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Aquaculture Research and Development as an Entry-Point and Contributor to Natural Resources and Coastal Management

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Recent, fervent international dialogue concerning the existence and magnitude of impacts associated with aquaculture has had both positive and negative outcomes. Aquaculture stakeholders have become sensitized to requirements for improved environmental management of aquaculture. On the other hand, in some cases aquaculture development has been negatively affected by some of the unwarranted and unproved allegations to the detriment of the stakeholders most in need of aquaculture development (i.e., resource users, particularly the poor, who are dependent on natural resources). These resource users are targeted by, and directly influence biodiversity and conservation agendas; hence the need to understand how to gain their active participation. This discussion

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focuses on examples of how aquaculture research and development can be a useful tool or strategy for resource management initiatives and provide tangible positive including increased stakeholder participation and cooperation, offering alternatives to resource extraction and use in otherwise difficult or intransigent resource management conflicts.

Keywords Amazonian fishes, aquaculture, community-based management, mariculture, Mexico, Micronesia, Nicaragua, stock enhancement

Introduction

Integrated coastal management (ICM) is often defined as some variant of the definition provided by Cicin-Sain and Knecht (1998, 11) as "a continuous and dynamic process by which decisions are taken for the sustainable use, development, and protection of coastal and marine areas and resources. ICM acknowledges the interrelationships that exist among coastal and ocean uses and the environments they potentially affect, and is designed to overcome the fragmentation inherent in the sectoral management approach. ICM is multipurpose oriented, it analyzes and addresses implications of development, conflicting uses, and interrelationships between physical processes and human activities, and it promotes linkages and harmonization among sectoral coastal and ocean activities." Aquaculture is a wide-ranging economic development activity involving culture of marine or brackish water plants, animals, or microorganisms at some point in their life cycle. As such, aquaculture has traditionally occupied a primary place among development activities in coastal areas, and is rapidly expanding to supply protein-rich foods and other products, filling the gaps left by the decline of capture fisheries as the world population continues to grow. Growth is also expected as culture technologies and species development increasingly make new forms of aquaculture, such as off-shore systems, feasible. Aquaculture supplies approximately 47% of the world's seafood supply and is the fastest growing form of animal husbandry at 6.9% per annum. Per capita production rose from 0.7 kg in 1970 to 7.8 kg in 2006 producing 66.7 million tons of plant and animal material with a value of $85.9 billion (Food and Agriculture Organization [FAO], 2008).

Consideration of aquaculture within the context of ICM is critical as both become more important. Changes brought on by climate change will also affect the role of aquaculture along the world's coasts, major rivers and watersheds. Aquaculture is often regarded primarily in a negative light when considered by coastal management programs, often ignored completely. Aquaculture is also often viewed as an "industry" responsible for habitat destruction, competing with other economic activities, displacing local peoples and their traditional occupations, and as an inefficient use of inputs and resources. Use of the term "industry" is misleading as very few forms of aquaculture are sufficiently large and consolidate, and geographically or structurally coherent enough to merit this term. Shrimp or salmon culture may merit this designation. Most aquaculture is conducted on a small to medium scale. FAO estimates that 80% of world aquaculture production is produced by smallholders (Subasinghe & Phillips, 2005). In fact, the lack of cohesiveness and sectoral organization is a major challenge for inclusion in natural resources management programs. Social and economic impacts are also commonly alleged to occur. This is a more problematic topic than the issue of environmental impacts since social or economic inequities or injustices are rarely well documented and are difficult to distinguish from similar issues occurring throughout a particular nation's socioeconomic milieu. The environmental, social, and economic costs and benefits of aquaculture are highly nuanced and variable depending on which region, species, and form of aquaculture is practiced. The authors' intention is not to debate whether or not impacts occur, to what extent or which sectors within aquaculture

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are most culpable, but to move beyond this contentious topic to consider what might be: (1) workable strategies to include aquaculture in NRM (natural resources management) or ICM programs to gain multiple, positive outcomes; (2) how inclusion of aquaculture can be a strategic and cost-effective means of developing an entry point in otherwise intractable or difficult situations; and (3) discuss cases of where this has been effectively accomplished. The following discussion provides both conceptual and practical examples.

Stock Enhancement

Aquatic species and habitats are a constant source of concern for resource managers. Stock enhancement is one of several management tools that can be effectively used in combination to address species and habitat issues. Stock enhancement is generally defined as the release of culture juveniles into the wild to restore spawning biomass, augment natural supplies of juveniles to increase harvests or as a form of aquatic ranching whereby juveniles are released to grow in the wild with subsequent re-harvest. The end goals maybe driven by economic considerations (i.e., increasing or maintaining catches) or for conservation (ensuring adequate numbers of breeding adults) (Bell et al., 2006). Stock enhancement has been a part of fisheries management in the United States and Europe since at least the 19th century, but fell somewhat into disfavor during the late 20th century due to difficulties confirming whether the released juveniles actually increased adult stocks, questions related to population genetics, and issues of cost-effectiveness as compared to other management methods. Despite some uncertainties, stock enhancement has been highly effective in some circumstances. Although the Alaska salmon fishery is popularly conceived of as a "wild" fishery, it depends heavily on hatchery production. In 2006, 19% of the total ex-vessel value of harvested salmon was due to hatchery produced fish. This figure can be much higher for specific species; 66% of chum salmon ex-vessel value was from hatchery fish for the same period. For certain endangered or rare salmon or trout stocks in North America, hatchery production may account for close to 100% of existing fish and these populations would go extinct without hatcheries (White, 2007). In Japan, stock enhancement accounted for approximately 90% of the chum salmon, 40% of flounder, and nearly all of the scallop catch (Kitada et al., 1992; SCORE, 2008). Fewer successful cases can be documented for tropical and developing countries where stock enhancement tools might be relatively more effective in cases where weak governance or enforcement handicap other strategies. Successful examples include sea cucumbers (Holothurians), trochus snails (*Trochus niloticus*), pearl oysters, queen conch (*Strombus gigas*), and giant clams (tridacnids) (Bartley & Leber, 2004; Bell & Battaglene, 2004; Born et al., 2004, Haws, pers. obs.).

While heeding FAO's recommendation, "not use artificial propagation as a substitute for precautionary methods" (FAO, 1995) and the desirability of other approaches such as improving fisheries management, stock enhancement should be considered as one tool in the arsenal of NRM programs where the situation merits. Stock enhancement is already widely used with success. One weakness is that hatchery production for some marine finfish lags behind other aquatic species. Strategic utilization of stock enhancement where local capacity exists to support such efforts can be a rapid response to saving valuable fisheries resources until long-term measures such as fisheries habitat restoration can be implemented.

Aquaculture Research Produces Basic Knowledge and Capacity for Management

Effective management and conservation require sound scientific knowledge of species and habitats. Although the role of scientific information is sometimes downplayed in

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management programs, accurate information enhances the probability of effective implementation. While use of typologies can allow for proactive approaches in the face of a paucity of detailed information, generalized approaches have limits. In particular, engagement of certain key stakeholders requires a science-based approach as many are unwilling to take action without a rigorous informational basis. Aquaculture research provides necessary information for management, often when other sources are lacking. Aquaculture scientists and farmers regularly investigate basic biological parameters such as reproduction, nutrition, habitat requirements, behavior, growth rates, and tolerance to environmental stressors; information that can be difficult to obtain if the species in question are obscure or are not prioritized for research funding by conservation organizations. Economic utility is often the strongest driver of research. Fortunately many species with economic importance turn out to be important in resource management (e.g., keystone species or those with cultural importance). Other species may be targeted for aquaculture that would otherwise be overlooked by conservation efforts for a variety of reasons, and therefore lost.

