of the Code of Conduct for Responsible Fisheries, assisting, for example, in development of national codes of practice and technical guidelines.[17] That this is worth doing from a biodiversity standpoint is not simply a matter of protecting mangrove ecosystems or reducing pressure on wild larvae. The wild shrimp fishery, a bottom fishery that uses gear dragged over the sea floor, is notoriously one of the most destructive fisheries in the world. By-catch, the capture of unwanted species, exceeds shrimp catch by the huge factor of six to one, meaning that 12 million tones of unwanted organisms are caught every year, two-thirds of which is thrown back dead. The benthic community is seriously damaged by trawling, and the overall effect on marine ecosystems may be profound. The depredations of the wild shrimp fishery are probably the last thing on the mind of farmers, but there is a strong argument to be made that a sustainable farming industry could reduce not only the pressures on the wild stocks but also the collateral biodiversity damage caused by trawling.

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

65. While mariculture has a variety of adverse effects on biodiversity, many of these effects can be mitigated or even eliminated. The areas offering the most promise of improvement include **changes in nutrition** (reformulation of feeds, reduction in use of animal protein, improving utilization); **reducing waste**; **culturing species together** to make better use of available resources; **containing cultured animals** to prevent escapes; **reducing dependence on wild seed**; **reducing the use of chemical additives and treatments** that promote ecosystem changes; and **reducing disease transmission** between cultured and wild stocks. For all of the foregoing strategies, development of appropriate **policies and legislation** is an overarching necessity.

A. Changes in nutrition

1. Reformulating fish feeds to contain less animal protein

66. The biodiversity effects of the growout stages of finfish mariculture are profoundly influenced by the kind and amount of feeds used. Two aspects of aquaculture nutrition require critical attention if aquaculture is to be sustainable: alternative protein sources must be developed, and diets must reduce the amount of nitrogen and phosphorus released into the environment.[46] Minimizing the production of nutrients, synthetic chemicals and biological pollutants will reduce wastes, and recycling water in closed systems will keep the wastes from reaching and degrading wild ecosystems. This process is already taking place: the discharge of nutrients and organic material in waste products have started to decrease ([5] for cage farming in Nordic countries and [178]) due to better feed quality and feeding technology, a better understanding of fish behaviour, and more consideration of environmental factors.

67. Partly because of the problems caused by excessive feed waste, and partly because of growing global shortages (and rising prices) of fish meals and fish oils, attention is turning to plant-based sources of proteins and fats, formulated to better reflect environmental performance criteria. However, such feeds are not yet widely available.[76]

68. The amino acid composition of soybean protein is among the best at meeting the requirements of fish[119], and various plant proteins have already been tried in several freshwater cultured species of fish.[46] Storebakken *et al.* [171] reported that up to 75% of the fish meal protein in salmon diets was replaced by soy protein with good results, and Kaushik *et al.* [107] stated that 100% of the fish meal fed to rainbow trout was replaced by soy protein concentrate. Research in Japan, stimulated by shortages of fish meal, has concentrated on new feed types using substitute proteins including soybean, and have had impressive success with high value species like yellowtail.[126]

69. Researchers are also evaluating the use of feeds containing proteins from algae, fungi, and bacteria.[175] A product made from *Thraustochytrids*, an Antarctic microorganism, mixed with canola oil, has been investigated for Atlantic salmon parr.[37] Converting natural gas (methane) to protein-rich single cell proteins by methanotrophic bacteria is also being investigated in Norway; this effort may create an alternative source of proteins for feeds for bivalves.[11] The final product is similar to fish meal, but contains less lysine and more tryptophan. No antinutrients have been detected in bacterial protein.[172]

70. Feed supplements, most notably microbial phytases, can now be produced economically using recombinant DNA technologies. Physiological modifications such as sustained exercise and compensatory growth can improve growth and conversion efficiencies, while other (controversial) biotechnological

methods that may help reduce waste management include endocrine manipulation and genetic engineering. [124]

71. Processing methods for fish-derived feeds can also be improved. In a Norwegian trial, fish feed was made directly from herring by an on-line coagulation method that extracted 100% of the protein and the major part of the lipid fraction. The by-product feed can apparently be stabilized to obtain high protein and lipid quality (without rancidity) and does fulfil the salmon's requirement for high growth and feed intake. Using specially designed vitamin, mineral and antioxidant mixtures can result in high salmon fillet quality.[92]

72. Unfortunately, protein is not the only important dietary factor in mariculture feeds. Marine sources of lipids are nutritionally far superior to plant-based oils, and the source of the lipid strongly affects the nutritional quality.[156] Sandnes and Ervik suggest that herring offal presently exported from Norway inside whole frozen herring be filleted out and converted to fish meal for salmon, this sole source being capable of supporting a yearly production of 100,000-150,000 tonnes of salmon. [156]

73. Another option, and one that admittedly bucks the trend in mariculture, is to add herbivorous fish to the culture list. For example, the western buffalo bream *Kyphosus cornelii*, found off Western Australia, could be researched for its adaptability to culture methods, capacity to consume marine algae, and palatability. At present, very few herbivorous fish species are attractive to consumers in Western countries, and only a few, such as mullets and siganids, are popular in developing countries.[6]

2. Reducing phosphorous and nitrogen waste

74. Increasing the amount of plant-derived protein in fish feed can reduce phosphorous pollution, since plant proteins contain less phosphorous than does fishmeal.[152] Unfortunately, most of this phosphorous is phytin-phosphorous, which fish cannot digest. However, treating soybean meal or formulated feed with the phytase enzyme will break down phytinphosphorous, allowing it to be digested before it is released into the water.[36]

75. When feeds are deficient in a particular amino acid, the other amino acids are used for energy, and the unneeded nitrogen is discharged as waste.[116] Excretions of nitrogen can be reduced by ensuring correct amino acid balances in feed. Nitrogen excretion can also be reduced by using feeds high in lipids.[12]

76. In the last twenty years the feed conversion ratio for Norwegian salmon feeds has been cut by about half, resulting in 80% fewer solids being discharged from salmon farms.[116] From 1974 to 1994, Ackefors and Enell [4] [5] report a drop in the feed coefficient (amount of feed/amount of fish) for fish raised in cages and pens in Nordic countries from 2.3 to less than 1.3. Simultaneously, the nitrogen content in the feed has fallen to 6.8% (from 7.8%) and the phosphorous content to less than 1% from 1.7%. These percentages translate into decreases in discharges of phosphorous and nitrogen from net cage farming of finfish, expressed in kilograms per tonne produced, from 31 kg to less than 9.5 kg for phosphorous and from 129 to 53 kg for nitrogen.[50]

77. Waste can also be reduced by improved filtration and fallowing. Technological means of collecting suspended solids include biofilters that transform excreted nitrogen into nitrite, nitrate, and finally nitrogen gas.[6] In Australia, a study of submerged flow biofilter systems built in modular form showed complete denitrification of fish farm waters could be achieved, with approximately 40 percent of the phosphorus removed as well.[2] Shutting down mariculture sites for months or years can allow accumulated nutrients to break down or disperse.[144]

3. Improving feed conversion ratios, uptake and palatability

78. Exposing raw plant-based feeds to high pressure and heat, followed by rapid lowering of pressure [12], a process called extrusion, improves digestibility of feeds, yields high lipid levels, and inactivates many of the "antinutrients" found naturally in oilseeds and legumes that make those feeds toxic to fish.[177 12 116] Pellets produced by extrusion tend to float better, giving more time for fish to consume them before they sink to the bottom.[32] Feed uptake can also be improved using hydroacoustic monitoring to track feeding behaviour.[6]

79. Feed supplements, most notably microbial phytases, can now be produced economically using recombinant DNA technologies. Modifications of culture conditions to ensure sustained exercise can improve growth and conversion efficiencies, while (controversial) biotechnological methods that may help reduce waste include endocrine manipulations and genetic engineering.[124]

B. Integrated mariculture systems (polyculture)

80. 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.[182]

81. Nitrogen-rich effluents from shrimp culture can also be taken out by bivalves, either by commercially valuable species for harvest or by non-valuable species for use as fish meal.[150] 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 (e.g. [191]) and increases the efficiency of protein production.[30] In Northern China, for example, kelps are cultured in the outer portions of Sungo Bay, using nitrogen excreted by the 2 billion scallops produced there yearly. The potential competition of kelps with phytoplankton that might reduce the food supply available to scallops has not, however, been investigated.[80] In Chile, salmon are farmed in polyculture with the red alga *Gracilaria chilensis*, which removes dissolved nitrogen and phosphorus and can be sold.[186]

C. Contained culture systems

82. Water bodies used for intensive mariculture must receive wastes and ensure a good living environment. Stocking density is the critical factor for determining carrying capacity of the water body. Computer simulation models for stocking density are now beyond the development phase and able to be used as management tools.[80] Low-exchange systems are being developed for intensive shrimp farming[189] and will reduce the load placed on natural waters.

83. Mariculture is in general far from achieving much actual *separation* of environments, despite the serious concerns posed by, for example, siting net pen operations in sheltered bays. The lack of new sites in countries like Japan and Taiwan, whose coastlines are already clogged with aquaculture operations, is forcing new operations further offshore.[126]

84. Closed systems can, however, contain domesticated species and keep them from mixing with wild populations. Though such water-recycling facilities are expensive, large, well-capitalized firms perceive greater opportunities for long-range planning at diminished risk. 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.[51]

85. Options for separation of fish from the marine environment include indoor, recirculating systems and contained systems sited in saltwater. Indoor systems allow contaminants, predators, diseases and parasites to be better controlled, and fewer organisms can escape. However, they are more expensive to build and to run than open water systems. The high stocking densities that make them more competitive increase costs for supplemental oxygen and for dealing with other water-quality problems. The commercial advantage of the recirculating systems is the freshness of the product that can be available all year round and produced close to large markets. Moreover, because the water is treated, the fish themselves may be free of pollutants[187] and bring a higher price in niche markets.[117] [118] At present, because of their costs, indoor systems are used only for 'expensive' fish such as sturgeon, eels and flatfish, and rearing of fry for high value marine finfish like salmon, yellowtail and bream.

86. Contained systems sited in saltwater offer a distinct biodiversity advantage in that they reduce discharge and disease transmission (thereby reducing trophic and ecosystem effects) and can eliminate escapes (reducing genetic effects). Replacing net pens with bags suspended in seawater has been endorsed as a way of growing exotic species with minimal escape risk; however, the initial capital outlay is higher.[35] Nevertheless, closed systems offer much better control of feeding and better flesh quality due to increased exercise, and are slowly becoming established (www.futuresea.com). Since netpens externalize costs to the environment, future policy and regulations that impose environmental penalties on such systems may help the development of aquaculture systems that produce less waste.[76]

87. Even in the absence of contained or closed systems, culture systems can be improved to limit escapes. Cages or netpens anchored to heavy moorings will suffer less storm damage[69] [1], and anti-predator nets can keep seals from tearing the fish nets. If large tanks are to be used inland, they should be sited above the 100-year flood level.[139]

88. Finally, it is well to accept that, if something is farmed, it will eventually escape, no matter how good the containment. In 1997, a truck transporting salmon fry from a hatchery to a saltwater growout operation in British Columbia overturned conveniently close to a stream and dumped its load of young fish directly into the water. This kind of industrial spill is inevitable.

