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Overcoming the impacts of aquaculture on the coastal zone

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Abstract

The wide variety of goods and services provided by the coastal zone (food, medicines, nutrient recycling, control of flooding, typhoon protection) account for its many uses (fisheries, aquaculture, agriculture, human settlements, harbors, ports, tourism, industries). Aquaculture now provides a third of total fisheries production. Half of the total aquaculture yield comes from land-based ponds and water-based pens, cages, longlines and stakes in brackish water and marine habitats. But the opportunities for employment, income and foreign exchange from coastal aquaculture have been overshadowed by negative environmental and social effects. The environmental impacts include: mangrove loss, bycatch during collection of wild seed and broodstock, introductions and transfers of species, spread of parasites and diseases, misuse of chemicals, and release of wastes. The socioeconomic impacts include: privatization of public lands and waterways, loss of fisheries livelihoods, food insecurity, and urban migration. The paper gives recommendations on the attainment of responsible and sustainable aquaculture with emphasis on herbivorous and omnivorous species, polyculture, integration with agriculture and mangroves, and self-regulation in the form of codes of conduct and best management practices. Recommended approaches include holistic Integrated Coastal Zone Management based on stakeholder needs, mechanisms for conflict resolution, assimilative capacity of the environment, protection of community resources, and rehabilitation of degraded habitats, to improvements in the aquaculture sector pertaining to management of feed, water, and effluents.

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1. Introduction

Since time immemorial, the coastal zone has been a center of human activity because of its high biological productivity and easy accessibility—close to half of the world's population resides within 100 km of the coastline. The wide variety of goods and services provided by mangroves, seagrasses, coral reefs and other coastal ecosystems include the production of aquatic plants and animals used for food, medicines, construction and other human needs; recycling of nutrients and filtration of pollutants; control of flooding and soil erosion; and protection from typhoons, storm surges and tsunamis. The global value of coastal ecosystems has been estimated at US$12.57 trillion/year and those of mangrove forests, together with tidal marshes, at US$1.65 trillion/year [1]. The many uses of the coastal zone include artisanal and commercial fisheries; aquaculture; agriculture; human settlements; harbors, ports and navigation; recreation and tourism; and mining and industries. Such multiple uses have given rise to conflicts over resource use. In recent years, some of the most controversial conflicts have been related to the apparent and potential negative impacts of aquaculture.

2. Aquaculture

In 2002, aquaculture worldwide produced a total of 51.4 million metric tones (mmt) valued at US$60 billion [2]. Freshwater fish contributed 47.7% of volume, followed by mollusks (22.9%), plants (22.6%) and crustaceans (4.2%) (Fig. 1). Aquaculture harvests were predominantly from Asia (91.2%), followed by Europe (4.0%) and the Americas (3.6%). Around 55% of production in 2001 came from land-based ponds and water-based pens, cages, longlines and stakes in brackish water and marine habitats; freshwater habitats contributed ~45%. Table 1 matches commodities to their respective production systems, e.g., ponds and pens.