An example of aquaculture research and development that significantly advanced conservation and management is a ten-year initiative to develop multiple species of Amazonian fishes for culture by the Pond Dynamics/Aquaculture Collaborative Research and Support Program (CRSP) funded by USAID. The Aquaculture Center of the Sao Paulo University, Ohio State University and Southern Illinois University at Carbondale partnered with researchers and communities in Brazil, Peru, and Ecuador. This effort produced a significant data base on the biology and ecology of a major group of freshwater fishes of ecological and commercial importance.

South America has the most diverse freshwater fish fauna on earth. Much of this diversity evolved with the rainforest (Araújo-Lima & Goulding, 1997). The Amazon Basin alone harbors 3,000 fish species (Val et al., 2006), half of the 6,000 Neotropical fish fauna of the 13,000 freshwater fish species in the world (Reis et al., 2003). The South American fishes are distinguished by their diversity and unique life history traits. Diversity represents potential to develop new culture species which can adapt to a variety of environments. Among the unusual traits are species which grow to very large sizes, have herbivorous or fructivorous feeding habits, and are resistant to extreme environments.

The hydrology of the Amazonian basin is characterized by a complex of rivers, seasonal tributaries, lagoons, and channels representing about 20% of the freshwater in the planet (Vieira et al., 2006). Fisheries represent an important economic activity in the region, being a source of food, trade, income, and leisure for the population (Santos & Santos, 2005). The subsistence fishery is an important social activity, considering the high daily fish consumption in the Amazon (550g/per capita), and could represent about 60% of the total fisheries production in the region (Freitas & Rivas, 2006). In 2006, inland fisheries in Brazil amounted 251.241 tons, from which 147.931 tons in the North Region (IBAMA, 2008), represented mainly by silurids and characids species. Inland capture fisheries result in many cases in dangerous imbalances of the food chain, particularly when top predators are removed.

A second driving force is the aquarium trade. An attractive characteristic of some Amazonian fishes is that many species make interesting aquarium fish as juveniles, but serve as food fish when larger. The ability to improve culture of ornamental species both in the Amazon and in captivity in other areas lends itself to sustainable economic development (Dabrowski et al., 2008). Imports of ornamental fishes have increased in the United States by 50% since 2000, amounting to $46.1 million in 2002. Exports from the Peruvian Amazon in 2001 to North America, Singapore, and Japan, for instance, totaled 1 million

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silver arowana juveniles (Moreau & Coomes, 2006). Aquarists are increasingly receptive to buying cultured rather than wild collective fish.

Fisheries and fisheries habitat management has been hampered by a lack of information on the basic biology, ecology, and utilization of many of these heavily exploited species. Attempting to minimize over-exploitation, the Brazilian government protects the natural stocks of the migratory fishes, restricting fisheries during the breeding period. For many reasons (complexity of the hydrographic basin, ichthyofauna diversity, variety of fisheries apparatus, quantity of fishermen, professional disorganization, etc.) fisheries management in the Amazon is extremely difficult. Violent social conflicts occur frequently (Santos & Santos, 2005). The Amazonian fisheries are typical of major freshwater inland fisheries that the FAO considered among the most heavily pressured and endangered fisheries (FAO, 2008). Aquaculture now provides 76% of freshwater fish production, mainly from Asia and more potential exists in developing nations in Africa and the Americas to increase freshwater fish production through aquaculture for food security as well for management purposes for the benefit of local communities. Additionally, it provides an opportunity for indigenous people to utilize their local species for economic development rather than relying on introduced species.

The collective work has closely investigated a number of the most prominent Amazonian and non-Amazonian characids species (pacu—*Piaractus mesopotamicus*, tambaqui—*Colossoma macropomum*, matrinxã—*Brycon amazonicum*, curimbata—*Prochilodus lineatus*, piau—*Leporinus macrocephalus*, and dourado—*Salminus brasiliensis*), silurids (surubins—*Pseudoplatystoma fasciatum* and *P. corruscans*, cascudo—*Rhinelepis aspera*, and jundiá—*Rhandia quelen*), erytrinids (*Hoplias lacerdae*), and cichlids (peacock bass—*Cichla ocellaris*, oscar—*Astronotus ocellatus*, and angelfish—*Pterophyllum scalare*). The tambaqui (*Colossoma macropomum*) and the surubins (Figure 1) are considered species of major importance in the Amazon. Tambaqui can reach more than 1 m in length and weigh 30–45 kg. The species has social and economic importance accounting for 44% of the total fish weight in the Manaus fish market in 1976. This value diminished by around 18% at the beginning of the 1990s (Graef, 1995). Despite the inconsistency of the statistical data in Brazil, the stocks of tambaqui are critical, and the surubins also give indications of over-fishery (FAO, 2009). Additionally, the pirarucu or paiche (*Arapaima gigas*), the largest freshwater fish in the Amazon (up to 250 kg) was intensively studied. This fish is listed in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species since 1996 due to illegal fishing. As a species at the top of the food web, maintaining paiche populations in the wild also contributes to the ecological balance



Figure 1. A ten-month-old surubim (Amazonian catfish) bred in captivity. Development of native fish species allows communities to utilize local biodiversity in sustainable ways. Photo credit: Maria Celia Portella.

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in the Amazon rainforest. Controlled culture of *Arapaima* can offer an alternative to illegal harvest of this species and other osteoglossid species.

Considerable success was encountered in the research efforts including developing the ability to spawn the fishes in captivity, elucidation of larvae feeding requirements, feeding behaviors, metabolic characteristics, development of methods to wean fish onto artificial feeds specially formulated for their nutritional requirements and digestive systems, culture methods, and economic studies. Additionally, this work provided the information, developed human resources, and built capacity so that a number of extension efforts were spawned. Extension efforts throughout the region allowed for fast transfer of practical information to local communities. For instance, the fish consumption in the municipality of Tingo Maria, Peru was only 1.05 kg/capita/year but during the CRSP extension efforts, 107 farmers in the Huallaga River Valley owning over 234 ponds became involved in fish culture. Recently, the SEAP (Special Secretariat for Aquaculture and Fisheries) started a program to improve aquaculture extension in Brazil as a means for increasing participation in aquaculture. The program aims to train 6,000 extension agents to assist 400,000 fishermen and 200,000 aquaculture farmers. Another program promotes conservation and management of *Arapaima* populations in Conservation Units in the Amazon, where fisher families protect the lagoons containing breeding pairs of fish. The number of pirarucu individuals is evaluated annually (possible because it is an air-breathing fish and comes periodically to the water′s surface) and families are authorized to capture up to 30% of the adult fish (>1.5 m). The project, called tambaqui-curumim (curumim = boy in the indigenous Tupi language), aims to rear tambaqui juveniles (400 g) in small ponds or floating cages and sell these small fish into a niche market (Portella, pers. comm.).

In addition to promoting improved fisheries management, addressing food security and raising awareness of the need to protect these unique fish species, one goal of this work is to offer alternative livelihoods in areas such as Brazil, Peru, and Ecuador where participation in drug cultivation, processing, and trade is an attractive proposition to impoverished communities with few alternatives, as discussed in a following section.

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Managing Species and Habitats

Coastal management and conservation efforts routinely attempt to link key species and habitats to broader efforts to provide incentives to local stakeholders and communities to participate in programs. Often these species may be high-profile, highly visible species such as panda bears, rare tropical birds, or other similarly "glamorous" species. For example, Rare Conservation (www.rareconservation.org) effectively uses its Pride campaigns as a social marketing tool. A target species is selected to promote identification and local pride in natural resources and conservation among local communities. These types of efforts, however, have a high probability of failure if local stakeholders cannot go beyond the aesthetic value of the species, which developing world organizers may prize, but that may not be of consequence to the poor who prioritize economic survival. An alternative is to target species that have local economic importance and have a tight linkage to critical habitat.