D. Avoiding destruction of natural seedstock

89. Collection of wild fry or larvae poses a biodiversity risk primarily for tropical marine finfish and shrimp culture. While the motivation behind research to close the life cycle of cultured species may not in fact have been protection of wild seedstocks (ensuring a supply of disease-free larvae or streamlining operations are more likely economic stimuli), the end result *is* theoretically beneficial to biodiversity. However, if captive broodstocks are developed through selective breeding and then inadvertently or deliberately released to the wild, any biodiversity gains may be obliterated by the loss in genetic variability as hatchery-raised animals enter the wild environment.

90. Despite these caveats, the drive to control reproduction of economically important marine cultured species continues, including the bringing in of new species, with increasing use of sophisticated hormonal triggers and the tools of molecular biology.[198] Environmental manipulation – the provision of conditions in which broodstock spawn naturally – is also important, and has been responsible for the first experimental rearing of bluefin tuna larvae spawned in captivity (M. Kihara 2001 pers. comm.).[126]

91. Along with new methods of producing marine larvae go new husbandry methods for larviculture, a discipline with enormous challenges, especially for high-value carnivorous marine finfish species that do

best on small, live first feed like rotifers and bivalve larvae. Mass-culture systems for bivalve larvae and rotifers, cryopreservation of live feeds, genetic selection of rotifers for small size, and the eventual replacement of live feeds with micro-particulate artificial diets that do not pollute tanks are all active research areas.

E. Reducing the use of chemicals and antibiotics in mariculture

92. The key to reducing chemical use lies in preventing pests and diseases from becoming problems in the first place.[96] Lower stocking densities and adequate water flow will help keep stress to levels at which diseases make fewer inroads. Over-use of antibiotics has had the predictable effect of development of resistance, in effect a change in microbial ecosystem structure. In 1990 and 1991 in Scotland, for example, more than half of the bacteria causing furunculosis (a disease affecting salmonids) were estimated to be resistant to treatment with oxolinic acid.[149] There has been a general move in the industry away from heavy use of man-made chemicals and toward lower stocking densities and the use of probiotics (live microbial feed supplements).[33] Partly this shift is due to limited markets and the high costs of testing and approval for new chemicals.

93. 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[89], for example coldwater vibriosis, once a serious problem for salmon farms in Norway.[137] Vaccines can be administered orally or by injection or through immersion or spraying.[13] Major diseases for which vaccines have been developed include furunculosis, coldwater vibriosis, vibriosis, yersiniosis, and edwardsiellosis.[89]

94. Most tributyltin (TBT) paints and dips used for anti-fouling have been banned in many parts of the world, and use of copper compounds is highly restricted in the United States.[169] The PVC material now used in the United States salmon industry has antifouling chemicals bound into the plastic, reducing the chemicals' leaching into the environment. It has also been noted by salmon farmers in Maine that biofouling deters predation by seals.[76]

F. Avoiding transmission of diseases to wild stocks

95. Most fish-health problems in aquaculture are stress-related,[151] where culture conditions give native or exotic disease organisms an opportunity to multiply. Minimizing exposure of fish to pathogens and reducing stress through proper management will make fish less susceptible to the diseases[89] that will be passed on in the inevitable escapes from netcage systems. Farmed fish are stressed by poor water quality (high ammonia and low oxygen levels), and high stocking densities, which can induce behavioral and other problems. By lowering densities, limiting handling of fish, and avoiding noises such physical stresses can be minimized.[76] The spread of diseases can also be slowed by spacing farms; that is, by maintaining a certain quarantine distance around them, or by replacing net pens with containment systems.

96. Biological control of diseases and parasites is another option. A small wrasse, which eats sea lice off salmon, can be used as a biological alternative to insecticides[140] [103] and to reduce the accompanying stress. [103]

97. On the policy side, developing and implementing strict quarantine and health certification protocols and policies is needed to avoid the spread of diseases; regionally agreed-upon lists of notifiable pathogens, standardisation of diagnostic techniques and health certification should also be developed.[20] Organic certification standards for fish production are another option, although unlikely to be justified by the market

outside Europe and North America. Criteria for organic fish in the United States have yet to be developed (M. Sligh, Pers. Communication to Goldburg).[76]

1. Breeding programmes and engineered sterility

98. Selective breeding can lessen the biodiversity effects of escapes by producing not only animals with improved growth and disease resistance, but also traits that drastically lessen the likelihood of survival in the wild. Genetic gains from selection programmes in aquaculture have been far less than those with traditional livestock, most of which are unlikely to present a competitive threat to wild populations. However, the potential is there for significant gains in some marine species, largely because of high fecundity and high genetic variability.[134] For example, genetic gains per generation in growth rate have been 10.6-14.2 % in Atlantic salmon, 10.1%[91] and 8.2%[135] in coho salmon, and 4.4% in marine shrimp.[64]

99. The culture of monosex or sterile animals ensures total avoidance of the effects of establishing populations of escaped species or stocks (although such animals can still disrupt natural stocks by competing for food and spawning areas). It is especially important where transgenic fish are to be cultured.[51] A variety of techniques are being developed, and there are still problems to be overcome.

100. Culturing of sterile triploids could be used to limit disruption of wild conspecifics.[143] Triploidy, however, does not always result in perfect sterility, as some organisms produced may have the normal two sets of chromosomes and readily reproduce.[140] Some male triploid finfish develop gonads able to produce small amounts of genetically abnormal sperm[115] [21]; these fish may disrupt spawning by wild fish, even though they produce only non-viable progeny.[184] Male triploid shellfish may also produce normal haploid (one set of chromosomes) sperm.[9] In one 1993 experiment, 20% of supposedly sterile Pacific oysters introduced to Chesapeake Bay reverted back to their sexually fertile state.[28] Nor will sterilisation be feasible in all cases; most algae species, for example, reproduce asexually.[105]

2. Growing native species

101. Fears of introducing exotic species from aquaculture operations have often prompted calls for domestication and culture of native species. However, the substitution is not necessarily a panacea. While domesticated native species may have less chance of introducing disease, and may grow better under local conditions and even bring better local prices, native species that are domesticated or genetically modified may introduce risks to the remaining wild stocks.[58] A domesticated species in fact has an even greater chance of altering biodiversity if it escapes, because it has a better chance of interbreeding with its wild relatives. Again, containment may be the only way to prevent this kind of "genetic pollution".

3. Legislation and policy

102. In a review of legislative controls for aquafeed manufacture in some Asian countries, Tacon *et al.* [176] drew attention to the implications of applying legislative controls (over feed composition, manufacture, efficiency or water pollution) in different environmental settings or countries. The authors urge countries to develop their own solutions depending upon the aquaculture system, national government policies and priorities, and available resources.

103. Minimizing the effects of mariculture on biodiversity depends not only on technical solutions but also on the creation and application of policies that in many cases are served by existing technologies. These policies, like all effective ones dealing with aquatic biodiversity, need to be created with consultation of the very wide spectrum of stakeholders and user groups that use or affect aquatic resources. A policy that eventually regulates some form of mariculture may need input from a variety of government

departments and sectors of society and could as easily be the responsibility of the Ministry of Environment as of Fisheries or Agriculture.

104. In the United States, for example, federal oversight of introductions of biological pollutants is still largely uncoordinated.[139] Regulation of biological pollutants from aquaculture focuses on non-native or exotic species, rather than on genetically differentiated populations of "local" fish or transgenic fish.[76] Much scope also remains for collaboration on sustainable aquaculture among countries sharing transboundary aquatic ecosystems, for example, at subregional or regional levels. [58]

4. *Siting of facilities*

105. Mathematical modelling can help estimate the relative impacts of an aquaculture operation. For such modeling however, basic information, such as estimates of other nutrient inputs to bodies of water, is often hard to find.[144] Cooperation with other sectors is needed.

106. In Japan, where nearshore sites are at a premium, large scale offshore aquaculture systems are being developed. There are no rules in Japan governing the utilization of surface seawater for aquaculture. Aquaculture netpens and cages in the open ocean might prevent conflicts with most users of coastal resources.[170] However, aquaculture wastes in relatively shallow or placid marine waters such as the Gulf of Mexico could cause serious environmental damage, since the deposition of sediments and waste could build up over a larger area for many years before reaching a critical mass. Storm and wave damage as well might be more severe and sustained, increasing the number of escapes.

5. *Biosafety assessment and management*

107. The risks posed by escape of genetically modified organisms (GMOs) demand the creation of interdisciplinary teams for assessment and monitoring. Biosafety assessment needs to consider not only "fast" events (e.g. escape of GMOs into the immediate environment) but also "slow" ones (e.g. adaptive evolution of GMOs in the environment, or delayed movement of released individuals leading to establishment of a new, remote GMO population). Monitoring also needs to consider long-term environmental changes such as decadal changes in upwelling conditions in coastal waters that would affect the survival and dispersal of released marine GMOs [105]

108. Governments in the Asia-Pacific region recognise the need for policies on introductions of alien species and their environmental risks, but few have the legal instruments to do so. There are still no policies in a number of Asian countries (Indonesia, Malaysia. China, and Thailand) for safe laboratory practices or restricting environmental release of GMOs. An international system for identifying GMOs will be needed, because finding novel DNA (minor changes in levels of genetic variation or quantitative traits) is relatively difficult.[83] Forensic DNA testing is already beginning to be used in livestock, and may be applicable to farmed marine organisms.

6. *Market mechanisms*

109. Eco-certification programmes can encourage environmentally sound production[111] and the Marine Stewardship Council has promoted certification of fisheries for the past half-decade. The MSC's criteria include international guidelines such as the FAO Code of Conduct for Responsible Fisheries, which includes provisions for the development of sustainable aquaculture. Unfortunately, despite the growing contribution to aquaculture of global fish landings and its undoubted biodiversity effects, the MSC has not yet included culture fisheries.

110. In 1989 the Soil Association, the UK's leading campaigning and certification organization for organic food and farming, produced the first draft of 'Aquaculture Standards'. Since then, other organic fish farming initiatives have developed in the USA, New Zealand, Norway and Ireland. To harmonize these various initiatives, the International Federation of Organic Agriculture Movements (IFOAM) has drawn up Basic Standards for Organic Aquaculture, approved as Guidelines in 1998.

G. Enhancing the positive effects of mariculture on marine and coastal productivity

111. Humans consume less than 1% of terrestrial primary organic matter production, which totals about 132 billion tons, and less than 0.02% of the 82 billion tons of the primary production of the oceans (assuming that the fish caught are secondary consumers). Because of better feed conversion ratios, fish can replace terrestrial animals generally at about half the level of feed inputs. In other words, a hundred kilos of feed can produce thirty kilos of fish or fifteen kilos of pork.[11] In this sense, mariculture is a more efficient user of primary productivity than is the farming of livestock.

112. Mariculture is normally a consumer of marine productivity, so it is unlikely that many existing methods will increase productivity other than in harmful ways (such as algal blooms caused by decaying wastes). However, if one is prepared to consider new and untested technologies and adopt a liberal reading of the concept of enhanced productivity, a few examples can be found.