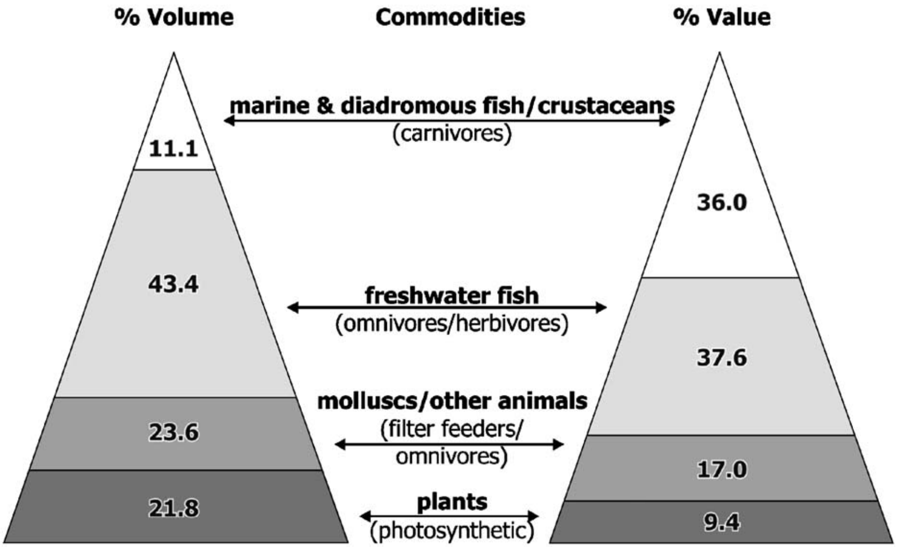

Fig. 1. 2001 World Aquaculture Production (FAO, 2002) = 48.4 million metric tons (mmt), US$ 61.5 billion (values not drawn to scale).

Table 1
Coastal aquaculture systems in Asia

Group	System	Method
Plants		
Eucheuma, Kappaphycus, Laminaria, Porphyra	Stakes, rafts, longlines, beds	Extensive
Molluscs		
Oyster, Mussel, Cockle	Rafts, longlines, stakes	Extensive
Crustaceans		
Prawns/Shrimps, Crabs	Ponds, pens	Extensive, semi-intensive, intensive
Marine/brackish water fish		
Milkfish, Grouper, Snapper	Ponds, pens/cages	Extensive, semi-intensive, intensive

Fig. 2. Aerial view of Dagupan, Pangasinan, northern Philippines showing runaway development of culture ponds and pens blocking access to waterways (Photo by G. Jacinto, U.P. Marine Science Institute).

Widely projected to compensate for declining fisheries catches, aquaculture now provides a third of total fisheries production compared to only 16% in 1991. But the phenomenal growth of aquaculture in recent years combined with a tendency to ease out other stakeholders and convert multiple-use coastlines to a single-use resource have given rise to social disruption and conflicts. A typical example is Dagupan, Philippines (Fig. 2) where mangroves, tidal creeks, estuaries and nearshore areas traditionally accessible to small-scale fishers, intertidal gleaners and other local folks have been converted first from mangroves to fishponds in the 1950–80s, then later to pens and cages—both in estuarine waterways and subtidal habitats such as seagrass beds. This paper reviews the negative impacts of coastal aquaculture and recommends measures to improve the environmental and socioeconomic sustainability of the activities.

3. Environmental impacts

The coastal zone bears most of the ecological consequences of aquaculture development, as shown in Fig. 3. These include habitat loss/modification, excessive harvesting of wild seed/spawners and damage to bycatch, introductions of exotic species, escapes of cultured animals, spread of diseases, interactions with wild populations, misuse of chemicals and antibiotics, release of wastes, and dependence on wild fisheries.

3.1. Habitat loss/modification

Mangrove conversion to shrimp ponds is the single major factor that has contributed to the negative press received by aquaculture. Southeast Asia has 35% of the world's 18 million ha of mangrove forests [3], but has also suffered from the highest rates of mangrove