Aquaculture to Manage Wetlands and Wetlands Fish Species

Efforts in northern Ecuador to develop a full-fledged coastal management program in Cojimies (Manabi Province) began with a strategy emphasizing a focus on species, habitats, and issues of local economic importance to raising awareness and creating demand for

coastal management. This effort was part of the USAID SUCCESS Program and implemented partners including the Coastal Resources Center/University of Rhode Island, Pacific Aquaculture and Coastal Resources Center/University of Hawaii at Hilo and Ecocostas, an Ecuador nongovernmental organization (NGO). Cojimies was selected as a site for coastal management initiatives as the area hosts some of the largest intact segments of mangroves and wetlands in Ecuador.

Manabi is one of the few areas where wetlands-inhabiting fish, the Pacific Fat Sleeper (Eleotridae: *Dormitator latifrons*), is highly prized. In other parts of its extensive range (from southern California to Peru) (Fishbase, 2008), the "*chame*" as it is called locally, is generally regarded as a "trash" fish due to its unexceptional appearance and habit of ingesting mud (with subsequent regurgitation when caught). Its most common use is as an emergency food or for fish meal production (Figure 2). In Manabi, however, it has been a highly desirable food source since Pre-Columbian times due to its firm, white flesh and ability to live without water for several days. Unfortunately, the *chame*, like many wetlands species, is threatened due to large scale habitat alteration that has eliminated extensive tracts of freshwater and brackish coastal wetlands.

The SUCCESS Program chose development of *chame* aquaculture as a focal point to begin working with local communities as an entry point for future ICM efforts. *Chame* had desirable attributes for a campaign: (1) current and potential economic value; (2) tight linkages with critical habitat (coastal wetlands); (3) previous research and experience indicated relative ease of culture; (4) institutional preference for developing local species over introduced; (5) potential for restocking from aquaculture fingerlings; (6) *chame* stakeholders had other interests to be targeted by future coastal management efforts. The local stakeholders most interested in *chame* also engaged in shrimp farming, mangrove cutting, hillside cutting, and slash-and-burn agriculture and fishing.

Although the Cojimies focus on *chame* was chosen due to its local appeal, extensive but not widely known past research indicated that *chame* had potential as an aquaculture



Figure 2. A "*chame*" fish—*Dormitator latifrons*, a goby-like fish found widely throughout the Pacific Coast of Latin America. Field trials have shown this species to be an excellent candidate for aquaculture.

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species for much of Latin America. The *chame* has life history traits and culture methods similar to tilapias. For example, it reproduces in ponds and can consume feeds made from local ingredients. If the pilot efforts in Ecuador proved successful, *chame* could potentially become the "new tilapia" for Latin America. Discovery of an alternative aquaculture species is important. Past history has clearly shown that overdependence on a single crop carries a high degree of risk. Additionally, there is concern about tilapia introduction as their aquaculture becomes a global industry. Although specific impacts related to introduction of tilapia are rarely documented, the precautionary principle suggests that their introduction into watersheds where not currently present should be avoided unless careful assessment indicates otherwise. A preference for culture of local species is wise; aside from reducing risks, local species are better adapted to local conditions and are more likely to be immediately accepted in the local market (Haws, unpub. data).

Chame was also an attractive choice since it represented a means of engaging shrimp farmers in coastal management efforts. In the 1980s and 1990s some of partners engaged in the SUCCESS Program had worked with the Ecuador National Coastal Management Program (PMRC). Shrimp farming at that time had caused extensive impacts on the coast due to mangrove removal (during the early development) and water pollution, among others. Despite repeated efforts, it proved difficult to engage shrimp farmers in the PMRC work. The SUCCESS team hoped to engage shrimp farmers through utilizing approaches that were more appealing, less threatening, and offered mutual benefits, but built on the industry's change in attitude and increased awareness of the need for improved management.

Pilot *chame* aquaculture trials began in Cojimies Ecuador in 2004 at the same time that interactions were beginning with a wide range of stakeholders. For example, since *chame* reproduce naturally in ponds, shrimp ponds were a ready source of fingerlings for stocking the *chame* experimental ponds. During this time, shrimp farming in Ecuador was suffering from one of its periodic lows after years of epidemics of White Spot disease (White Spot Syndrome Baculovirus Complex, WSSV) culminating in 2005, which devastated shrimp production. When the project team began work, most shrimp hatcheries were shut down and few shrimp ponds stocked. When shrimp farming prospects are dim, interest in alternative species increases. Shrimp farmers also believed that the presence of some *chame* in their ponds was good since they allegedly eat moribund, infected shrimp, thereby limiting the spread of infection. Hence, the shrimp farmers, both large and small, exhibited a high degree of interest in *chame* farming.

Trials were begun at stocking *chame* as a single crop and in polyculture with small and medium scale shrimp farmers. In addition to the shrimp farmers targeted for the *chame* trials, the project team continued outreach and dialogue with about two dozen of the local shrimp farmers on topics related to water quality, estuary management, and shrimp best management practices. *Chame* culture proved successful as the fish grows to market size in 6–8 months, eats a wide variety of food, including local feed sources such as green bananas and corn meal, and is easy to sell. The limiting factor to scaling up *chame* production turned out to be insufficient numbers of fingerlings, which were difficult to source except from shrimp ponds as much of their native wetland habitats had disappeared. Captive reproduction has not been successfully achieved. Another difficulty encountered was selling quantities of fish greater than could be sold directly from the pond bank during a harvest due to limited transportation to market.

The experiments were widely regarded as a success and continue. The continuous presence of the local extension team overseeing the *chame* trials began to pay off. Initially positioned largely as an alternative livelihood program, which was successful in starting a variety of efforts such as passionfruit/cacao replanting on denuded hillsides, development

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of local tree nurseries and medicinal plant crops, and back-yard gardening, the project team was now able to undertake more significant efforts that began to represent more integrated management and planning efforts. For example, the rapidly developing tourist town of Mompiche requested assistance for a local development plan and the Pedernales Municipality also requested assistance in zoning their shoreline activities. Work began with large scale shrimp farmers to develop Best Management Practices (BMPs) for shrimp farming, which focused on water quality monitoring and development of guidelines and a coastal water quality atlas (Ecocostas, 2008).

Thus, this effort was a two-fold success. The concept of *chame* culture was proven to be feasible and has begun to contribute economically to the region as well as offering an alternative to shrimp culture during bad years or for stakeholders without the resources to invest in this. Developing an aquaculture initiative with local economic relevance allowed the project team to engage in social marketing and awareness-raising that provided an entry point to the beginning of a true coastal management program. Although the efforts have not yet reached the point of being considered a full scale coastal management program, significant strides have been in establishing such a program and tangible, positive outcomes for the environment were made.