1. Using feed more efficiently

113. Because fish are cold-blooded, feed intake above the level needed for maintenance results in growth. Therefore the higher the feed intake, the higher the energy retention in the form of protein. Cultured fish have greater efficiencies than wild fish because they need to use less energy hunting for food.[11]

114. Transgenic strains of Atlantic salmon, Chinook salmon (*Oncorhynchus tschawytscha*) and rainbow trout (*O. mykiss*) grow 400-600% faster than non-transgenic siblings during early life stages and reach full market size in less than half the time needed for non-transgenic fish of the same species.[51] Dramatic growth rates based on gene promoters linked to growth hormone genes have been reported for trout, salmon, tilapia, carp and other species.[93 45 121] Transgenic salmon can also reach market size in one-third to one-half the time historically required, with roughly 20% less feed input.[66] There may be a corresponding reduction on the impact on primary productivity.

2. Deep seawater as a source of nutrients and clean water

115. In Japan, a system to pump deep seawater rich in nutrients into nearshore areas to stimulate primary productivity has been studied since 1989. In shallow water culturing methods, growth characteristics and nutritive value have been studied for phytoplankton and zooplankton, demonstrating that using the deep seawater enables energy-saving continuous mass culture and production of high-quality plankton. Marine algae such as *arame* (*Eisenia bicyclis*) and *kajime* (*Ecklonia cava*), and edible coldwater algae such as *makonbu* (*Laminaria japonica*) and wakame (*Undaria pinnatifida*) fare better in deep seawater than in untreated surface seawater. Coldwater fish including Atlantic salmon (*Salmo salar*), coho salmon (*Oncorhynchus kisutch*) and the Northern abalone (*Haliotis discus*) which cannot normally be cultured in warm seawater areas can be cultured by using deep seawater. Studies have demonstrated that diseases are few and survival rates are better than in warm seawater. The long-term culturing of deep-sea fish, Japanese butterfish (*Hyperoglyphe japonica*) and deep-sea coral (*Corallium japonicum*) is also possible. Culturing larvae of spiny lobsters (*Panulirus japonicus*) and of Japanese flounder over the summer (when Japanese flounder normally do not grow at an acceptable rate)

is also being studied, as is the effect of deep seawater on the survival rate of juvenile abalone and oysters. [131]

116. Implications that need further investigation are the effects of deep seawater on the natural environment. Using an area that is already an upwelling site would help mitigate any such unnatural impact.

117. In Norway, using deep seawater OTEC (Ocean Thermal Energy Conversion) pumps to exchange local waters via a low-cost diffusion pump may increase production and lower environmental problems in salmon farming. The pump could also refresh stagnant deep fjord waters which may be completely depleted of oxygen and giving off harmful hydrogen sulphide gas.[77]

H. Case-study--enhancement and sea-ranching: damn the torpedoes

118. The idea makes perfect sense: use the tools of mariculture to create huge numbers of young animals that can be released into the wild at an early age, there to feed, grow and add to the fishery. If the fishery is gone they can even replace it, and the tools are so powerful that fry can be produced and released in staggering numbers. Why not?

119. Enhancement started before the turn of the century, with the rise of the salmon hatchery system in Western North America[181], and as methods for controlled reproduction and larviculture were developed for more fish, and then for mollusks and crustaceans, those organisms began to be enhanced too. Stock enhancement and sea ranching are now done for a wide variety of species in over 70 (generally developed) countries. Enhanced species include Japanese flounder, Atlantic cod, penaeid prawns, European lobster, scallop, giant clam, abalone and sea cucumber. [98 41 18] In Texas, red drum enhancement has been successful through a programme that includes large-scale stocking and management controls on commercial and sport catches, and habitat protection measures.[125] Each year, North American hatcheries release more than 5 billion juvenile salmon[112], and school programmes geared to classroom hatcheries have convinced several generations of children in the Pacific Northwest that salmon are produced in hatcheries. The Japanese programme for chum salmon is also well known, and maintains a consistent fishery targeted largely on roe (*ikura*) that has grown from 5 million tons in the 1960s to over 70 million in 1995.[138] In fact, most stocks of Pacific salmon in Japan derive from hatcheries, and enhanced chum salmon are a key component of the Japanese coastal fishing industry.

Are there any wild fish left?

120. When large numbers of hatchery-bred fish are released to the wild there are significant genetic considerations, especially as the fish are fully expected to breed with "wild" stocks. Such questions did not even appear on the radar screens of fisheries managers until the past two decades; now, fisheries scientists grapple with them daily in an attempt to establish a role for enhancement that does not do outright damage to biodiversity. The recent *Wild Salmon Policy* of the Government of Canada, for example, has great difficulty even defining a "wild" salmon – after so many decades of wholesale enhancement the introgression of hatchery genes is assumed to require that a new category, "feral", be invented. Pacific salmon have endured a combination of insults (overfishing, habitat loss, pollution and change in ocean conditions) that have collectively severely reduced genetic diversity in the five main species.[112]

121. The practice of releasing hatchery fish is now under criticism for threatening native biodiversity (through competition with wild fish or introgression of hatchery genes), as well as for deflecting energy and resources away from management and habitat rehabilitation measures that might equally increase

natural production. Enhancement has also been attacked for simply not working very well and costing too much. Many stocking programmes do not mark the released fish so that the effect on fishery landings simply cannot be measured. In fact, very little is known about the behaviour, survival, growth and even genetic impact of enhanced organisms. Scientists and managers have tended to divide into camps for or against enhancement (see for example [189]), with little in the way of data to back up their claims. And environmentalists almost uniformly decry the practice. In North America today, managers try to avoid the term "hatchery" at all, preferring to concentrate on "supplementation", a technique that uses the same aquacultural tools but takes pains to use only broodstock representative of local populations where in the past a single population might be raised and broadcast well outside its native range. Technical protocols and methods for avoiding genetic problems with enhancement have been reviewed for some coldwater species[130] [23] General principles and recommendations have been published by FAO[55] and codes of practice for transfer of stock have been drawn up by ICES[100] to be applied to all enhancement programmes.[165]

122. The main uncertainties surrounding marine enhancement include:

(a) Do hatchery fish really contribute to fishery production?

(b) Can the same effect be gained through fishing reduction, habitat restoration or protected areas?

(c) Can the environment support the additional production?

(d) Do released fish displace wild stocks?

(e) What are the genetic, health and ecological effects of releases?

(f) Are the gains cost-effective and sustainable?

Some unexpected results

123. The most obvious and controversial biodiversity question – do hatchery fish alter the genetic composition of wild stocks – is generally answered affirmatively. However, new data gathered with the molecular tools of microsatellite DNA analysis are not entirely consistent with this conclusion. In a just-released study of the genetic makeup of Atlantic salmon in Maine, some unexpected conclusions surfaced. Maine salmon have been enhanced since the 1970s, using eggs from local and more distant (Canadian) stocks. River-specific stocking (supplementation) did not start until 1991. In addition to this aggressive stocking programme, farming of Atlantic salmon began in the 1980s, using European-derived strains that invariably escaped to breed in the rivers.

124. What has been the genetic effect of this concerted addition of non-native salmon genotypes to Maine rivers? A scientific committee charged with examining all the available DNA evidence concluded that wild salmon in Maine are still genetically distinct from Canadian salmon, that there is considerable genetic divergence among populations in the eight rivers where wild salmon are found, and that the pattern of genetic variation seen in Maine rivers is similar to patterns seen elsewhere in salmon where no stocking has occurred. The committee concluded that Maine salmon populations were as genetically distinct from Canadian salmon populations and from each other as would be expected in natural populations anywhere else.[132]

125. Clearly, more such studies are called for before the pros and cons of enhancement are sorted out. Maine salmon may be an anomaly, the data may be insufficient, or enhancement may turn out to be more

grey than the black in which it is currently painted. The genetic stakes, and the costs, certainly justify more research.

IV. MARICULTURE CRITERIA RELATED TO BIODIVERSITY

126. While mariculture has a variety of deleterious effects on biodiversity, the literature presents few if any examples of criteria for judging the seriousness of an effect. For example, while there are many scientific papers discussing the dangers of introgression of hatchery genes into wild fish populations, we looked in vain for any measure of what constituted a "significant degree of genetic pollution", or of any suggestion that such criteria were even contemplated. Although the lack of criteria doesn't stop the polemics, charges and countercharges on such issues, it represents a gaping hole in arguments for or against a particular mariculture practice.

127. 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. In addition, 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.

A. Principles and standards

128. Article 9 of the FAO Code of Conduct for Responsible Fisheries[58] provides a set of voluntary principles and standards that, if applied, ensure 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 aquaculture is not only the responsibility of governments and aquaculture producers, but also the responsibility of scientists, media, financial institutions and special interest groups.[58]

129. Environmental principles and standards are also being applied to the aquaculture industry through various certification processes. These include organic certification, professional accreditation and environmental certification.

1. Organic certification

130. 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)[101] 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, but can't be used as certification on their own.

131. Some organizations that are using IFOAM standards are The Naturland Standards for the Production of Salmon and Other Cold Water Fish (primarily in use in Germany and Ireland for trout and salmon farming), KRAV Kontroll AB Organic Standards 1999 (certifies salmon, trout, Arctic char and Brown trout farming in Sweden), National Association for Sustainable Agriculture Australia (used in Australia, PNG, Sri Lanka and Indonesia), BioGro New Zealand Production Standards and AgroEco (based in Holland, organic shrimp farming in Ecuador).

132. IFOAM includes criteria for:

(a) Rearing of fish and servicing of cages;

(b) Water quality;

(c) Feeding;

(d) Health;

(e) Fish re-stocking, breeding and origin;

(f) Propagation of fish stocks and breeding;

(g) Transport, killing and processing.

2. Professional accreditation

133. Aquaculture operations are professionally certified as producing cultured species to guidelines or codes of practice, sometimes followed by Eco-labeling of product. For example, Global Aquaculture Alliance (GAA)[74] is an international, nonprofit 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.

134. GAA's Codes of Practice for Responsible Shrimp Farming contain the following sections:

(a) Mangroves;

(b) Site evaluation;

(c) Design and construction;

(d) Feeds and feed use;

(e) Shrimp health management;

(f) Therapeutic agents and other chemicals;

(g) General pond operations;

(h) Effluents and solid wastes;

(i) Community and employee relations.

3. Environmental certification

135. Aquaculture operations may be certified, through operational audits and assessments, as producing cultured species to defined criteria. Certification is followed by eco-labeling of the product and often requires the implementation of a documented Environmental Management System (EMS). The International Organization for Standardization (ISO)[102] has developed sets of generic management system standards which provide general standards and criteria for the development of an EMS. ISO's 14001 Environmental Management System has been used by various organizations as a basis for environmental certification.

136. On such organization is the European Eco-Management and Audit Scheme (EMAS)[53]. EMAS is a management tool for companies and other organizations to evaluate, report and improve their environmental performance. Participation is voluntary and extends to public or private organizations operating in the European Union and the European Economic Area. An increasing number of candidate countries are also implementing the scheme in preparation for their accession to the EU. Some companies, local authorities and other organizations outside the European Economic Area are already putting EMAS into practice informally and benefiting from continuous improved environmental performance.