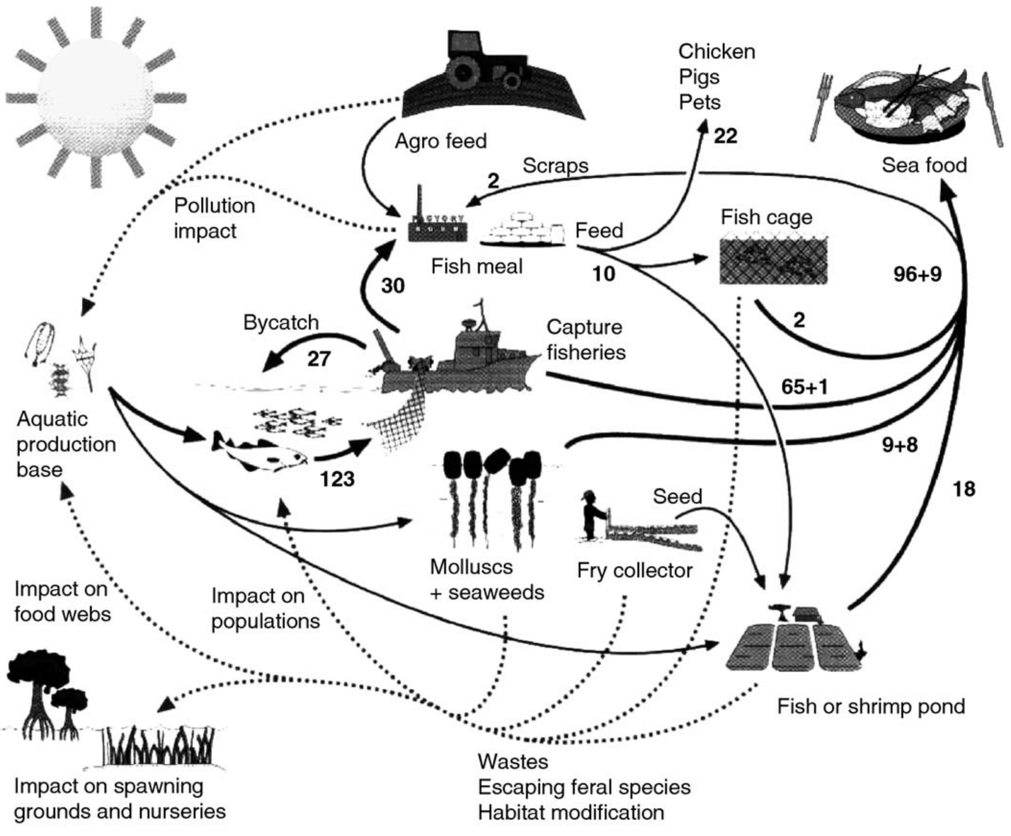

Fig. 3. Ecological links between intensive fish/shrimp aquaculture and capture fisheries. Thick lines = main flows from aquatic production base through fisheries/aquaculture to human consumption; thin lines = other production inputs, and hatched lines = negative feedbacks; numbers refer to mmt of fish, shellfish and seaweeds in 1997 [41].

loss, e.g., 70–80% in the Philippines and Vietnam for the last 30 years [4,5]. Around half of the 279,000 ha of Philippine mangroves lost from 1951 to 1988 were developed into culture ponds; 95% of Philippine brackish water ponds in 1952–1987 were derived from mangroves [6]. Globally, more than a third of mangrove forests have disappeared in the last two decades, and shrimp culture is the major human activity accounting for 35% of such decline [7]. This transformation results in loss of essential ecosystem services generated by mangroves, including the provision of fish/crustacean nurseries, wildlife habitat, coastal protection, flood control, sediment trapping and water treatment. Fish pens and cages also degrade nearshore habitats through their physical installations on seagrass beds and sediment communities, or through deposits of uneaten feeds [8].

3.2. *Collection of wild seed and broodstock; loss of bycatch*

Many aquaculture farms in Asia stock wild-caught juveniles rather than hatchery-reared post-larvae derived from wild spawners or broodstock. Collection of such 'seedstock' can have major consequences for wild fisheries in terms of high rates of bycatch. For example, juvenile milkfish collected for grow-out constitute only 15% of total finfish fry from inshore seine net catches [9]; the remaining 85% are discarded and left to die on the beach. The use of 1.7 billion wild milkfish fry stocked annually in Philippine milkfish ponds [10] corresponds to a loss of about 10 billion fry of other finfish species. In shrimp culture, the favored species, *Penaeus monodon*, constitutes a very small proportion of wild juvenile and adult populations. For every fry of *P. monodon*, up to 330–475 other shrimp fry are caught in Malaysia [11] and the Philippines [12]. Given a yearly collection of one billion *P. monodon* in southeast Bangladesh, the amount of bycatch destroyed is likely to have important consequences for marine food webs [13]. A similar problem occurs when wild adult *P. monodon* are collected to provide eggs for hatcheries, or for broodstock. Adult *P. monodon* are rare and comprise only 0.06–0.14% of total catch from trawls in Peninsular Malaysia [14] and the Arafura Sea, Indonesia [15]. The high demand for wild adult *P. monodon* in the late 1990s—220,000 broodstock for 185 hatcheries in India [A. Ganapathy, pers. comm., 1996], 90,000 broodstock and spawners for >200 hatcheries in Indonesia (A. Taufik, pers. comm., 1998), and 6400 wild spawners for 300 hatcheries in Vietnam (V.D. Qinh, pers. comm., 1998)—undoubtedly resulted in the loss of substantial numbers of fish and invertebrates through bycatch.