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Pearl Farming

Another example of aquaculture functioning as a means to preserve habitat occurs for some types of aquaculture currently practiced in the Pacific Islands. Pearl culture has documented positive effects in protecting both biota and habitats, as well as preserving island cultures. Pearl farming has become an important economic contributor to island economies that may have few other development alternatives. For example, pearl farming produces about $120 million annually in French Polynesia and $15–18 million in the Cook Islands (Fong et al., 2005). In French Polynesia and other Pacific Islands, pearl oysters (*Pinctada* spp.) populations were one of the driving forces for European exploration and colonization in the remote Pacific Islands (Kunz & Stevenson, 2001). The pearls, but more importantly, the mother-of-pearl shell material, were an important material for ornamental and functional objects before the days of plastics. In many cases, pearl oyster populations were decimated, particularly after the advent of air diving in the late 19th century, which accelerated the trend. Once a lagoon is de-populated of pearl oysters, it appears that natural recovery of pearl oysters rarely occurs. This is hypothesized to occur due to the Allee effect. When breeding-age adults are widely separated, fertilization may decrease to nearly zero, hence effectively preventing repopulation even if harvest ceases. One example of this is found in the Northwestern Hawaiian Islands at the Pearl and Hermes Reef. Once nearly stripped of its pearl oyster populations in the early 1900s, pearl oysters are still rare today (Keenan et al., 2006). Once pearl farming technologies were transferred from Japan to the South Pacific in the 1970s, juvenile pearl oyster began to be transferred from a few atolls that still had significant populations to other atolls where pearl farms were established. In the case of the island of Apataki, it is reported that within 8 years of the initial transfer of juveniles, recruitment began to visibly increase. Wild pearl oyster spat then became abundant enough that it was feasible to obtain pearl oyster stock for farming using plastic spat collectors (Figure 3). Now atolls in the Tuamotus, where most pearl farming occurs, once again have abundant pearl oyster populations. Pearl farming also has other beneficial effects on the environment, although impacts at intensely farmed areas such as Takaroa (Tuamotus Islands) and Manihiki, Cook Islands, have also been documented. Impacts may include depletion of particulate organic matter in the water, increases in fouling organisms and



Figure 3. Pearl oysters and some other bivalves can be readily collected by hanging "spat collectors" made from artificial substrates in the water, in this case, shade cloth. Photo credit: Maria Haws.

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effects related to increased human activities such as pollution or increased use of other resources. At the same time, pearl farming plays an important social role as in some cases it may be the only factor that encourages continued habitation of remote, outer islands and subsequently, preservation of local cultures and languages that might otherwise disappear (RDA International, 1995; Rapaport, 1995).

Overall, it appears that more positive effects have resulted than negative. One of the most direct effects of pearl farming is the exclusion of damaging activities. For example, in Lampung Bay, Indonesia, pearl farms were documented to have high coral cover under and adjacent to the farms than in surrounding areas due to successful exclusion of fishers using bombs and poison (Black, 1999). In most cases, pearl farmers can effectively limit the amount of fishing done near the farms. Although in some sense this represents a de facto privatization of water areas, which may cause concerns regarding equitable access to resources, in heavily fished areas where illegal fishing occurs, it may serve as one of the only means of controlling destructive fishing. Development strategies that emphasize equitability in resource use can help address such concerns. Currently this approach is being tested at Namdrik Island in the Republic of the Marshall Islands where community supported MPAs (marine protected areas) are being established in pearl farm and spat collection areas.

Pearl farming can also help reduce mortality within the pearl oyster population when a switch is made from pearl oyster fishing to pearl farming. An implanted pearl oyster bearing a developing pearl is more valuable than a pearl oyster harvested for its shell or meat (Haws & DiMichele, 1999). In Zanzibar, the SUCCESS Program working with the Western Indian Ocean Marine Sciences Association (WIOMSA) and the Institute of Marine Sciences (IMS) developed a half-pearl farming program for village women at Menai Bay that included set-up of pearl farming, spat collection, and jewelry making (using shells from all species gleaned for food). Menai Bay has two species that can be used for pearl production (*Pteria penguin*—Winged pearl oyster and *Pinctada margaritifera*—Black-lip pearl oyster). Previously women harvested pearl oysters for the meat that was sold for a few cents a pound and the shells went largely un-used. Pearl farming has helped

improve utilization of the pearl oyster resources, raised awareness of the management of bivalve populations, led to a co-management effort for cockles (Crawford et al., 2010), and development of community water programs. Pearl farms provide structure in the form of submerged or floating lines, buoys, and anchors that serve as unintentional fish attracting devices (FADS) and provide increased substrate for other organisms. It is quite common to find small and juvenile fishes taking refuge in the nets used to hold pearl oysters and corals and sponges cover the lines. When pearl farmers are exposed to environmental education, they rapidly become convinced of the need to protect the environment as pearl quality is affected by environmental quality.

Coral and Sponge Farming

Based on the pearl farming example, the concept of using invertebrate farming to enhance conservation efforts has been expanded in Micronesia. Invertebrate culture is desirable since many are filter feeders that do not require feeds. Their filter feeding habits also help improve water quality. One advantage of sedentary organisms is that less farm structure is required, thereby reducing costs and impacts that could be associated with infrastructure creation. Two of the authors (Haws and Ellis) and collaborators have specifically designed sponge and coral farming as incentive programs for conservation. This program is similar to the incentive model offered by Seacology, which provides grants to communities that have acted to put marine and terrestrial areas under effective management (Seacology, 2008). To obtain Seacology grants, communities may use grant funds for a wide range of projects with community benefits with no strict requirement that these projects related to management, although in many cases the communities choose to fund projects that enhance continued sustainability of chosen management initiatives. The program aims to recognize communities that voluntarily develop management efforts and is well received by the participating communities as it allows them to obtain objectives for which funding might otherwise not be available.

The incentive program based in Pohnpei, Federated States of Micronesia (FSM) attempted to closely link an economic development activity with conservation and to use the extension effort as an opportunity for awareness-raising. Per capita income in Pohnpei is ~$1200 per year and the FSM is heavily dependent on funding from the United States as part of the Second Compact for Free Association. Coastal residents have few income generating opportunities other than fishing and traditional agriculture. Fishing pressure in the narrow Pohnpei lagoon has increased in recent years, driven by the need to fish more to generate income. The fringing lagoon of Pohnpei is relatively small in relation to the growing population of Pohnpei and leading to concern about sustainability. In 2007 fishing had increased to approximately 1,521 kg/day taken from an area of 152 km^2, believed to represent unsustainable levels (Rhodes et al., 2008). Over the last ten years, farming of bath sponges (*Coscinium mathewsi*) and a variety of live corals for the marine aquarium trade has been developed on Pohnpei by workers from the University of Hawaii at Hilo, the Marine and Environmental Research Institute of Pohnpei (MERIP), and the Conservation Society of Pohnpei (CSP) with support from the David and Lucille Packard Foundation and the United States Department of Agriculture.

In 2004, efforts began to expand coral and sponge farming for farmers living in communities adjacent to MPAs. Pohnpei currently has 11 MPAs, of which 8 are community-based and co-managed. All MPAs in Pohnpei are designated "no take" zones under the Pohnpei Marine Sanctuaries Act of 1998. Although other fishing areas are still open, the MPAs may represent in some cases the most readily accessible areas and are high in

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biodiversity. As an incentive to encourage continued collaboration, but also as a way to replace income possibly lost due to the fishing ban, interested villagers were assisted to establish small coral or sponge farms.

Sponges are processed locally, then sold primarily in New Zealand as a "green" product. The largest buyer of sponges is New Zealand TradeAid, a fair trade retailer with 32 outlets in the country. Average price to the farmer is US$1.00.