B. Aquaculture laws and regulations

137. Due to growing global concerns over the environmental impact of aquaculture and its effects on biodiversity, many countries have enacted laws that specifically regulate the aquaculture industry. Unfortunately, many countries still depend on more general environmental protection laws or local environmental plans that are sometimes hard to enforce in relation to aquaculture operations or are vulnerable to political or legal manipulation. Many countries require environmental impact assessments (EIAs) to be carried out for proposed aquaculture projects, leaving established operations unregulated.

138. Some examples include:

(a) In Malaysia, an EIA is required for "land based aquaculture projects accompanied by clearing of mangrove swamp forests covering an area of 50 hectares or more," pursuant to the Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order 1987 of the Environmental Quality Act 1974. However, the EIA law in relation to aquaculture projects is weak. There is a voluntary "Code of Practice for Aquaculture" (6th Sept 1999);[52]

(b) New South Wales regulates aquaculture pursuant to Part 6 of the Fisheries Management Act, the Fisheries Management Aquaculture Regulations 1995 and by the Environmental Planning and Assessment Act. These laws designate aquaculture as a "designated development," which requires an EIA; [52]

(c) In 1996 the Supreme Court of India ordered the closure and rehabilitation of several non-traditional large-scale aquaculture industries that have caused harm to India's coastal areas. Traditional approaches and improved traditional methods of aquaculture was allowed to continue. The Supreme Court based its order on the reasoning that aquaculture is an industry and is hence prohibited under the Coastal Regulation Zone (CRZ) notification (which prohibits new industries or expansion within the CRZ area);[31]

(d) In Chile, an EIA could be required for any project proposed in coastal areas pursuant to the Environmental Framework Law (No. 19.300); [52]

(e) Sri Lanka's National Environmental Act (NEA) requires an EIA for any fisheries project larger than 4 hectares and prohibits any person from discharging, depositing or emitting waste into the environment that will cause pollution without a license issued by the authority or in accordance with standards prescribed under the act. This involves the issuing of license by the Central Environmental Authority (CEA). In addition, the Fisheries & Aquaculture Resources Act No. 2 of 1996, includes rules for the management, regulation, conservation and development of fisheries and aquatic resources in Sri Lanka. [52]

139. In recent years, the increasing global concern for the destruction of mangrove habitat by aquaculture operations, most commonly shrimp farming in brackish-water ponds, has led to more stringent regulations. In 2000, only Belize and Ecuador had laws in place that specifically prohibit the destruction of

mangroves resulting from aquaculture projects, while other countries, such as Chile, Malaysia, India, Thailand and China, depend on EIAs or moratoriums on development projects in mangroves, and general environmental regulations.

C. Specific criteria on the effects of mariculture on biodiversity

140. Although we were unable to discover any established sets or reviews of mariculture criteria, we have run across a few examples of specific criteria that have been adopted as indicators of environmentally sound or sustainable aquaculture.

141. For example. the Government of Japan has enacted regulations to ensure sustainable aquaculture, with regard to improvement and preservation of aquaculture grounds and the spread of disease. In the case of surface aquaculture, it was determined that oxygen levels in cages should be more than 4.0 ml/L of sea water, the quantity of sulfide in the mud under cages should be less than the oxygen available to reset with sulfide, and benthos, such as lugworms, should be present in the mud under the cages.[102]

142. Norway has established quality criteria for fish oil used in fish feed by commercial fish farmers. The feed must contain 5% free fatty acids, have a total oxidation value of 30 and contain only 0.5% water and impurities.[7] This is significant because increasing the fat content in feeds helps reduce wastage by supplying a ready energy source and reducing the nitrogenous waste producing breakdown of protein for energy.

REFERENCES

1. Aalvik, B. Production of Atlantic salmon and rainbow trout in Norway, preventive health care. Cultivation of Salmon II Conference. Bergen, Norway, May 7-10, 2001. Abstract available as pdf file at: http://www5.imr.no:8080/salmon/innhold.htm

2. Abeysinghe, D. H., A. Shanableh, and B. Rigden. 1996. Biofilters for water reuse in aquaculture. Water Science and Technology 34(11):253–260. IWA Publishing . Abstract and link to full article available at: http://www.iwaponline.com/wst/03411/wst034110253.htm

3. ABRAC. 1995. Performance standards for safely conducting research with genetically modified fish and shellfish. Part I. Introduction and supporting text for flowcharts. Agricultural Biotechnology Research Advisory Committee, United States Department of Agriculture, Office of Agriculture Biotechnology, Washington, DC. Doc. No. 95-04. 63pp. *Cited in* Penman 1999.

4. Ackefors, H., and M. Enell. 1990. Discharge of nutrients for Swedish fish farming to adjacent areas. AM-BIO 19(1):28-35. *Cited in* Ackefors 1999.

5. Ackefors, H., and M. Enell. 1994. The release of nutrients and organic matter from aquaculture systems in Nordic countries. Journal of Applied Ichthyology 10(4):225-241. *Cited in* Ackefors 1999.

6. Ackefors, H. 1999. Environmental impacts of different farming technologies. Pages 145-169 *In* N. Svennevig, H. Reinertsen, and M. New (eds.). Sustainable aquaculture: food for the future? A. A. Balkema, Rotterdam. 348 pp.

7. Albrektsen, S., Ø. Høstmark, and K. Hamre. 2001. Fish silage - effects on fish oil quality and on growth performance and quality of Atlantic salmon (Salmo salar L.). Cultivation of Salmon II Conference, 7-10 May, 2001. Bergen, Norway, Abstract available as pdf file at: http://www5.imr.no:8080/salmon/innhold.htm

8. Alderman, D. J. 1999. Chemicals in aquaculture. Pages 203-219 *In* N. Svennevig, H. Reinertsen, and M. New (eds.). Sustainable aquaculture: food for the future? A. A. Balkema, Rotterdam. 348 pp.

9. Allen, S. K., Jr. 1987. Reproductive sterility of triploid shellfish and fish. Ph.D. dissertation, University of Washington, Seattle. *Cited in* Thorgaard and Allen (1992); c*ited in* Goldburg.

10. ASEAN-SEAFDEC. Aquasilviculture. The world of mangroves, mangrove-friendly shrimp culture. http://www.mangroveweb.net/html/f_aqua.htm

11. Åsgård, T., E. Austreng, I. Holmefjord, and M. Hillestad. 1999. Resource efficiency in the production of various species. *In* N. Svennevig, H. Reinertsen, and M. New (eds.). Sustainable aquaculture: food for the future? A. A. Balkema, Rotterdam. 348 pp.

12. Autin, M. 1997. Commercial aquafeed manufacture and production. Pages 79-104 *In* A. Tacon and B. Basurco (eds.). Feeding tomorrow's fish. Proceedings of the CIHEAM Network on Technology

of Aquaculture in the Mediterranean, jointly organized by CIHEAM, IEO, and FAO, June 24-26, 1996. Cahiers, Options Mediterranees. *Cited in* Goldburg.

13. Avault, J. W. 1997. Prevention of diseases: some fundamentals reviewed. Aquaculture Magazine (March/April. 1997):78-83. *Cited in* Goldburg.

14. Bæverfjord, G., and T. Åsgård. 2001. Production related disorders in Atlantic salmon. Cultivation of Salmon II Conference. Bergen, Norway, May 7-10, 2001. Abstract available as pdf file at: http://www5.imr.no:8080/salmon/innhold.htm

15. Baluyut, E. A. 1989. Aquaculture systems and practices: a selected review. UNEP/FAO, Rome. ADCP/REP/89/43. http://www.fao.org/docrep/T8598E/t8598e00.htm#Contents

16. Bardach, J. E, J. H. Ryther, and W. O. McKarney. 1972. Farming and Husbandry of Freshwater and Marine Organisms. John Wiley & Sons, Inc.

17. Barg, U., R. Subasinghe, R. Willmann, K. Rana, and M. Martinez. 1999. Towards sustainable shrimp culture development: implementing the FAO Code of Conduct for Responsible Fisheries (CCRF). Pages 64-81, *In* B. W. Green, H. C. Clifford, M. McNamara, and G. M. Montaño (eds.). Central American Symposium on Aquaculture, 18-20 August, 1999. San Pedro Sula, Honduras. Asociación Nacional de Acuicultores de Honduras (ANDAH), Latin American Chapter of the World Aquaculture Society (WAS), and Pond Dynamics/Aquaculture Collaborative Research Support Program (CRSP), Choluteca, Honduras. Available at: http://www.fao.org/fi/faocons/shrimp/honduras.asp#F1

18. Bartley, D. M. Marine ranching summary. World Aquaculture Societies Working Group on Stock Enhancement and Sea Ranching Homepage. Available at: http://www.efan.no/was/WAS_ranch.html

19. Bartley, D. M. 1996. Conservation of biological diversity in hatchery enhancement programs. Pages 425-437 *In* F. di Castri and T. Younes (eds.). Biodiversity, science and development: towards a new partnership. CAB International, Oxford.

20. Bartley, D. M., R. Subasinghe and D. Coates. 1996. Draft framework for the responsible use of introduced species. EIFC/XIX/96/Inf. 8 June, 20 p.

21. Benfey, T. J., I. I. Solar, G. De Jong, and E. M. Donaldson. 1986. Flow-cytometric confirmation of aneuploidy in sperm from triploid rainbow trout. Transactions of the American Fisheries Society 115:838-840. *Cited in* Goldburg.

22. Bentsen, H. B., and I. Olesen. 2001. Designing aquaculture mass selection programs to avoid high inbreeding rates. Cultivation of Salmon II Conference, May 7-10, 2001. Bergen, Norway, Abstract available as pdf file at: http://www5.imr.no:8080/salmon/innhold.htm

23. Benzie, J. A. H., and S. T. Williams. 1996. Limitations in the genetic variation of hatchery produced batches of giant clam *Tridacna gigas*. Aquaculture 139:225-241. *Cited in* Smith 1999.

24. Bergheim, A., Aabel, J.P., and Seymour, E.A. 1991. Past and present approaches to aquaculture waste management in Norwegian pen culture. Pages 117-136 *In* C. B. Cowey and C. Y. Cho

(eds.). Nutritional strategies and aquaculture waste. Proceedings of the First International Symposium on Nutritional Strategies in Management of Aquaculture Waste. University of Guelph, Guelph, Canada *Cited in* Ackefors.

25. Bernal, P.A. 1999. Challenges and strategies for the use of the available fish meal resources. *In* N. Svennevig, H. Reinertsen, and M. New (eds.). Sustainable aquaculture: food for the future? A. A. Balkema, Rotterdam. 348 pp.

26. Beveridge, M. C. M. 1996. Cage aquaculture, 2nd Ed. Fishing News Books, Oxford.

27. Beveridge, M. C. M., L. G. Ross, and J. A. Stewart. 1997. The development of mariculture and its implications for biodiversity. Pages 372-393 *In* R. F. Ormond, J. D. Gage, and M. V. Angel (eds.). Marine biodiversity: patterns and processes. Cambridge (UK): Cambridge University Press. *Cited in* Smith 2000.