3.3. *Introductions and transfers of species; spread of diseases*

The greatest number of introductions of exotic fish and crustacean species outside their natural range has occurred for aquaculture purposes [16]. The potential negative effects of such introductions include the degradation of host environment, disruption of the host community, genetic degradation of the host stock, and the introduction of diseases and parasites. Disease risks are particularly acute: almost all of the 20 identified viruses in marine shrimp have been described in cultured animals [17]. Impacts from disease have also been observed in the case of transfers of species within their range. In recent years, viruses, notably the Whitespot Syndrome Virus (WSSV) and Yellowhead Virus, have caused catastrophic multimillion dollar crop losses in shrimp farms across Asia. The origin of the WSSV pandemic has been traced to the import into Japan of infected hatchery-produced *P. japonicus* from Chinese hatcheries in 1993 [18]. Since then, it has spread to

China, Taipei, Korea, India, the Philippines and even tropical America [19]. In the Philippines, cultured *P. monodon* showed 100% incidence of the infectious hypodermal and hematopoietic necrosis virus (IHHNV) compared to a mean of only 51% in four wild tiger shrimp populations [20]. Moreover, IHHNV prevalence among the wild shrimp populations was directly proportional to shrimp culture intensification and mangrove degradation.

3.4. Use of antibiotics and chemicals

Chemicals used in shrimp culture may be classified as therapeutants, disinfectants, water and soil treatment compounds, algicides and pesticides, plankton growth inducers (fertilizers and minerals), and feed additives [21,22]. Excessive and unwanted use of such chemicals can result in toxicity to non-target populations (cultured species, human consumers, and wild biota), development of antibiotic resistance, and accumulation of residues [23]. The widespread or excessive use of an antibiotic leads to the development of resistance in bacterial populations, and the rotating use of several antibiotics contributes to the occurrence of multiple drug resistance patterns [24]. High rates of antibiotic resistance to tetracycline, oxytetracycline, oxolinic acid, furazolidone and chloramphenicol were observed in bacteria from fish ponds [25] and from shrimp ponds [26] where antibiotics were routinely used; widespread multiple resistance was observed in the latter study. A majority of Thai shrimp farmers (74%) have used antibiotics [23], mostly on a prophylactic basis. The collapse of the 1988 shrimp crop in Taiwan was due, among other factors, to the indiscriminate use of antibiotics that led to higher short-term survival in the cultured animals but long-term resistance among their pathogens [27].

Risk to humans also stems from the persistence of chemicals in edible tissues. The antibiotics oxytetracycline and oxolinic acid were detected above permissible levels in 8.4% of 1461 *P. monodon* sampled from Thai domestic markets in 1990–1991 [28]. The direct effects of these chemotherapeutants and antibiotics on humans constitute a public health concern—chloramphenicol can cause aplastic anemia, hypoplastic anemia, stomatitis and other less severe conditions [29]. From June 1992 to April 1994, Japanese quarantine stations found antimicrobial residues in 30 shipments of cultured shrimp from Thailand [30]. Organotin pesticides have long been used to control *Cerithidea cingulata* snails that prevent growth of natural food in Philippine milkfish ponds. More than 10 years ago, the government banned these substances because of potential harm to humans and the environment. But the ban has not stopped the clandestine use and backdoor smuggling of these molluscicides from Indonesia and Malaysia where they remain legal. Coloso and Borlongan [31] found evidence of triphenyltin contamination of sediment and milkfish tissues collected from ponds previously treated with organotins. Milkfish is an important food fish, accounting for a third of total aquaculture production in the Philippines.