The corals are ornamental varieties in demand for the aquarium trade but not rare in the wild. MERIP and the farmers maintain a pool of broodstock coral specimens so that wild corals are not harvested to supply farms, after a first initial cutting, which is done in a sustainable manner. Farmers receive $2 to $3 for each coral fragment and begin receiving income in less than 6 months. The rapid growth of the small coral fragments is highly advantageous in that farmers see an immediate reward for their efforts and ensures regular cash flow as harvests can be done on a nearly monthly basis once production is in progress. Minimal environmental impact occurs because the first small harvest of either corals or sponges is taken from the wild and is under supervision of scientists and trained extension agents. Only the top part of each wild sponge is harvested with the base left to grow. In the case of corals, only a few fragments are carefully removed from each coral colony by the scientists. These fragments are then grown out on the small farms. A requirement for receiving the technical assistance and start-up funding is that each farmer is required to set aside 30% of the first harvest to establish their own broodstock farm from which future farming "stock" will be taken rather than continuing to harvest from the wild.

In addition to receiving intensive training for farming methods, materials were provided for the initial farm start-up and assistance is also provided for marketing. Given the remote location of the farmers' educational level, individual marketing and off-island shipping is not possible. Permits to comply with requirements of CITES (Convention on International Trade in Endangered Species) and United States Fish and Wildlife are also handled by the associated scientists. Aside from being a form of assistance to farmers who would otherwise not be able to comply, the assistance with marketing and shipping ensures a degree of accountability and adherence to best management practices mutually agreed on by scientists and farmers. A key part of the program is that farmers also receive education in basic coral biology and ecology to help increase the awareness of the importance of coral reefs in ways that are important to villagers (e.g., habitat for fish, tourism attraction, water quality). Other efforts that help the environment have also been undertaken such as installing mooring buoys for the farms in order to reduce anchor damage and to encourage this practice at sites near the MPAs as a good practice that should be followed elsewhere.

After four years of extension efforts to transfer methods for sponge and coral culture, while at the same time conducting training in conservation and management, a follow-up survey was conducted among 16 of the farmers. Of these 16 farmers, there was an average of 12 persons per household. Eighty-seven percent of the farmers felt (1) having an MPA near their community was important, primarily to protect the fish populations and (2) that fish populations outside their local MPA had increased. All of the respondents agreed with the following statements: (1) the land and sea must be cared for in order for them to provide in the future; (2) the sea should be managed to provide fish for the current and future generations; (3) coral reefs are important for protecting the land from storm waves; and (4) fishing should be restricted in certain ways to allow for the fish and corals to grow. Sixty-three percent of respondents claimed to fish less since beginning farming, 25% fish about the same, and 13% fished more. The decrease in fishing may be a function of the farmers spending more time working on their farms and due to the increased fuel prices. It appears that farming was a more cost-effective way to use fuel and/or time than fishing (Ellis & Haws, 2008).

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A combination of factors was required to make this approach effective in promoting conservation while providing options for small scale economic development: (1) technical support and materials were provided explicitly as a means to support the MPA management; (2) support included marketing assistance that made rapid economic returns feasible; (3) the marketing and shipping assistance acted to increase the number of jobs created; (4) when marketing and shipping is supervised by scientists, adherence to best management practices and control of export volume is controlled; (5) extension visits used as an opportunity for social marketing re-enforced the work of conservation promoters. The latter requires close planning and coordination between conservation and aquaculture promoters. An additional factor of success is the relatively simple culture methods; at the same time, a considerable amount of support is needed to facilitate the shipping, permitting, and marketing. In the Pohnpei case, three private sector companies are the buyers of the products, but the two NGOs involved need to facilitate the communication, shipping, and logistics required to move the product from producer to buyer. One benefit of the institutional involvement is that not only is employment provided for the 19 farmers involved, but also at least 6 local extension agents. Given the high average family size, the effort was cost-effective as a relatively small amount of funding results in long-term productive activities that directly benefited at least 300 community members.

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Linking Human and Environmental Health

Food security and human health and their inner-connectivity with the environment are often overlooked in coastal programs. A principal use of coastal resources will be to supply needs for food and other necessities. In some cases, the relationship of aquaculture to human health can serve as a key entry point to broader efforts. The nexus for human health and environmental health often comes in the form of water (i.e., volume, availability, and quality). Estuaries, bays, and coastal lagoons are the connection between the coast and the watershed, and influences sanitation, food safety, and economics. Near-shore areas are also the natural habitat of thousands of species of intertidal and sub-tidal organisms, that serve as relatively easily accessible sources of food.

Of particular interest from a human health and environment perspective are the bivalve mollusks, such as clams, oysters, and scallops. Bivalves are critical food sources and are generally filter feeders, removing plankton and algae from the water column. This habit makes them excellent candidates for aquaculture since feeding is not required, but also represents a double edged sword. Contaminated bivalves are one of most dangerous types of seafood to consume. As they ingest algae from the water column, they can also accumulate potentially harmful substances and pathogens as well as from direct contact with the water. Algae can be the source of a variety of natural toxins (e.g., from red tides). Harmful algae blooms appear to be increasing and may be related to environmental changes such as nutrient enrichment from runoff and spread through ballast water and other sources of inadvertent transport.

Bivalves also accumulate human pathogens such as bacteria (e.g., *E. coli*, Salmonella) and viruses (Hepatitis A), present in water most due to contamination by human or animal wastes. Other pathogens such as the bacterial Vibrios (e.g., *Vibrio vulnificus*) are zoonotic, ubiquitous organisms in marine and brackish water. Vibrios infections can cause serious illness and death. *Vibrio* levels appear to be correlated with temperature and nutrient increases. Their occurrence as shellfish borne diseases has been on the rise. Hence, when water is contaminated by human or animal wastes, and/or subject to changes in temperature, salinity, and nutrient due to human activities or climate change, the likelihood of

contaminated bivalve consumption leading to illness or death increases. The increasing numbers of coastal residents who may have impaired immune systems due to HIV/AIDS, cancer or even old age compounds the problem.

Increasing attention is being paid to the status of bivalve populations due to recognition of the ecological services they render, such as providing benthic habitat, reducing sedimentation, and improving water quality and increasing threats. The recent discovery that ocean acidification is impacting marine invertebrates that depend on deposition of calcium carbonate for skeleton or shell development heightens the urgency to manage bivalve resources. In some areas ocean pH has dropped as much as 0.11 pH units. The Pacific West Coast of the United States is one area that appears to be particularly vulnerable (Feely et al., 2008). Coupled with habitat degradation, deteriorating water quality, and over-exploitation, improved management of molluscan populations is critical.

Recognizing the need for increased emphasis on bivalve fisheries, aquaculture, and sanitation, the SUCCESS and CRSP Programs developed an integrated approach in three estuaries on the Pacific Coasts of Nicaragua and Mexico. Since 2003, researchers from the Autonomous University of Sinaloa, CIAD (Center for Food and Development Research) and the University of Hawaii at Hilo, along with partners such as Louisiana State University, have worked in two large coastal bays in Sinaloa and Nayarit States to promote bivalve culture and institute programs of shellfish sanitation. Assessments of these large estuaries (Bahia Santa Maria, 57,909 ha and Boca de Camichin, 300 ha of oyster cultivation area) identified issues linking the utilization of bivalves and human health, as well as a number of social and political issues linked to human health and aquaculture. The goals of this work were to:

- Promote bivalve culture as an alternative livelihood for coastal fishing communities, with emphasis on utilization of native species such as the "pleasure oyster" *Crassostrea corteziensis*, rather than rely on imported seed of the Pacific Oyster, *Crassostrea gigas*. Coastal fishing communities which need additional sources of income to reduce the attraction of the drug trade or outmigration were targeted.
- In areas currently culturing bivalves (e.g., Boca de Camichin), the site of the production of 80% of *C. corteziensis*, improve food safety by developing shellfish sanitation programs implementing best management practices (BMPs) for pre- and post-harvest stages.
- Relay and depuration methods are also underway. This entails moving bivalves from a contaminated grow-out site to a certified cleaner site (relay) and to be purge of pathogens for a designated period of time (depuration). This method is commonly used in the developed world and is effective for eliminating many, although not all pathogens. A question is whether additional costs incurred can be compensated for by willingness of consumers to pay a surcharge for shellfish which is guaranteed to be uncontaminated.