28. Blankenship, K. 1994. Experiment with Japanese oysters ends abruptly. Bay Journal 10:1-4. *Cited in* OTA (1995).

29. Blankenship and Leber. 1995. Guidelines for a "responsible approach" to stock enhancement. American Fisheries Society Symposium 15:167-175. Available at: http://www.efan.no/was/recomen.htm

30. Bodvin, T., M. Indergaard, E. Norgaard, A. Jansen, and A. Skaar. 1996. Clean technology in aquaculture – a production without waste products? Hydrobiologia 327:83-86. *Cited in* Grant 1999.

31. Bonora, M. 1999. Shrimp Aquaculture in India. The Shrimp Sentinel Online, National Reports. http://www.earthsummitwatch.org/shrimp/index.html

32. Botting, C. C. 1991. Extrusion technology in aquaculture feed processing. Pages 129-137 *In* D. M. Akiyama and R. K. H. Tan (eds.). Proceedings of the Aquaculture Feed Processing and Nutrition Workshop, September 19-25, 1991. American Soybean Association, Singapore. *Cited in* Goldburg.

33. Boyd and Clay, 1999. *cited in* Wang 1999.

34. Bricelj, V. M., and D. J. Lonsdale. 1997. Aureococcus anophagefferens: causes and ecological consequences of brown tides in U.S. mid-Atlantic coastal waters. Limnology and Oceanography 42:1023-1038. *Cited in* Smith.

35. British Columbia Environmental Assessment Office. The Salmon Aquaculture Review Final Report. ISBN 0-7726-3317-7 (set). http://www.eao.gov.bc.ca/project/aquacult/salmon/report/final/vol1/toc.htm

36. Cain, K. D., and D. L. Garling. 1995. Pretreatment of soybean meal with phytase for salmonid diets to reduce phosphorus concentrations in hatchery effluents. Progressive Fish-Culturist 57:114-119. *Cited in* Goldburg.

37. Carter, C. G., M. P. Bransden, T. Lewis, M. Attard, and P. D. Nichols. 2001. The potential of Thraustochytrids as a replacement for fish oil in feeds for Atlantic salmon, Salmo salar L.

Cultivation of Salmon II Conference. Bergen, Norway, May 7-10, 2001. Abstract available as pdf file at: http://www5.imr.no:8080/salmon/innhold.htm

38. Cho, C. Y., and D. P. Bureau. 1999. Fish Nutrition Research in Ontario: From beef liver through pellets to "Norwegian" doughnuts. Fish Nutrition Research lab, Ontario Ministry of Natural Resources & Dept. Animal and Poultry Sci., University of Guelph, Guelph, Ontario, Canada N1G-2W1. http://www.uoguelph.ca/fishnutrition/Points-3/

39. Clugston, J. P. 1990. Exotic animals and plants in aquaculture. Reviews in Aquatic Sciences 2(3,4):481-489. *Cited in* Goldburg.

40. Courtenay, W. R., Jr., and J. D. Williams. 1992. Dispersal of exotic species from aquaculture sources, with emphasis on freshwater fishes. Pages 49-81 *In* A. Rosenfield, and R. Mann (eds.). Dispersal of living organisms into aquatic ecosystems. College Park, MD: Maryland Sea Grant College, University of Maryland. *Cited in* Goldburg.

41. Cowx, I. G. (ed.). 1998. Stocking and introduction of fish. Papers form a symposium held March, 1996. Hull, UK. Okford: Fishing News Books. 456 pp.

42. Daniels, H. V. 2000. Species profile – Southern Flounder. Southern Regional Aquaculture Centre. SARC Publication no. 726. http://texaserc.tamu.edu/pubs/efish/726fs.pdf

43. De Silva, S. S. 1999. Feed resources, usage and sustainability. Pages 221-242 *In* N. Svennevig, H. Reinertsen, and M. New (eds.). Sustainable aquaculture: food for the future?. A. A. Balkema, Rotterdam. 348 pp.

44. De Silva, S. S. 2001. A global perspective of aquaculture in the new millennium. Pages 431-459 *In* R. P. Subasinghe, P. Bueno, M. J. Phillips, C. Hough, S. E. McGladdery, and J. R. Arthur (eds.). Aquaculture in the Third Millennium. Technical proceedings of the Conference on Aquaculture in the Third Millennium, 20-25 February, 2000. Bangkok, Thailand. NACA, Bangkok and FAO, Rome.

45. Devlin, R. H., T. Y. Yesaki, C. A. Biagi, E. M. Donaldson, P. Swanson, and W. K. Chan. 1994. Extraordinary salmon growth. Nature 371:209-210. *Cited in* Entis.

46. Donaldson, E. M. 1997. The role of biotechnology in sustainable aquaculture. Pages 101-126 *In* J. E. Bardach (ed.). Sustainable aquaculture. John Wiley and Sons, Inc. N. York,. Cited in Bernal.

47. Durand, P., K. T. Wada, and F. Blanc. 1993. Genetic variations in wild and hatchery stocks of the black pearl oyster *Pinctada margaritifera* from Japan. Aquaculture 110:27-40. *Cited in* Smith 1999.

48. Egidius, E., and B. Moster. 1987. Effect of NEGUVON and NUVAN treatment on crab (*Cancer pagurus, C. maends*), lobster (*Homarus gammarus*) and blue mussel (*Mytilus edulis*). Aquaculture 60:165-168. *Cited in* Goldburg.

49. Einum, S. and I. A. Fleming. 1997. Genetic divergence and intyeractions in the wild among native, farmed and hybrid Atlantuc salmon. Journal of Fish Biology 50:634-651. *Cited in* Smith 1999.

50. Enell, M. 1995. Environmental impact of nutrients from Nordic fish farming. Water Science and Technology 31(10):61–71. Swedish Environmental Research Institute (IVL), P.O. Box 21060 S-100 31 Stockholm Sweden. IWA Publishing. Abstract available at http://www.iwaponline.com/wst/03110/wst031100061.htm

51. Entis, E. 1999. Policy implications for commercialization of transgenic fish. Pages 35-42 *In* R. S. V. Pullin, D. M. Bartley, and J. Kooiman (eds.). Towards policies for conservation and sustainable use of aquatic genetic resources. ICLARM Conf. Proc. 59. 277 pp.

52. The Environmental Law Alliance Worldwide (E-LAW). 2000. Survey of laws on aquaculture. Available on the Industrial Shrimp Action Network website at http://www.shrimpaction.com/ESurvey.html

53. European Eco-Management and Audit Scheme. http://europa.eu.int/comm/environment/emas/index_en.htm

54. FAO. 1978. Aquaculture development in China. Report on an FAO/UNDP Aquaculture Study Tour to the People's Republic of China, led by T.V.R. Pillay, Aquaculture Development and Coordination Programme, FAO, Rome, Italy, 2 May-1 June 1978. http://www.fao.org/docrep/X5686E/X5686E00.htm

55. FAO. 1993. Expert consultation on utilization and conservation of aquatic genetic resources. FAO Fisheries Report No. 491. FIRI/R49. FAO, Rome, Italy.

56. FAO. 1996. Aquaculture development and resource limitations in Egypt. FAO Aquaculture Newsletter December 1996, Number 14. http://www.fao.org/fi/newslet/fan14/articl1f.asp

57. FAO. 1997. Review of the state of world aquaculture. FAO Inland Water Resources and Aquaculture Service, Fishery Resources Division. FAO Fisheries Circular. No. 886, Rev.1. Rome, FAO. 163 pp.

58. FAO. 1997. FAO technical guidelines for responsible fisheries. FAO Fisheries Department, Aquaculture development. No. 5. FAO, Rome. 40p. http://www.fao.org/docrep/003/w4493e/w4493e00.htm#Contents

59. FAO. 2000. Yearbook of fisheries statistics: summary tables. FAO, Rome. http://www.fao.org/fi/statist/summtab/default.asp

60. FAO. 2000. The state of the world fisheries and aquaculture 2000. FAO, Rome. ISBN 92-5-104492-9. http://www.fao.org/DOCREP/003/X8002E/x8002e00.htm

61. FAO. 2000. FAO FISHSTAT Plus, Universal software for fishery statistical time series. http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp

62. Fish Farming International. 1997. Sargo sea farm in tanks on test near Seattle. Fish Farming International 24(2):38-39.

63. Fish Farming International. 1997. U.S. scallop experiment is ready for launching. Fish Farming International 24(4):42-43. Service, U.S. Department of Agriculture.

64. Fjalestad, K. T., T. Moen, and L. Gomez-Raya. 2001. Prospects of gene technology in Salmon breeding programmes. Cultivation of Salmon II Conference, May 7-10, 2001. Bergen, Norway. Abstract available as pdf file at: http://www5.imr.no:8080/salmon/innhold.htm

65. Flegel, T. 1998. Shrimp disease epizootics: significance of international pathogen transfer. Pages 51-52 *In* Regional programme for the development of technical guidelines on quarantine and health certification, and establishment of information systems, for the responsibility movement of live aquatic animals in Asia. TCP/RAS/6714. Field Doc. No. 1. FAO/NACA/OIE, Bangkok.

66. Fletcher, G., R. Alderson, E. A. Chin-Dixon, M. A. Shears, S. V. Goddard, and C. Hew. 1997. Transgenic fish for sustainable aquaculture. Pages 193-201 *In* N. Svennevig, H. Reinertsen, and M. New (eds.). Sustainable aquaculture: food for the future? A. A. Balkema, Rotterdam. 348 pp.

67. FMC BioPolymer website. FAQ on the benefits of cottonii and spinosum seaweed farming. http://www.fmcbiopolymer.com/contents/seaweed_farming/index.cfm?scrn=faq&answer=4#4

68. Funge-Smith, S., and M. J. Phillips. 2001. Aquaculture systems and species. Pages 129-135 *In* R. P. Subasinghe, P. Bueno, M. J. Phillips, C. Hough, S. E. McGladdery, and J. R. Arthur (eds.). Aquaculture in the Third Millennium. Technical proceedings of the Conference on Aquaculture in the Third Millennium, 20-25 February, 2000. Bangkok, Thailand. NACA, Bangkok and FAO, Rome.

69. Gausen, D., and V. Moen. 1991. Large-scale escapes of farmed Atlantic salmon (*Salmo salar*) into Norwegian rivers threaten natural populations. Canadian Journal of Fisheries and Aquatic Science 48:426-428. *Cited in* Goldburg.

70. GESAMP (IMO/FAO/Unesco/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution). 1991. Reducing environmental impacts of coastal aquaculture. Rep. Stud. GESAMP 47:35.

71. GESAMP (IMO/FAO/Unesco-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). 1996. Monitoring the ecological effects of coastal aquaculture wastes. Rep.Stud.GESAMP 57:38.

72. GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). 1997. Marine biodiversity: patterns, threats and conservation needs. Rep.Stud.GESAMP 62:24.

73. GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). 2000. Report of the Thirtieth Session, Principality of Monaco, 22–26 May, 2000. Rep. Stud. GESAMP 69:68.

74. Gharrett, A. J., and W. W. Smoker. 1993. A perspective in the adaptive importance of genetic infrastructure in salmon populations to ocean ranching in Alaska. Fis. Res. 18:45-58. *Cited in* Smith 1999.