3.5. Aquaculture wastes and coastal pollution

A major factor behind the mass mortalities in the 1988 Taiwanese shrimp crop was the re-use of waste-laden pond water discharge [27]. As fish/shrimp biomass and feed inputs grow, the water quality in intensive ponds, pens and cages deteriorates over the cropping cycle. Total nitrogen (N) and phosphorus (P), nitrite, silicate, orthophosphate, dissolved oxygen, and biological oxygen demand increased and water visibility decreased in intensive

Thai ponds throughout the grow-out period [32]. Sediment is the major sink accounting for 31% of N output, 84% of P, 63% of organic matter and 93% of solids, and accumulates in intensive shrimp ponds at the rate of 185–199 mt/ha/cycle DW while effluent water during regular flushing and at harvest accounts for 45% of N and 22% of organic matter output [33]. Intensive shrimp ponds form a thick sludge layer at the rate of 20–290 mt/ha/crop DW. Quality of receiving waters deteriorates if the assimilative capacity of the environment is exceeded.

In early 2002, massive milkfish kills in pens and cages in Pangasinan, Philippines, of 110,000 mt valued at US$16 million were traced to overstocking, overfeeding and low dissolved oxygen levels. Nutrient fluxes and organic matter levels were found to be higher inside fish pens compared to outside levels [34]. Pens released 51–68% of total carbon and nitrogen inputs to the surroundings, and P was bound in the sediments, resulting in significant environmental impacts [34]. Another concern is that the composition of phytoplankton communities may be altered by nutrients added to the water column from aquaculture farm wastes. Nishimura [35] has shown that yellowtail feces may stimulate growth of the red tide-forming dinoflagellate *Gymnodinium*. Mass mortalities in a Taiwan shrimp pond were traced to blooms of the toxic dinoflagellate *Alexandrium tamarense* [36]. Closely related to *A. tamarense,* and also associated with paralytic shellfish poisoning, *A. minutum* appeared only in samples from aquaculture ponds and coastal areas but was not present at other sites [37].

3.6. Salinization of soil and water

Pumping large volumes of underground water to achieve brackish water salinity in the 1980s to mid-1990s led to the lowering of groundwater levels, emptying of aquifers, land subsidence and salinization of adjacent land and waterways in Taiwan and Southeast Asia. Even when fresh water is no longer pumped from aquifers, the discharge of salt water from shrimp farms located behind mangroves still causes salinization in adjoining rice and other agricultural lands [38]. The development of low salinity shrimp farming in Thailand paved the way for industry expansion into rice paddies and other inland sites [39]. However, due to opposition from community groups, academicians and NGOs because of salinization (estimated salt loading of 5.6 mt/ha/year), the government banned inland shrimp farming in 1998 [40].

3.7. Dependence on fish meal and fish oil

The promotion of aquaculture development has been based on the premise that it can compensate for the shortfall in food production due to declining wild fisheries. To assess whether farmed fish production adds to global fish supplies on a net basis, Naylor et al. [41] traced the flow of aquatic primary production that moves through aquaculture (Fig. 4). Of the total 1997 capture fisheries landings of 96 mmt (excluding bycatch), 66 mmt was directly consumed by humans and 30 mmt was used in fish meal and fish oil production (Fig. 4). The total 1997 aquaculture production of 37 mmt−10 mmt of fish used for aquafeeds gives a net aquaculture production of 27 mmt comprising seaweeds, filter feeders and herbivorous species (41). The proportion of fish meal in aquaculture feeds is much higher than in poultry and livestock feeds, with one kilogram of carnivorous fish requiring up to 5 kg of wild fish [42]. The increasing demand for fish meal, fish oil and raw ('trash') fish is fastest in aquaculture, growing from 10% in 1988 to 33% in 1997 and