Shellfish sanitation programs are predicated on periodic water quality sampling for contaminants of interest. Generally *E. coli* is used as an indicator organism that can be directly measured, easily analyzed, and whose presence indicates the presence of human or animal wastes. Typically bivalve growing areas would be monitored monthly for at least one year, with additional samples taken during periods of high rain when contamination levels might increase through runoff from the adjacent water shed.

The SUCCESS and CRSP efforts to develop shellfish sanitation programs are part of larger coastal management and fisheries management efforts. In the case of Pacific Mexico Coast, coastal management initiatives were begun by a team of partners in 1998 and

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culminated in 2000 in legal constitution of a bay management committee for Santa Maria Bay following adoption of a bay management plan in 1999 (Haws et al., 2006). The management plan called for improvements to water quality and development of alternative livelihoods, in particular, aquaculture alternatives to shrimp culture. Water quality monitoring of Santa Maria Bay and the adjacent Altata estuary, began in 2004. Altata is south of Santa Maria Bay and is the primary culture site for *C. gigas* in Sinaloa State. Boca de Camichin (Nayarit State) is a small estuary fed by the Santiago and San Pedro rivers and is part of the larger, extensive wetland area of the Marismas Nacionales (National Wetland), a nationally important area for biodiversity. Boca de Camichin has hosted culture of *C. corteziensis* for nearly 30 years. A smaller coastal inlet area, Pozo Chino, just south of Boca de Camichin is also an oyster culture site. Water quality was also monitored in both of these small estuaries for one year.

Water quality for shellfish culture is regulated by Mexican regulation NOM-031-SSA1–1993, which establishes that acceptable water quality for shellfish production based on total and fecal coliform levels which are similar to U.S. standards.

In the case of Santa Maria Bay and Altata, a year of water sampling determined that *E. coli* levels were well below the maximum accepted levels during the entire year and for nearly all sampling stations. Thus, promotion of oyster culture could safely proceed at Santa Maria Bay and that the *C. gigas* oyster growers now operating in Altata can promote their oysters as being cultured in clean water. Long-term monitoring and certification of the Altata area by the Mexican government is now under discussion. Given that community sanitation programs in Santa Maria Bay organized by UAS faculty have been underway for some years now, this added economic incentive should provide added impetus to continue with this work.

In the case of Boca de Camichin, unacceptably high *E. coli* levels were found for most of the year and at most of the stations, while for Pozo Chino, levels were within the acceptable range most of the year. Given that approximately 1,200 tons/year of oysters are produced at Boca de Camichin and transported to other coastal areas, including popular tourist destinations (e.g., Mazatlan), the food safety issue becomes one of national and international food safety.

Current work now focuses on addressing the health issues associated with water quality and the impacts on oyster trade. The contamination at Boca de Camichin is the result of effluents produced in the upper watershed, rather than simply being a result of poor local community sanitation. Since this is beyond the control of local communities and farmers, one of the only feasible, immediate options is relay and depuration of the oysters. Hence, the CRSP project is now experimenting with moving oysters produced at Boca de Camichin to Pozo Chino for depuration at that site. Additionally, the construction of a low-technology depuration plant at Boca de Camichin is also being evaluated. Certification of the shellfish growing grounds at Pozo Chino by the government is also being considered, which would help ensure the long-term status of the water quality. An offer from a major U.S. shellfish importer has been made to buy oysters from this area if certification is conducted by Mexican agencies and is approved by the U.S. Food and Drug Administation (FDA). This could allow the Boca de Camichin growers to double or triple their production.

In Nicaragua, a similar scenario occurs in the coastal lagoons and estuaries where the principal shellfish resource consists of several species of black cockles (*Anadara* spp.). Nicaragua relies on a closed season from April to July to regulate the cockle fishery. Cockles are gathered from intertidal areas near mangroves, mainly by women and children. The timing of the closed season is not based on any biological parameters but rather because demand is highest during these months. Compliance with the law was minimal as cockle

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gatherers find it hard to give up this resource for an extended period because of their reliance on it as a primary means of food and revenue, particularly by women and children. In 2004 the trials began to test the effectiveness of no-take zone to increase cockle populations (Crawford et al., 2010).

There is also a lack of shellfish sanitation programs in Nicaragua. The risk is magnified by the tradition of consuming raw cockles, usually in a cocktail with lemon juice (ceviche). Lemon juice is believed to kill bacteria, but is not effective. Water quality monitoring was therefore initiated in three Nicaragua estuaries (Aserradores, Padre Ramos, and El Realejos) with the goal of determining which areas had sufficiently good water quality that cockles could be safely consumed. The results of the first year of monitoring in three estuaries indicated that during the rainy season, nearly all areas in the estuaries exceeded acceptable levels of *E. coli*. In the dry season, *E. coli* levels were significantly lower and in some areas cockles might be safely gathered. Since the correlation between *E. coli* levels and seasonality was variable, however, setting guidelines for the cockle gatherers would be overly complex thereby limiting effectiveness. Of the three estuaries, Aserradores had the lowest levels of contamination. Since this community was involved in the co-management efforts, subsequent, more fine grained monitoring focused on this estuary. Given that at this early stage the no-take areas appear to be effective in increasing the cockle populations, water quality data could help determine future siting for the no-take zones—ideally these would be situated in the contaminated areas, thus adding to the incentive not to harvest from these areas as long as the community was aware of the risks of doing so. This would also assure that cleaner areas were reserved for harvest.

Once water quality monitoring within the Aserradores estuary is completed, it should provide the informational basis to: (1) position cockle no-take zones in the most contaminated areas leaving clean areas open to harvest, thereby optimizing both management and the extraction of safe cockles; (2) identify areas where relay and depuration can take place; (3) allow for location of a depuration plant for which funding has been secured from EU sources; and (4) open the way to certification of the Aserradores product as the only certified "clean" cockles in Central America. This added value can further encourage voluntary compliance with the co-management and support of the shellfish sanitation efforts. An additional benefit that has accrued is that the partners' initiatives have been the key to beginning work and dialogue with a community for a wide range of management and human health topics. Using of this critical issue with importance to the health and welfare of the residents has been more effective rather than starting with management issues alone, which might have little appeal to people primarily concerned about food security and safety issues.

Implementation of Best Management Practices for Aquaculture

Aquaculture Best Management Practices (BMPs) are one approach to addressing environmental and socioeconomic issues related to aquaculture. BMPs vary considerably in their range and specificity, but ideally BMPs should provide sufficient guidance that practitioners wishing to adopt them should understand both the intended outcome of an individual BMP and how to achieve this, but leave enough flexibility that an operation can be managed within the constantly varying environmental and economic parameters. BMPs may or may not include recommended quantitative standards or metrics, for example, optimal ranges for water quality parameters, or recommended ranges for feed and fertilizer application. In most cases, BMPs are intended for voluntary adoption although in some cases they may become codified into law or policies. BMPs should also be flexible enough that they can be

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modified over time as empirical experience and science allows for improvement or alteration. Aquaculture science, like all productive sciences, is still evolving and improvements can be made incrementally as the science improves.