75. Global Aquaculture Alliance. http://www.gaalliance.org/

76. Goldburg, R., and T. Triplett. 1997. Murky waters: environmental effects of aquaculture in the US. The Environmental Defense Fund. 197 pp. Available at: http://www.environmentaldefense.org/pdf.cfm?ContentID=490&FileName=AQUA.PDF

77. Golmen, L. 1995. OTEC in cold regions. IOA Newsletter 6(4). Available at: http://ioa.erl.itri.org.tw/vol6-4.htm.

78. Gowen, R. J., and N. B. Bradbury. 1987. The ecological impact of salmon farming in coastal waters: a review. Oceanorg. Mar. Biol. Rev. 25:563-575.

79. Graneli, E., E. Paasche, and S.Y. Maestrini. 1993. Three years after the *Chrysochromulina polylepis* bloom in Scandanavian water in 1988: some conclusions of recent research and monitoring, Pages 23-32 *In* T. J. Smayda, and Y. Shimizu (eds.). Toxic phytoplankton blooms in the sea. Amsterdam: Elsevier. *Cited in* Goldburg

80. Grant, J. 1999. Ecological constraints on the sustainability of bivalve aquaculture. *In* N. Svennevig, H. Reinertsen, and M. New (eds.). Sustainable aquaculture: food for the future? A. A. Balkema, Rotterdam. 348 pp.

81. Grisdale-Helland, B., and S. J. Helland. 1995. Methods to assess optimal nutrient composition of diets for Atlantic salmon. J. Appl. Ichtyol. 11:359-362. *Cited in* Asgard.

82. Groombridge, B., and M. D. Jerkins (eds.). 1996. The diversity of the seas: a regional approach. World Conservation Monitoring Centre. World Conservation Press, Cambridge, UK. 132pp.

83. Guerrero, R. D., 1999. Sustainable aquaculture for marginal coastal fisherfolk in the tropics. *In* N. Svennevig, H. Reinertsen, and M. New (eds.). Sustainable aquaculture: food for the future? A. A. Balkema, Rotterdam. 348 pp.

84. Gupta, A. K. 1999. Fishing in the 'troubled waters': recognizing, respecting and rewarding local ecological knowledge, innovations and practices concerning aquatic biological diversity. Pages 145-160 *In* R. S. V. Pullin, D. M. Bartley, and J. Kooiman (eds.). Towards policies for conservation and sustainable use of aquatic genetic resources. ICLARM Conf. Proc. 59. 277 pp.

85. Gupta, M. V. 1999. Perspectives on aquatic genetic resources in Asia and the Pacific. Pages 101-116 *In* R. S. V. Pullin, D. M. Bartley, and J. Kooiman (eds.). Towards policies for conservation and sustainable use of aquatic genetic resources. ICLARM Conf. Proc. 59. 277 pp.

86. Hallerman, E. M. 1993. Public policies regulating the use of genetically modified aquatic organisms: current and future needs internationally. Pages 32-47 *In* K. L. Main, and B. Reynolds (eds.). Selective breeding of fishes in Asia and the United States. Oceanic Institute, Honolulu.

87. Harvey, B. Fish genetic conservation in Canada and Brazil: field programs and policy development. Pages 17-22 *In* R. S. V. Pullin, D. M. Bartley, and J. Kooiman (eds.). Towards policies for conservation and sustainable use of aquatic genetic resources. ICLARM Conf. Proc. 59. 277 pp.

88. Harvey, B., and J. Carolsfeld. 1993. Induced breeding in tropical fish culture. IDRC. Ottawa, Ont. 144pp.

89. Hastein, T. 1995. Disease problems, use of drugs, resistance problems and preventive measures in fish farming worldwide. Pages 183-194 *In* H. Reinertsen, and H. Haaland (eds.). Sustainable fish farming, Proceedings of the First International Symposium on Sustainable Fish Farming, August 28-31, 1994. Oslo, Norway. Rotterdam: A. A. Balkema. *Cited in* Goldburg.

90. Heggberget, T. G., B. O. Johnsen, K. Hindar, B. Jonsson, L. P Hansen, N. A. Hvidsten, and A. J. Jensen. 1993. Interactions between wild and cultured Atlantic salmon: a review of the Norwegian experience. Fisheries Research 18:123-146. *Cited in* Goldburg.

91. Hershberger, W. K., J. M. Myers, R. N. Iwamoto, W. C. McCauley, and A. M. Saxton. 1990. Genetic changes in growth of coho salmon (*Oncorhynchus kisutch*) in marine net-pens, produced by ten years of selection. Aquaculture 85:187-184. *Cited in* Neira 1999.

92. Hevrøy, E. M., G. I. Hemre, and K. Sandnes. 2001. By-catch and offal feed from the herring industry - performance of Atlantic salmon as concerns growth, feed utilisation and fillet quality. Cultivation of Salmon II Conference, May 7-10, 2001. Bergen, Norway. Abstract available as pdf file at: http://www5.imr.no:8080/salmon/innhold.htm

93. Hew, C. L., G. L. Fletcher, S. J. Du, Z. Gong, M. A. Shears, M. J. King, and D. R. Idler. 1992. Growth enhancement intransgenic Atlantic salmon by the use of an 'all fish' chimeric growth hormone gene construct. Biotechnology 10:176-181. *Cited in* Entis.

94. Hopkins, J. S., C. L. Browdy, P. A. Sandifer, and A. D. Stokes. 1995. Effect of two feed protein levels and two feed rates, and stocking density combinations on water quality and production in intensive shrimp ponds which do not use water exchange. Journal of the World Aquaculture Society 26(1):93-97. *Cited in* Goldburg

95. Hopkins, D. D., R. J. Goldburg, and A. Marston. 1997. An environmental critique of governmental regulations for open ocean aquaculture. Ocean and Coastal Law Journal 2:235-260. *Cited in* Goldburg.

96. Hoppin, P., R. Liroff, and M. Miller. 1997. Reducing reliance on pesticides in Great Lakes Basin agriculture. Washington, DC: World Wildlife Fund. (ID DEQ). *Cited in* Goldburg

97. Horsted, S. J., T. G. Nielsen, B. Riemann, J. Pock-Steen, and P. K. Bjornsen. 1988. Regulation of zooplankton by suspension-feeding bivalves and fish in estuarine enclosures. Mar. Ecol. Prog. Ser. 48:217-224.

98. Howell, B. R., E. Moksness, and T. Svasand (eds.). 1999. Stock Enhancement and Sea Ranching. Blackwell Science Ltd. Osney Mead, Oxford, UK.

99. Huq, S., and K. Mainuddin. 1999. Sustainable trade and environmental concerns in Bangladesh. Bangladesh Environmental Newsletter 10(2). http://www.bcas.net/ben/bd_environment_news01012000.htm

100. ICES. 1996. Report of the working group on introductions and transfer of marine organisms. ICES C.M. 1996/ENV:8. http://sgnis.org/publicat/papers/skora.pdf

101. International Federation of Organic Agriculture Movements. http://www.ifoam.org/

102. The International Organization for Standardization. http://www.iso.ch/iso/en/ISOOnline.frontpage

103. Johnson, S. C., M. L. Kent, and L. Margolis. 1997. Crustacean and helminth parasites of seawater-reared salmonids. Aquaculture Magazine March/April:40-64.

104. Josupeit, H. 2000. Environmental issues of warmwater prawns. Presented at Coldwater Prawn Forum, 22-23 June, 2000. Edinburgh, UK. FAO GLOBEFISH. http://www.globefish.org/index2.htm

105. Kapuscinski, A. R., T. Nega, and E. M. Hallerman. 1999. Adaptive biosafety assessment and management regimes for aquatic genetically modified organisms in the environment. Pages 225-251 *In* R. S. V. Pullin, D. M. Bartley, and J. Kooiman (eds.). Towards policies for conservation and sustainable use of aquatic genetic resources. ICLARM Conf. Proc. 59. 277 pp.

106. Kaspar, H. F., P. A. Gillespie, I. C. Boyer, and A. L. MacKenzie. 1985. Effects of mussel aquaculture on the nitrogen cycle and benthic communities in Kenepuru Sound, Marlborough Sounds, New Zealand. Marine Biology 85:127-136. *Cited in* Goldburg.

107. Kaushik, S. J., J. P. Cravedi, J. P. Lalles, J. Sumpter, B. Fauconnau, and M. Laroche. 1995. Partial or total replacement of fish meal by soybean protein on growth, protein utilization, potential estrogenic or antigenic effects, cholesterolemia and flesh quality in rainbow trout, Oncorhynchus mykiss. Aquaculture 133,257-274. *Cited in* Asgard *et al.*

108. Kent, M. L. 1994. The impact of diseases of pen-reared salmonids on coastal marine environments. Pages 85-95 *In* A. Ervik, P. Kupka, P. Hansen, and V. Wennevik (eds.). Proceedings of the Canada-Norway workshop on environmental impacts of aquaculture. Bergen, Norway: Norwegian Institute of Marine Research. *Cited in* Ellis and Associates (1996). *Cited in* Goldburg.

109. Koljonen, M. L. 1989. Electrophoretically detectable genetic variation in natural and hatchery stocks of Atlantic salmon in Finland. Hereditas 110:23-35. *Cited in* Smith 1999.

110. Kooiman, J. 1999. Governance, and the conservation and sustainable use of aquatic genetic resources. Pages 175-186 *In* R. S. V. Pullin, D. M. Bartley, and J. Kooiman (eds.). Towards policies for conservation and sustainable use of aquatic genetic resources. ICLARM Conf. Proc. 59. 277 pp.

111. Lefferts, L., and M. Heinicke. 1996. Green food labels: emerging opportunities for environmental awareness and market development. Mothers and Others for a Liveable Planet, New York, NY.

112. Levin, P. S., and M. H. Schiewe. 2001. Preserving salmon biodiversity. American Scientist 89:220-227.

113. Li, S. 1987. Energy structure and efficiency of a typical Chinese integrated fish farm. Aquaculture 65:105-118. *Cited in* Asgard *et al.*

114. Lightner, D. V. 1999. The Penaeid shrimp viruses TSV, IHHNV, WSSV, and YHV: current status in the Americas, available diagnostic methods, and management strategies. Journal of Applied Aquaculture 9(2):27-52.

115. Lincoln, R. F., and A. P. Scott. 1984. Sexual maturation in triploid rainbow trout, *Salmo gairdneri* Richardson. Journal of Fish Biology 25:385-392. *Cited in* Goldburg.

116. Lopez Alvarado, J. 1997. Aquafeeds and the environment. Pages 275-289 *In* A. Tacon and B. Basurco (eds.). Feeding tomorrow's fish. Proceedings of the CIHEAM Network on Technology of Aquaculture in the Mediterranean, June 24-26, 1996. Cahiers, Options Mediterranees. Jointly organized by CIHEAM, IEO, and FAO. *Cited in* Goldburg.

117. Losordo, T. M., and P. Westerman. 1991. An analysis of biological, economic, and engineering factors affecting the cost of fish production in recirculating aquaculture systems. Pages 1-5 *In* Design of high-density recirculating aquaculture systems. September 26-27, 1991 workshop proceeding. National Sea Grant College Program, Louisiana Sea Grant College Program, U.S. Fish and Wildlife Service, U.S. Department of Agriculture. Available from the National Sea Grant Depository, University of Rhode Island.