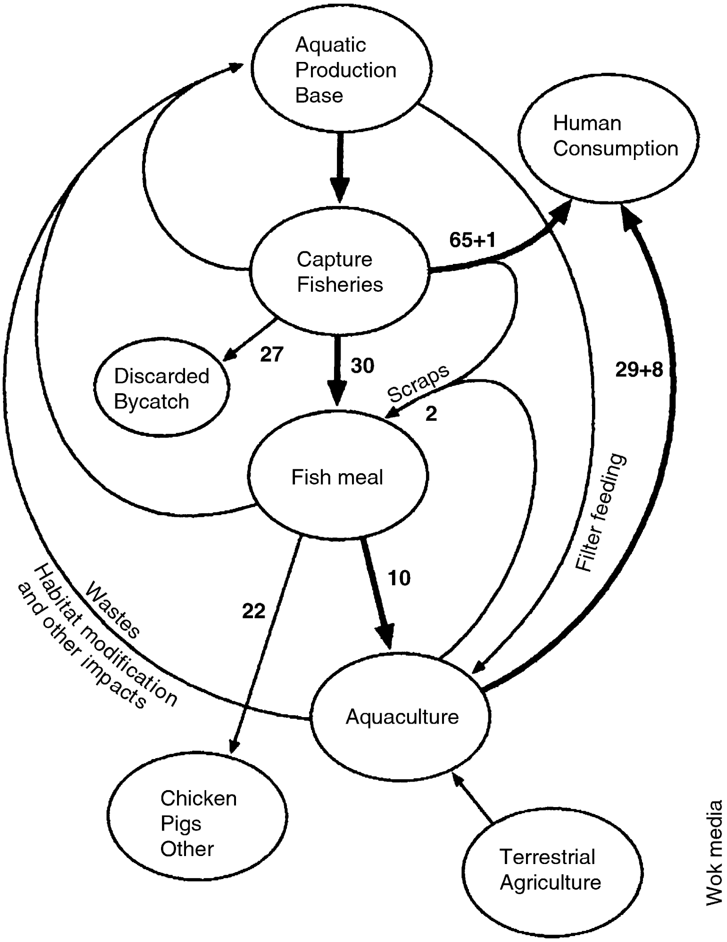

Fig. 4. Flow chart of capture and farmed fisheries products from aquatic primary production (in 1997 mmt of fish). Heavy lines refer to direct flows, light lines to indirect and minor flows [41].

65–68% in 2002 [42,43]. But the aquaculture industry cannot continue to rely on finite stocks of wild-caught fish, a number of which are already overexploited or depleted. This appropriation of aquatic productivity for fish feeds reduces wild fish supplies for human consumption, e.g., small pelagic fishes, such as mackerel, anchovy and sardines in Southeast Asia [44,45]. Only production of filter-feeding molluscs, and herbivorous and omnivorous fish that directly consume microalgae and seaweeds, represents a net contribution of aquaculture to global fish supplies.

4. Socio-economic impacts

4.1. Loss of mangrove goods and services

Reviews of mangrove valuation data give a range of US$6–400 ha for individual and combined forestry goods [46] and $40–5300 ha for different fisheries products [47].

However, they underestimate the true value of mangroves because of the difficulties in assigning monetary values to functions like coastal protection and waste processing. Aside from conventional cost-benefit analysis, valuation tools currently available include non-market methods, e.g., hedonic pricing, contingency valuation and indirect opportunity cost. In Trang Province, Thailand, maximum Net Present Value could be generated from 35,665 ha of mangrove economic zones by retaining 61% of the entire area as mangrove forest, reforesting 10%, and allowing only 17% for wood concessions and 12% for shrimp farms [48]. Considering forest products and fisheries, as well as social benefits of coastal protection, shoreline stabilization and carbon sequestration, Sathirathai [49] concluded that mangrove conversion to commercial shrimp farms in Surat Thani, Thailand was economically viable only for private persons but not for society as a whole. Further analysis of this mangrove system revealed that the intact forest had a total economic value ~70% higher than when converted to a shrimp farm (~$60,000 ha versus $16,700 ha) [50]. The recent tsunami in Southeast Asia has also highlighted the critical role and immeasurable value of mangroves as protection for coastal communities.