Shrimp culture in Central America and Mexico provides some illustrative examples of how stakeholders from many sectors can work together to develop BMPs and work toward their implementation. First, BMPs cannot be effective and in fact, can actually be harmful, unless crafted using the best scientific knowledge moderated by acknowledgment of the constraints for application in the field. In the case of Central America, much of the groundwork was laid for eventual development of shrimp culture BMPs in the region by a research project sponsored by CRSP. Beginning in 1996, this project focused on a series of experiments designed to elucidate the effectiveness of various management practices (e.g., feeding, fertilization, water exchange) on farms. For example, one of these studies demonstrated that if certain conditions were met, shrimp could grow well on feeds with lower protein contents than previously thought (Teichert-Coddington & Rodriguez, 1995). Another finding was quantification of the amount of fertilizer needed by ponds with differing water sources (e.g., water taken from estuaries versus the open ocean) (Teichert-Coddington, 1995). Considerable emphasis was also put on determining the economic ramification of BMPs under Central American conditions. Targeted research of this nature is necessary in order for any aquaculture industry to determine which management practices are applicable to specific local conditions, which can vary greatly between geographic sites. Additionally, the project established a regional laboratory in Choluteca for water quality analysis conducted as part of a voluntary industry-wide water quality monitoring program. Capability for disease diagnostics was also part of the laboratory's mission. Other institutions and researchers were also actively working during the 1980s and 1990s to better define optimal management practices for the Latin American shrimp industry.

For example, the foundation for similar research and scientific capacity was also simultaneously being laid in Nicaragua at the Central American University (UCA) in Managua, as well as in the Mexican States of Sonora and Sinaloa.

The National Aquaculture Producer Associations in Honduras (ANDAH) and Nicaragua (ANDA) adopted code of practice in 1995 and 1998, respectively, with the Nicaraguan government formally adopting a national code of conduct in 2007. Additionally, both industries proactively undertook efforts designed to further the adoption of best management practices such as retaining environmental management personnel, conducting water quality monitoring and disease surveillance, developing cooperative arrangements with universities and international agencies, as well as philanthropic and related efforts designed to improve the social well-being of their workers and surrounding communities.

Although having available data, policy and producer willingness are necessary for eventual implementation of best management practices; in many cases, this is not sufficient for full scale adoption of BMPs. In particular, small scale producers may need additional support (Egna & Boyd, 1997), particularly in the form of extension and financial assistance. A specific case of an intensive effort to enable small producers to adopt BMPs took place under the SUCCESS project in Nicaragua beginning in 2004, the Nicaraguan industry is characterized by the presence of many small community-based or cooperative groups with concessions to farming areas, including some groups operated almost entirely by women. These groups most often practice shrimp farming using the most rudimentary practices, including exchanging water using the tides, stocking with wild caught post-larvae, low density stocking levels, and minimal use of feeds and fertilizers. UCA had worked with small producers with some SUCCESS since the 1990s, but the economic survival of small farmers was becoming increasingly more tenuous due to economic factors and changing

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market dynamics. The recent efforts to develop certification for shrimp farms, driven by international environmental groups, and the increasing requirements for traceability, disproportionately affect small farmers who do not have the technical skills or economic means to meet the requirements.

UCA and the SUCCESS were particularly interested in working with groups who were farming in protected areas, having been granted concessions before designation of the areas as protected areas. It is estimated that greater than 60% of shrimp farming in Nicaragua takes place in protected areas (e.g., Estero Real and Padre Ramos). Two cooperatives, FINCAMAR and AGROPESCA, farm shrimp in the protected area of the Padre Ramos estuary. Preliminary assessments conducted at the ponds indicated that production was seriously affected by issues of poor pond construction, which impeded proper farm management, lack of water quality monitoring, low rates of feeding and fertilization, lack of knowledge of the actual numbers of post-larvae stocked, and a general lack of knowledge of good management practices. Only minimal production and financial records were kept making it difficult to track production parameters and keep track of the financial status of the operation. Additionally, both groups had to borrow money to buy post-larvae and feed at the beginning of each production cycle, incurring interest costs at the end of the production cycle.

Intensive technical assistance was provided to the groups over three production cycles through formal training courses and farm visits. Coverage was provided for the entire cycle, from the initial stages of stocking the post-larvae at the correct densities, through the final harvest. Monitoring and record keeping was taught, as well as how to interpret data and apply the findings to daily management practices. After three production cycles, considerable improvement for key production parameters was achieved (e.g., stocking densities and frequent biomass calculations were used to calculate the amount of feed and fertilizer needed). Water quality was monitored on a regular basis. Survival and growth rates significantly increased. Financial records were consistently checked. At the end of the third cycle, production and profitability had improved considerably, demonstrating that consistent technical support coupled with some limited financial support can produce significant improvements for production, the environment, and financial returns.

Despite the accomplishments of the two cooperatives and their extension agents, some limitations were encountered. In particular, the FINCAMAR pond was poorly reconstructed after having been partially destroyed by Hurricane 1999 so that the pond wall height was not sufficient to allow filling of the pond to a suitable depth by tidal inflow. The shallow depth resulted in an inability to produce a suitable bloom of natural productivity in the pond (Figure 4). The pond could not be repaired without a major investment in capital and is a good example of how implementation of BMPs can be limited by resources and most often, by flaws in design or construction, which are among the most difficult and costly to resolve.

This case illustrates that successful implementation of BMPs can be achieved even by pond operators with the lowest technical and financial capabilities, if adequate levels of support are provided over the long-term so that there is adequate time to test the methods and assure their effectiveness. The intensive level of effort is justified as it ensures that both the livelihood of the poorest producers is protected, as well as providing environmental benefits. It may be that re-allocation of much of the international efforts associated with the environmental management of aquaculture would be wise if directed toward implementation rather than policy or certification efforts, which have tended to have relatively few tangible benefits except for in some cases presenting small producers with even more constraints and challenges as they struggle to maintain independence from

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Figure 4. FINCMAR cooperative shrimp pond being dried between production cycles. Note the very shallow depth of the pond, which impedes proper pond management.

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the global tendency to consolidate productive operations. Making small producers more competent and competitive helps address equity issues as well—many current certification schemes primarily benefit large producers associated with processing plants since it is the latter that tend to benefit from certification. One caution may be the observation that farm design and pond construction often represent the main obstacle to full implementation of BMPs and resolving management issues relying on infrastructure adaptation for improved management can be expensive.

Alternatives to High-Value, Illegal Extraction

The international drug trade is widely recognized as a major threat to human health and international security. A neglected dimension to this scenario is the environmental impacts associated with the production, processing, and transport of illegal drugs. The problem appears to be increasing in some areas and the nature of the impacts can be wide ranging. Critical habitats are usually invaded and converted to drug cultivation. For example, it is estimated that 2.5 million acres of U.S. public forest lands have required eradication of illegal marijuana cultivation since 1997. In addition to the initial habitat destruction, eradication requires physical or chemical means of destroying the crop, with accompanying impacts. Processing and producing drugs also produces impacts; ever pound of methamphetamine production is estimated to produce 5–6 pounds of toxic by-products (DEA, 2005). Colombia, which supplies 80% of the world's cocaine, mainly produced in rainforest areas, provides another extreme example of the environmental havoc a significant national drug trade can incur. Impacts include habitat alteration, toxic waste, killing of wildlife, and funding of terrorist groups; the latter results in increased environmental damage. Colombian terrorist groups linked to the drug trade attacked one of the major oil pipelines over 262 times between 2001–2004, causing oil spills in forest areas (Steinhausler et al., 2008; GAO, 2005). The impacts of the drug trade extend into the realm of wildlife smuggling. Illegal trade in wildlife, which is believed to be second only to drugs in terms of international illegal smuggling, is often conducted by the same groups that utilize the same

distribution channels (Roberts, 1996). The presence of drug operations puts many areas off limits to conservation workers and law enforcement who may need to enter wilderness and coastal areas (Aldhous, 2006), thus eliminating the possibility of putting these areas under effective management.