118. Losordo, T. M., and M. B. Timmons. 1994. An introduction to recirculating systems. Pages 1-7 *In* M. B. Timmons and T. M. Losordo (eds.). Aquaculture water reuse systems: engineering design and management. New York, NY: Elsevier.

119. Lovell, R. T. 1991. Use of soybean products in diets for aquaculture species: revised. Pages 173-187 *In* D. M. Akiyama and R. K. H. Tan (eds.). Proceedings of the Aquaculture Feed Processing and Nutrition Workshop, September 19- 25, 1991. Singapore: American Soybean Association. *Cited in* Goldburg.

120. MacAlister Elliot & Partners, Lymington. 1999. Environmental Certification in the Aquaculture Industry: Potential and Recommendations - Executive Summary. Available on SeaWeb Aquaculture Clearing House website at: http://www.seaweb.org/resources/sac/policy.html

121. MacLean, N., S. Nam, D. Williams, and L. Lavender. 1995. Abstract 118. *In* Molecular biology in fish, Fisheries and Aquaculture: an International Symposium. Fisheries Society of British Isles, Plymouth U.K. *Cited in* Entis.

122. MacQuaid, J. 1996. Thailand transformed by shrimp boom. Times-Picayune (New Orleans). http://spj.org/sdxawards/08pubservice/tp5d05.htm. *Cited in* Goldburg.

123. Mattsson, J., and O. Linden. 1983. Benthic macrofauna succession under mussels, *Mytilusedulis* L. (Bivalvia), cultured on hanging longlines. Sarsia 68:97-102. *Cited in* Goldburg.

124. Mayer, I., and E. McLean. 1995. Bioengineering and biotechnological strategies for reduced waste aquaculture. Water Science and Technology 31(10):85–102. IWA Publishing. Abstract available at: http://www.iwaponline.com/wst/03110/wst031100085.htm

125. McEachron, L. W., and K. Daniels. 1995. Red drum in Texas: a success story in partnership and commitment. Fisheries 20:6-8. *Cited in* Smith 1999.

126. Mires, D. 1999. Preparation and implementation of fisheries policy in relation to aquatic genetic resources. Pages 63-72 *In* R. S. V. Pullin, D. M. Bartley, and J. Kooiman (eds.). Towards policies for conservation and sustainable use of aquatic genetic resources. ICLARM Conf. Proc. 59. 277 pp.

127. Morikawa, K. 1999. Japan's Efforts on Technological Development for Sustainable Marine Aquaculture. *In* Journal of Sustainable Use: In Search of Innovative Conservation Initiative. Report of the proceedings of the 2nd Symposium on Sustainable Use of Wildlife Resources, 22-26 November, 1999. Chengdu, China. Available on IWMC World Conservation Trust website at: http://www.iwmc.org/sustain/2ndSymposium/issues/issues-08-4.htm

128. Morton, A. B., and H. K. Symonds, 2002. Displacement of *Orcinus orca* (L.) by high amplitude sound in British Columbia, Canada. ICES Journal of Marine Science 59:71-80.

129. Moss, S. M., and P. J. Crocos. Maturation. Report of the All India Shrimp Hatcheries Association. Available at: http://www.indiashrimphatcheries.com/maturation.html

130. Munro, A. L. S. 1988. Advantages and disadvantages of transplantations. Pages 75-83 *In* E. Grimaldi, and H. Rosenthal (eds.). Efficiency in aquaculture production: disease control. Proceedings of the 3rd Annual International Conference on Aquafarming "AQUACOLTURA '86," Verona, Italy. Edizioni del Sole 24 Ore, Milan, 227 pp. *Cited in* Goldburg.

131. Nakashima, T. 1995. Research activities at Kochi artifical upwelling laboratory in Japan on the utilization of deep seawater resources. IOA Newsletter 6(4). Available at: http://ioa.erl.itri.org.tw/vol6-4.htm

132. National Research Council. 2002. Genetic status of Atlantic salmon in Maine. Interim report from the Committee on Atlantic Salmon in Maine. National Academy Press. Washington, DC. ISBN 0-309-08311-7.

133. Naylor, R. L., R. J. Goldburg, J. H. Primavera, N. Kautsby, M. C. M. Beveridge, J. Clay, C. Folke, J. Lubchenco, H. Mooney, and M. Troell. 2000. Effect of aquaculture on world fish supplies. Nature 405:1017-1024. *Cited in* Smith.

134. Neira, R. 1999. National and regional perspectives on aquatic genetic resources in Latin America. Pages 117-130 *In* R. S. V. Pullin, D. M. Bartley, and J. Kooiman (eds.). Towards policies for conservation and sustainable use of aquatic genetic resources. ICLARM Conf. Proc. 59. 277 pp.

135. Neira, R., V. Martinez, and G. A. E. Gall. 1997. Realized selection intensities and genetic change for harvest weight in coho salmon (*Orcorhynchus kisutch*). Abstract presented at the Sixth International Symposium on Genetics in Aquaculture, 23-28 June, 1997. Stirling, UK. *Cited in* Neira 1999.

136. NMFS (United States Department of Commerce). National Oceanic and Atmospheric Administration. National Marine Fisheries Service, Gulf of Maine Aquaculture-Pinniped Interaction Task Force. 1996. Report of the Gulf of Maine Aquaculture-Pinniped Interaction Task Force. Submitted to the National Marine Fisheries Service, Office of Protected Resources, Silver Spring, MD, 70 pp.

137. Norwegian Fish Farmers' Association. 1990. The Norwegian fish farming industry in harmony with the environment. Trondheim/ Tromso, Norway: Norwegian Fish Farmers' Association. *Cited in* OTA (1995). (*Cited in* Goldburg.)

138. Ohnishi, K. Trends in salmon enhancement program in Japan. The Japanese Association of Salmonid Science. http://www.affrc.go.jp:8001/salmonid/sum1/summary.2e.html

139. OTA (United States Congress, Office of Technology Assessment). 1993. Harmful nonindigenous species in the United States, OTABA- 370. Washington, DC: U.S. Government Printing Office.

140. OTA (United States Congress, Office of Technology Assessment). 1995. Selected Technology Issues in U.S. Aquaculture, OTABP- ENV-171. Washington, DC: Office of Technology Assessment. (*Cited in* Goldburg.)

141. Pauly, D., V. Christensen, J. Dalsgaard, R. Froese, and F. Torres, Jr. 1998. Fishing down marine food webs. Science 279:860-863.

142. Pauly, D., R. Froese, L. Y. Liu, and P. Tyedmers. 2001. Down with fisheries, up with aquaculture? Implications of global trends in the mean trophic levels of fish. Presented at AAAS-sponsored mini symposium The Aquaculture Paradox: Does Fish Farming Supplement or Deplete World Fisheries, 18 February, 2001. San Francisco. 12 p.

143. Penman, D. J. 1999. Biotechnology and aquatic resources: genes and genetically modified organisms. Pages 23-33 *In* R. S. V. Pullin, D. M. Bartley, and J. Kooiman (eds.). Towards policies for conservation and sustainable use of aquatic genetic resources. ICLARM Conf. Proc. 59. 277 pp.

144. Pillay, T. V. R. 1992. Aquaculture and the environment. Cambridge, MA: Fishing News Books, 191 pp. *Cited in* Goldburg.

145. Pitts, J. L. 1997. The use of pesticides, Excis (R) (cypermethrin) to treat sea lice *(Lepeophtheirus* spp. and *Caligus* spp.) in farmed salmon and Sevin (R) (carbaryl) to control burrowing shrimp (*Neotrypaea californiensis* and *Upogebia pugettensis*) infestation on cultured Pacific oyster beds, both using integrated pest management programs. Page 371 *In* World Aquaculture Society book of abstracts, World Aquaculture '97, February 19- 23, 1997, Seattle, WA. Baton Rouge, LA: World Aquaculture Society. *Cited in* Goldburg.

146. Porter, M. J. R., D. Guerrero-Tortolero, N. Duncan, S. Handeland, S. Stefanson, G. L. Taranger, and N. Bromage. 2001. Daylength-melantonin and salmonid development. Cultivation of Salmon II Conference, May 7-10, 2001. Bergen, Norway. Abstract available as pdf file at: http://www5.imr.no:8080/salmon/innhold.htm

147. Primavera, J. H. 1993. A critical review of shrimp pond culture in the Philippines. Reviews in Fisheries Science 1:151-201. *Cited in* Goldburg

148. Primavera, J. H., C. R. Lavilla-Pitogo, J. M. Ladja, and M. R. Dela Pena. 1993. A survey of chemical and biological products used in intensive prawn farms in the Philippines. Marine Pollution Bulletin 26(1):35-40. *cited in* Goldburg

149. Richards, R. H., V. Inglis, G. N. Ferichs, and S. D. Millar. 1992. Variation in antibiotic resistance patterns of *Aeromonas salmonicida* isolated from Atlantic Salmon, *Salmo salar* in Scotland. Pages 276-287 *In* C. Michel and D. Alderman (eds.). Chemotherapy in aquaculture: from theory to reality. Office of International des Epizooties, Paris. *Cited in* Smith et al. 1994, *Cited in* Goldburg.

150. Robertson, A. I., and M. J. Phillips. 1995. Mangroves as filters of shrimp pond effluent: predictions and biogeochemical research needs. Hydobiologia 295:311-321. *Cited in* Grant 1999.

151. Rottmann, R. W., R. Francis-Floyd, and R. Durborow. 1992. The role of stress in fish disease. Southern Regional Aquaculture Center Publication No. 474.

152. Rumsey, G. L. 1993. Fish meal and alternative sources of protein in fish feeds, update 1993. Fisheries 18(7):14-19. *Cited in* Goldburg.

153. Ryman, N., and G. Stahl. 1981. Genetic Perspectives on the identification and conservation of Scandinavian stocks of fish. Can. J. Fish. Aqut. Sci. 38:1562-1575. *Cited in* Smith 1999.

154. Saitanu, K. A., A. Amornsin, F. Kondo, and C. Tsai. 1994. Antibiotic residues in tiger shrimp (*Penaeus monodon*). Asian Fisheries Science 7:47-52. *cited in* Goldburg

155. Samuelsen, O. B., B. T. Lunestad, B. Husevag, T. Holleland, and A. Ervik. 1992. Residues of oxolinic acid in wild fauna following medication in fish farms. Diseases of Aquatic Organisms 12:111-119. *cited in* Goldburg

156. Sandnes, K., and A. Ervik. 1999. Industrial marine fish farming. Pages 97-107 *In* N. Svennevig, H. Reinertsen, and M. New (eds.). Sustainable aquaculture: food for the future? A. A. Balkema, Rotterdam. 348 pp.

157. SEAFDEC - Aquaculture Department of the Philippines. http://www.seafdec.org.ph/home.html

158. Seymour, E. A., and F. Johnsen. 1990. Comparison of extruded and pressed pellets feeds for juvenile Atlantic salmon, *Salmo salar* L. in relation to efficiency and feed waste to the environment. Paper presented at the International symposium on Feeding Fish in our water: Nutritional Strategies in Management of Aquaculture Waste, 5-8 June, 1990. Guelph, Ontario, *Cited in* Ackefors.