Other negative impacts of aquaculture include: blocked access to coastal resources by pond and pen/cage structures; and navigational hazards; privatization of public lands and waterways; conversion of residential, agricultural (rice, pastures) and common lands; salinization of domestic and agricultural water supplies; fisheries decline and food insecurity; rural unemployment and urban migration; and in some cases human rights abuses, social disruption, conflicts and violence [51–55].

5. The way forward

For aquaculture to fulfill the promises of food security and poverty alleviation without causing negative environmental and socioeconomic effects, a more holistic approach is required. This must involve other stakeholders to avoid a sectoral focus on aquafarms. The key issues to consider and address are outlined below.

5.1. Integrated coastal zone management

The groups vulnerable to the negative effects of shrimp culture generally do not participate in the formulation and implementation of public policies, e.g., determining location of ponds, pens and cages, regulating farm activities, and environmental impact assessment preparation [56]. Community participation in coastal zone management is essential if questions of social equity are to be satisfactorily addressed. In community-based coastal resource management, fisherfolk and other local residents are the de facto day-to-day managers of resources.

Coastal zones should be delineated for fisheries, aquaculture, tourism and other uses through the process of integrated coastal zone management (ICZM). Allocation of activities to locations should be based on the carrying or assimilative capacity of the environment for a given use, protection of community resources, rehabilitation of degraded habitats, stakeholder needs and mechanisms for conflict resolution. ICZM is based on the concept of the ecological footprint which incorporates not only inputs such as feed and seed, but also outputs, e.g., effluent treatment [57].

5.2. Sustainable aquaculture

Grow-out systems need to reduce and mitigate negative impacts and improve sustainability through the development and wider dissemination of available on-farm technologies (e.g., recycling), and integration of aquatic species (polyculture of tilapia/fish and shrimp in ponds).

5.2.1. Farm siting

Criteria include such standard physical factors such as water supply, tidal regime, topography, soil quality and climate as well as the capacity of the environment to absorb effluents. More important than fish/shrimp density inside ponds is the farm density in a given area so that the (waste) absorbing or assimilative capacity of the environment is not exceeded. Wide-scale abandonment of ponds is often due to the proliferation of initially successful farms that ultimately overwhelm the system because they do not follow the ecological footprint concept.

5.2.2. Farm and effluent management

Good management of cultured stock, food, water and soil is the first line of defense against diseases and crop failures. Water quality standards should apply equally to influent water in ponds as to drainage waters flushed into adjoining estuarine and marine habitats. Closed and semi-closed water systems that recycle water through a series of reservoirs, treatment ponds (with fish, bivalves and algae) and canals back to production ponds serve to reduce the amount of discharged wastes and minimize the entry of disease organisms from natural waters.

Pond sludge may be reduced through the application of probiotics, or by the tilling and drying of the pond bottom. Alternatively, sludge may be collected and stored near the farm for mangrove planting or subsequent transfer to agricultural or forest land. Mangroves can be used to treat shrimp pond effluents with high levels of solids, organic matter and nutrients. Seedlings of various mangrove species survived in an abandoned shrimp pond [58], in intertidal dump sites near shrimp farms [59], and in shrimp pond effluents [60]. Abandoned ponds may be rehabilitated for shrimp production or other sustainable uses such as salt making and integrated aquaculture, or restored to a productive mangrove system.

5.2.3. Mangrove-friendly aquaculture

Mangroves and aquaculture are not necessarily incompatible. For example, seaweeds, bivalves and fish (seabass, grouper) in cages can be grown in mangrove waterways. Such mangrove-friendly aquaculture technologies are amenable to small-scale, family-based operations and can be adopted in mangrove conservation and restoration sites. Brackish water culture ponds may not necessarily preclude the presence of mangroves. Dikes and tidal flats fronting early Indonesian *tambak* were planted with mangroves to provide firewood, fertilizers and protection from wave action [61]. Present-day versions of integrated forestry-fisheries-aquaculture can be found in the traditional *gei wai* ponds in Hong Kong, mangrove-shrimp ponds in Vietnam, aquasilviculture in the Philippines, and silvofisheries in Indonesia [62]. Alternatively, mangroves adjacent to intensive ponds can be used to process nutrients in pond effluents.