Some countries are heavily reliant on the drug trade as a major component of their Gross National Product (GNP) (Afghanistan >50%, Bolivia 70%) (Betram et al., 1996). Production appears to be increasing, for example in Afghanistan (2007) with opium acreage increasing 17% (UNODC, 2008). Often large portions of a population are reliant on drug production. As most drugs have an agricultural source (opium poppy, coca leaves, etc.), poor agriculturists are likely to be involved. Coastal residents are also drawn-in due to the location of fertile agricultural areas in coastal areas and because coasts are natural routes for drug transport. Bays, lagoons, and islands make natural hiding places and transfer points for shipments. Poor fishers are vulnerable to being co-opted or coerced into participation and possess boats and maritime skills needed to move drugs. Many coastal areas suffer from lack of governance and enforcement; coupled with isolated and poor communities, coastal communities are prone to being enmeshed in the drug trade. Today nearly the entire Pacific and Caribbean coasts of Latin America are areas utilized and controlled by drug cartels.

Strategies to address the international drug trade involve multi-pronged solutions including eradication, education, security, and alternative development. Given that the economic driver is so key to growth of the drug trade, small scale alternative livelihoods with high returns are needed as options for stakeholders. Development of alternatives often fails because in addition to the usual host of complexities presented by the introduction of any economic development scheme, the returns from participation in the drug trade are often high enough that few crops or jobs can compete. Efforts to divert farmers to commodity crops will fail. High value aquaculture products that have good probability of technical success may present one alternative. For example, in Peru, the culture of *Arapaima* as promoted by the CRSP project, has been recognized as a potential high-value alternative crop in areas where there is heavy reliance on cultivation of coca leaves (Chauvin, 2007; Mueller 2005). USAID provided $250,000 to support *Arapaima* culture in the Amazon-Ucayali region with the goal of growing "endangered fish rather than endangering drugs." The high value of paiche ($5.00/kilogram) compared to $2.00/kilogram for coca leaves offer an attractive alternative. In Mexico, the AquaFish CRSP Human Health and Aquaculture project conducted a study of the interconnectivity of human and environmental health for Sinaloa and Nayarit States, two areas heavily impacted by the Mexico–U.S. drug trade. Offering alternatives for coastal residents and fishers was considered a priority in this area, not only as an alternative to the drug trade, but also as a way to stem high rates of outmigration to the United States and to combat other social issues such as poverty and social marginalization. Even lower-value aquaculture products such as oysters can offer an attractive alternative. High-value shellfish products (oysters, pearls, pen shells) or finfish (tuna, puffer fish) may be options for the Pacific coast of Mexico and appeal to precisely the coastal residents (fishers and their families) that may be targeted by the drug cartels for inclusion in the trade, and this approach remains to be tested.

Principles for Use of Aquaculture Options for Natural Resources Management

Based on these examples, what are the criteria for the decision to use aquaculture as an entry point to coastal management? Among the considerations might be:

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- In cases where fisheries management is an issue and stock enhancement can contribute by increasing the adult breeding populations or augmenting existing catches.
- Aquaculture-based stock enhancement can serve as a short-term or stop-gap measure to stem decreases in wild populations until such time as longer-term solutions such as effective management or habitat restoration can take place.
- Aquaculture can be used to maintain genetically heterogeneous stocks or rare populations within a species.
- Where spat (bivalve) collection can be utilized to increase recruitment to the overall population (wild plus farmed population), thereby sparing wild animals from collection for aquaculture purposes. Caution should be taken to use methods which do not present unacceptable practices. This strategy will be most effective when wild recruitment is limited by habit availability or competition for habitat.
- The use of wild juvenile fish as a source of stock may be acceptable if it relieves pressure on the wild stocks in some way. The value of a captured, cultured organism may be higher than it would be if left in the wild for capture later. In some cases, this practice may benefit a different segment of the population than the fishers, which also must be considered. The potential benefits and impacts must be weighed within the context of fisheries management principals.
- Breeding captive populations increase wild populations (e.g., farmed oysters act as breeding aggregations). The affect on the genetics of the overall population must be considered. For example, a pearl farm with oysters collected from the wild would not be problematic, but one stocked with hatchery-produced animals could represent an inbred population.
- If the species of concern is threatened through overexploitation or loss of critical habitat, development for culture purposes can provide an economic incentive to protect the species and its habitats. Additional precautions may need to be put into place to prevent unforeseen impacts from the aquaculture activities. In some cases, increasing the numbers of a particular species throughout the world is a hedge against extinction—the domestic chicken will most likely never become extinct. Equally, the millions of fragments of coral in aquaria represent a genetic resource that could be useful in cases of widespread bleaching that may affect particularly rare species.
- Aquaculture can provide direct protection of habitats through exclusion of harmful activities (e.g., bomb fishing) or where concerned farmers can help control unwanted activities. This also occurs when a particular habitat is required for successful culture.
- Ponds used for aquaculture can serve secondary purposes such as water catchment, artificial wetlands, watering sites for birds and wildlife, and as flood control.
- Alternative livelihoods can engage local inhabitants in management activities or provide alternatives to unsustainable activities. Investment in livelihoods demonstrates commitment and concern about quality of life issues that are generally foremost in the minds of most stakeholders, particularly the poor. Providing such alternates as an explicit *quid pro quo* exchange with stakeholders may be effective. In other cases, livelihood efforts coupled simultaneously with natural resources management develops ways to sustainably utilize local sources of biodiversity while beginning dialogue and capacity building based on tangible, locally relevant issues.
- Aquaculture activities can target stakeholder segments that might otherwise be difficult to engage in coastal management activities or neglected (e.g., women and youth).
- Aquaculture can be an alternative to more destructive, highly lucrative, and attractive options such as participation in the drug or wildlife smuggling trades.

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Conclusion

Examples of successful use of aquaculture as a strategic tool and investment in NRM and ICM programs are increasing. Methodologies for doing so are less well developed, and are not fully articulated nor rigorously tested on a global basis despite the growing number of examples. More work in this area will no doubt be fruitful.

When considering aquaculture as an activity to include in coastal management or NRM programs, caution should be exercised to assess both its feasibility and potential impacts. Clearly little is gained if aquaculture causes greater impacts than those practitioners wish to avoid. Tradeoffs need to be considered and accepted. Economic development is necessary, weighing locally available options is necessary, and establishing rational criteria for making such choices must be approached rationally. Care is needed to evaluate if sufficient technical assistance is available to make aquaculture (or any other form of economic development) an effective option. Failed aquaculture projects do little to further the main management agenda or help establish the credibility of the promoters. The world is littered with examples of failed small scale aquaculture projects. Aquaculture is a multifaceted activity depending on a wide range of natural resources, thus representing an opportunity to engage in integrated management of the same resources, but also presents risks if there is insufficient planning, assessment, and technical capability. Successfully integrating aquaculture and NRM will require closer cooperation between specialists. Both fields are prone to neglecting market forces and economics—teaming with experts in these areas for more comprehensive and effective assessment and planning before engagement is key. Timing is an important factor as there is a tendency to underestimate the time required to establish effective management or viable aquaculture endeavors. Funders may be reluctant to provide long-term funding and have a tendency to prefer short-term gains over long-term growth. Funders and practitioners need to have realistic goals and time frames for efforts that couple aquaculture and NRM efforts.

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