159. Shearer, K. D., J. J. Hard, W. Fairgrieve, D. A. Larsen, M. Strom. 2001. Some current issues related to the culture of Pacific salmon for enhancement. Cultivation of Salmon II Conference, May 7-10, 2001. Bergen, Norway. Abstract available as pdf file at: http://www5.imr.no:8080/salmon/innhold.htm

160. Shuanglin, D. Mariculture's two side effects on environment and their utilization in practice. Presented at Aquachalange Workshop Programme, April 27-30, 2002. Beijing, China. http://www.aquachallenge.org/programme/programme_menu.html. The main ideas of this article have been published *In* Shuanglin, D., P. Kehou and U. Brockmann. 2000. Review on effects of mariculture on coastal environment. Journal of Ocean University of Qingdao 30(4):575-582.

161. Silvert, W. Spatial Scales of Mariculture Impacts. Habitat Ecology Division From a paper presented at a workshop in Bergen, to be published in *Fisken og Havet.* Available at: http://www.mar.dfo-mpo.gc.ca/science/mesd/he/staff/silvert/scales.html.

162. Simba, V. R. P. 1999. Rural aquaculture in India. FAO RAP Publication 1999/21. Bangkok, Thailand. http://www.fao.org/DOCREP/003/X6944E/X6944E00.HTM

163. Skaala, O. 1995. Possible genetic and ecological effects of escaped salmonids in aquaculture. Pages 77-86 *In* Environmental impacts of aquatic biotechnology. OECD, Paris. *Cited in* Penman 1999.

164. Smith, C. 2000. Global Change and Biodiversity Linkages across the Sediment-Water Interface. Bioscience. Full article available at: www.bioscience.org

165. Smith, P. 1999. Genetic resources and fisheries: policy aspects. Pages 43-62 *In* R. S. V. Pullin, D. M. Bartley, and J. Kooiman (eds.). Towards policies for conservation and sustainable use of aquatic genetic resources. ICLARM Conf. Proc. 59. 277 pp.

166. Snelgrove, P. V. R., M. C. Austen, G. Boucher, C. Heip, P. A. Hutchings, G. M. King, I. Koike, P. J. D. Lambshead, and C. R. Smith. 2000. Linking biodiversity above and below the marine sediment-water interface. BioScience 50:1076-1088. *Cited in* Smith.

167. South, G. R. 1994. Cultivation of benthic marine algae in reef and lagoonal systems with special reference to the tropical South Pacific. Pages 93-96 *In* J. L. Munro, and P. E. Munro (eds.). The management of coral reef resource systems. ICLARM Conf. Proc. 44. 124 p. *Cited in* Guerrero.

168. Shpigel, M., A. Neori, D. M. Popper, and H. Gordin. 1993. A proposed model for 'environmentally clean' land-based culture of fish, bivalves and seaweeds. Aquaculture 117:115-128. *Cited in* Asgard *et al.*

169. Stickney, R. R. 1994. Principles of aquaculture. New York, NY: John Wiley & Sons, Inc. 502 pp. *Cited in* Goldburg.

170. Stickney, R. R. 1994. Offshore aquaculture: technology and policy issues. Contract paper prepared for the U.S. Congress, Office of Technology Assessment. *Cited in* Goldburg.

171. Storebakken, T., K. D. Shearer, and A. J. Roem. 1998. Availability of protein, phosphorous and other elements in fish meal, soy protein concentrate and phytose-treated soy-protein-concentrate-based diets to Atlantic salmon, Salmo salar. Aquaculture 161:365-379. *Cited in* Asgard *et al.*

172. Storebakken, T., G. M. Berge, S. J. Helland, and A. Skrede. 2001. Bacterial protein produced on natural gas - a novel alternative to fish meal in Salmon diets. Cultivation of Salmon II Conference, May 7-10, 2001. Bergen, Norway. Abstract available as pdf file at: http://www5.imr.no:8080/salmon/innhold.htm

173. Subasinghe, R. P., P. Bueno, M. J. Phillips, C. Hough, S. E. McGladdery, and J. E. Arthur (eds.). 2000. Aquaculture in the third millennium. Technical proceedings of the Conference on Aquaculture in the Third Millennium, 20-25 February, 2000. Bangkok, Thailand. NACA, Bangkok and FAO, Rome. 471pp.

174. Summerfelt, S. T., K. H. Holland, J. A. Hankins, and M. D. Durant. 1995. A hydroacoustic waste feed controller for tank systems. Water Science and Technology 31(10):123–129. IWA Publishing. Abstract available at: http://www.iwaponline.com/wst/03110/wst031100123.htm

175. Tacon, A. G. J. 1993. Feed ingredients for warmwater fish: fish meal and other processed feedstuffs. FAO, Fisheries Circular No. 856. Rome: Food and Agriculture Organization of the United Nations. *Cited in* Goldburg.

176. Tacon, A. G. J., M. J. Phillips, and U. C. Barg. 1995. Aquaculture feeds and the environment: the Asian experience. Water Science and Technology 31(10):41–59. IWA Publishing. Abstract available at: http://www.iwaponline.com/wst/03110/wst031100041.htm

177. Tacon, A. G. J. 1997. Fishmeal replacers: review of antinutrients within oilseeds and pulses – a limiting factor for the aquafeed Green Revolution? Pages 153-182 *In* A. Tacon, and B. Basurco (eds.). Feeding tomorrow's fish. Proceedings of the CIHEAM Network on Technology of Aquaculture in the Mediterranean, June 24- 26, 1996. Cahiers, Options Mediterranees. Jointly organized by CIHEAM, IEO, and FAO.

178. Talbot, C., and R. Hole. 1994. Fish diets and the control of eutrophication resulting from aquaculture. Journal of Applied Ichthyology 10(4):258-270. *Cited in* Ackefors 1999.

179. Tamaru, C., *et al.* (eds.). 2000. Spawning and maturation of aquaculture species. Proceedings of the twenty-eighth UJNR Aquaculture Panel Symposium, November 10-12, 1999. Kihei, Hawaii. University of Hawaii Sea Grant College Program. UJNR Technical Report no 28. http://www.lib.noaa.gov/japan/aquaculture/proceedings.htm

180. Tang, Q., and J. Fang. Impacts of intensive mariculture on coastal ecosystem and environment in China and suggested sustainable management measures. Yellow Sea Fisheries Research Institute, Qingdao, 266071. http://www.aquachallenge.org/abstracts/tang.html

181. Taylor, J. A. 1999. Making salmon: an environmental history of the Northwest fisheries crisis. University of Washington Press.

182. Tenore, K. R., J. C. Goldman, and J. P. Clarner. 1973. The food chain dynamics of the oyster, clam, and mussel in an aquaculture food chain. J. Exp. Mar. Biol. Ecol. 12:157-165.

183. Tenore, K. R., L. F. Boyer, R. M. Cal, J. Corral, C. Garcia-Fernandez, N. Gonzalez, E. Gonzalea-Gurriaran, R. B. Hanson, J. Iglesias, M. Krom, E. Lopez-Jamar, J. McClain, M. M. Pamatmat, A. Prez, D. C. Rhodas, G. deSantiago, J. Tietjen, J. Westrich, and H. L. Windom. 1982. Coastal upwelling in the Rias Bajas, NW Spain: contrasting the benthic regimes of the Rias de Arosa and de Muros. J. Mar. Res. 40:701-772.

184. Thorgaard, G. H., and K. Allen. 1992. Environmental impacts of inbred, hybrid and polyploid aquatic species. Pages 281-288 *In* A. Rosenfield, and R. Mann (eds.). Dispersal living organisms into aquatic ecosystems. College Park, MD: Maryland Sea Grant College, University of Maryland. *Cited in* Goldberg.

185. The Trade and Environment Database, Case Studies, Thailand Shrimp Farming. http://www.american.edu/TED/THAISHMP.HTM

186. Troell, M., *et al.* 1997. Integrating marine cultivation of *Gracilaria chilensis* (Gracilariales, Rhodophyta) and salmon cages for reducing environmental impact and increased economic output. Aquaculture 156:45-61.

187. Van Gorder, S. 1991. Optimizing production by continuous loading of recirculating systems. Pages 10-15 *In* Design of high-density recirculating aquaculture systems. A workshop proceeding, 26-27 September, 1991. National Sea Grant College Program, Louisiana Sea Grant College Program, U.S. Fish and Wildlife Service, U.S. Department of Agriculture. Available from the National Sea Grant Depository, University of Rhode Island. *Cited in* Goldberg.

188. Verspoor, E. 1988. Reduced genetic variability in first generation hatchery populations of Atlantic salmon (*Salmo salar*). Canadian Journal of Fish and Aquatic Science 45:686-690. *Cited in* Smith 1999.

189. Wang, Y. L. 1999. Utilization of Genetic resources in Aquaculture: A farmer's view for sustainable development. R. S. V. Pullin, D. M. Bartley, and J. Kooiman (eds.). Towards policies for conservation and sustainable use of aquatic genetic resources. ICLARM Conf. Proc. 59. 277 pp.

190. Waples, R. S. 1999. Dispelling some myths about hatcheries. Fisheries 24(2):12-21.

191. Wilkinson, S. B., W. Z. Zheng, J. R. Allen, N. J. Fielding, V. C. Wanstall, G. Russell, and S. J. Hawkins. 1996. Water quality improvements in Liverpool docks: the role of filter feeders in algal and nutrient dynamics. Marine Ecology 17:197-211. *Cited in* Grant 1999.

192. Windsor, M. L., and P. Hutchinson. 1995. Minimizing the impacts of salmon aquaculture on the wild salmon stocks. Pages 149-163 *In* H. Reinertsen and H. Haaland (eds.). Sustainable fish farming. Proceedings of the First International Symposium on Sustaintible Fish Farming, August 28-31, 1994. Oslo, Norway. Rotterdam: A. A. Balkema. *Cited in* Goldburg.

193. World Aquaculture Societies Working Group on Stock Enhancement. Issues in marine stock enhancement. Available at: http://www.efan.no/was/seissues.htm

194. Wu, R. S. S., K. S. Lam, D. W. MacKay, T. C. Lau, and V. Yam. 1993. Impact of marine fish farming on water quality and bottom sediment: a case study in the sub-tropical environment. Marine Environmental Research 38:115-45.

195. Yap, W. G. 1999. Rural aquaculture in the Philippines. FAO RAP Publication 1999/20. Bangkok, Thailand. http://www.fao.org/DOCREP/003/X6943E/X6943E00.HTM

196. Yap, W. G. Shrimp culture: a global review. ASEAN-SEAFDEC. The world of mangroves, mangrove-friendly shrimp culture. http://www.mangroveweb.net/html/ffarming.htm

197. Yeh, S., T. Yang, and T. Chu. Marine fish seed industry in Taiwan. Aquafind, Aquatic Fish Database. http://www.aquafind.com/articles/seed.html

198. Zohar, Y., and C. C. Mylonas. 2001. Endocrine manipulations of spawning in cultured fish: from hormones to genes. Aquaculture 197:99-136.