5.2.4. Disease control

The most realistic approach to combat diseases is combining good husbandry and good feed with the use of prophylactic agents, including immunostimulants and probiotics. The control of diseases (and pests) through the use of chemicals should be a last resort only after environmental conditions, nutrition and hygiene have been optimized. Chemicals used should be safe to the cultured crop, farm staff, environment and consumer. Farmers should avoid prophylactic treatment, apply effective and narrow spectrum antibacterials, adopt withdrawal periods and avoid discharge of effluents with toxic chemical levels into natural water bodies [63].

5.2.5. Low trophic level species, native species

There is a need to counter the market-driven trend towards carnivorous crustaceans and marine fish and focus on herbivorous species that do not require fishmeal-based pellets or raw ('trash') fish. Likewise, introduction of exotic species should be minimized and strictly follow established protocols.

5.2.6. Role of government, market mechanisms and self-regulation

Legislation is designed to prevent or reduce harm created by aquaculture by means of such instruments as: government authorizations (licenses, permits, certifications); environmental impact assessments and regulation in the form of standards on water quality, permissible emission levels, etc. [64]. However, the regulatory approach is fraught with problems because the targeted sectors, i.e., shrimp farmers, can be powerful and disregard or circumvent the laws [56]. Moreover, there is little will or ability to enforce legislation, often because the delineation of the government agencies responsible for enforcement of specific laws, and the level of authority, whether local, state, provincial, regional or national, for enforcement remain vague. Economic incentives and disincentives in the form of taxes, penalties and credits for effluent disposal, groundwater abstraction, chemical use, etc., may be more effective than regulatory approaches in inducing behavioral changes towards the environment and generating revenues to finance environmental policy programs [64]. Such fees should reflect the economic rent of the resource used, e.g., ground water and mangrove area converted to pond and encourage efficient pond utilization. Green taxes (based on the Polluter Pays principle) can mitigate the environmental and socioeconomic damage of shrimp farms by correcting water quality problems, financing alternative water supplies in salt-contaminated areas, rehabilitating mangroves and other damaged landscapes, and compensating local populations for the loss in livelihoods [56].

Market mechanisms provide financial incentives for industry to modify its production processes and include consumer boycotts and eco-labelling. Eco-labelled shrimp/fish grown in ecologically and socially responsible farms can command premium prices from generally affluent and environmentally aware consumers. There should be joint certification of such products by government representatives and independent third parties, and regular monitoring. Shrimp from extensive Indonesian farms certified as organically grown are marketed by a Japanese company to consumers through a Swedish cooperative. Site visits to the farms in Java revealed non-compliance by the shrimp farms with standards set by the certifier (e.g., mangrove protection and non-use of chemicals by hatcheries), and release of partially incorrect information to consumers by the cooperative [65].

These recommendations have been discussed in detail elsewhere, e.g., [56,66–68]. Country specific recommendations for the Philippines [69], Thailand and Vietnam [38,70], and Indonesia [71] also focus on redirections for industry and new strategies in political ecology. For aquaculture to fulfill the promises of food security and poverty alleviation, a paradigm shift is needed away from its sectoral promotion detached from traditional coastal activities to a more holistic approach requiring the participation of other stakeholders including fishers and local communities. Within the aquaculture sector itself, sustainability requires improvements in farm management, especially with regard to feed, water, effluents and diseases; focus on native and low trophic level species, and integration with agriculture and silviculture, in particular mangroves. Finally, responsible aquaculture can be promoted by government regulation, market mechanisms and self-regulation in the form of codes of conduct and best management practices, e.g., the 1997 FAO Code for Responsible Fisheries—Aquaculture Development, 1998 Homenkollen Guidelines, and the 2001 ASEAN-SEAFDEC Millennium Conference on Sustainable Fisheries [72].

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