Integrating marine conservation and sustainable development: Community-based aquaculture of marine aquarium fish

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Introduction

Conservation of marine biodiversity depends on the successful resolution of development challenges. Exploitation of marine resources increases and poverty is exacerbated as human populations grow. Nowhere is this clearer than in the subsistence fishing communities of tropical Indo-Pacific countries. Increasing demand for marine resources and the gap between supply and demand have led to the rapid depletion of conventional food fisheries (Pauly 1997). Poverty, a lack of alternative livelihoods and, in some cases, greed, drive fishers to exploit stocks to the point of growth and recruitment overfishing (Hall 1999). Fishing continues despite consequent declines in catch because fishing is typically the occupation of last resort.

Subsistence fishers find themselves in a downward spiral of resource degradation and increasing poverty as overfishing develops. These fishers tend to be socially and politically marginalised because of rural remoteness, low levels of education, and large numbers of dependants in each family. Their communities often lack the organisational and decision-making skills that are necessary for effective resource management. As overexploitation continues, effort shifts to species that previously supported limited levels of exploitation (Orensanz et al. 1998; McManus et al. 2000). Such shifts are problematic where they involve heavy exploitation of species poorly suited to fishing pressure, such as those with low growth rates or low fecundity (e.g. seahorses; Lourie et al. 1999). The costs of overfishing are thus two fold: marine biodiversity decreases as fishers sequentially exhaust resources and destroy the resource base; and poverty and marginalisation increase.

Alternatives to fishing as a primary livelihood are central to meeting development goals in fishing communities. However, alternative livelihoods cannot be considered in isolation if conservation as well as development goals are to be met. The high demand for marine resources suggests that as supply diminishes, prices are likely to rise. Eventually, fishery-derived income may become sufficiently high to entice fishers engaged in alternative livelihoods to re-enter the fishery. High prices will motivate such re-entry even if the resources are substantially depleted. Thus, the value of alternative livelihoods in promoting the conservation of biodiversity must be evaluated carefully.

Alternatives to fishing that actively reduce the demand for wild-caught marine resources are more likely to meet conservation goals than alternatives that only generate income. Marine aquaculture (mariculture) is a livelihood alternative to fishing with great potential to integrate conservation and sustainable development goals in developing countries. Aquaculture's conservation advantage over other alternative livelihoods is that it can both provide sustainable income and address ongoing market demand by creating high value alternatives to wild-caught animals.

Conservation and community-based aquaculture of marine ornamental fish

Marine ornamental fish, that is, the colourful fish collected for the marine aquarium trade, present an excellent opportunity for community-based, conservation-focused aquaculture initiatives in developing countries. Community-based aquaculture that has the effect of reducing exploitation of wild populations of marine ornamental fish (MOF) provides a number of direct conservation benefits, as discussed below.

First, most MOF come from coral reefs, and the high exploitation rates for some species have caused concern over their conservation status (Edwards and Shepherd 1992; Hawkins et al. 2000; Tissot and Hallanger 2003). Current estimates indicate that between 10 and 35 million fish are traded as marine ornamentals annually (Baquero 1999; Wood 2001), with more than a thousand species

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involved (Wood 2001; Wabnitz et al. 2003). However, the large number of species traded masks the regional impact of the marine ornamental trade on highly sought-after species.

The tropical Indo-Pacific region, with its high marine biodiversity, is the major supply centre for MOF (Baquero 1999; Wood 2001). Indonesia and the Philippines, for example, supply more than 85% of the global trade (Baquero 1999; Wood 2001). The bulk of the trade comprises a relatively small number of species, with the top 10 fish species traded accounting for approximately 36% of the overall volume traded (Wabnitz et al. 2003). In Hawaii, for example, 11 species accounted for 90% of the marine aquarium fish collected in 1995, and declines have been observed in the sizes of populations of the more highly sought after species (Tissot and Hallanger 2003).

Size selectivity and sex selectivity in the marine ornamentals trade are also conservation concerns. For many angelfish species, for example, juveniles are more desirable than adults due to their coloration patterns and their more suitable size for home aquaria. As a result, they are a primary target of the fishery. This practice is of concern as it may eventually lead to recruitment overfishing (Pauly 1988). Sex-selective fishing pressure in species that display sexual dichromatism/dimorphism is also of concern as it may lead to declines in reproductive output. By reducing the exploitation of vulnerable marine ornamental fish species, aquaculture could relieve much of the conservation concern over their status in the wild.

Second, community-based culturing of MOF promotes ecosystem stewardship. Environmental degradation poses threats to MOF as their coral reef habitats are among the most threatened in the world as a result of destructive fishing methods, agricultural runoff, coastal urbanisation and myriad other threats (Norse 1993; Bryant et al. 1998). Most MOF come from oligotrophic coral reef waters and only thrive when water quality is high. Culturing them also requires high water quality (Job et al. 1997). Community-based aquaculture will, therefore, place a measurable premium on maintaining high coastal water quality, as deteriorating water quality will be directly detrimental to aquaculture efforts. Linking successful marine ornamental aquaculture with the prevention of water quality deterioration and ecosystem damage will achieve far-reaching benefits in coastal communities.

Third, impacts on marine productivity may be minimised by culturing marine ornamentals. The majority of MOF are herbivorous or planktivorous. In contrast to piscivores, the dietary requirements for herbivorous and planktivorous species are such that culture operations for the latter have more potential for sustainability, and will lead to less pressure on feed fish (Naylor et al. 2000). Aquaculture of high value food fish species fed on piscivorous diets results in net costs to the marine food webs supporting this culturing, as the amount of fish consumed as feed substantially outweighs the amount produced in cultured biomass (Naylor et al. 2000). There are, for example, concerns over the use of so-called "trash fish" for grouper aquaculture in the region. MOF aquaculture, in comparison, would be far more ecologically sustainable.

Fourth, community-based culturing of marine ornamentals promotes global conservation objectives by respecting the spirit of the Convention on Biological Diversity (CBD). The CBD recognises that the commercial exploitation of valuable biological resources must benefit source countries and the communities that depend on these resources. In the absence of such benefits, there is little incentive for source communities to conserve their biodiversity in the face of overwhelming poverty. Moreover, resource users (e.g. fishers) will continue to exploit their biological resources in the absence of alternative livelihoods and in the presence of continued market demand. Community-based marine ornamental aquaculture provides an opportunity to culture species within their natural distributions, particularly in the Indo-Pacific region where the greatest biodiversity of MOF is found.

Fifth, aquaculture of marine ornamental fish may be more effective in ultimately conserving marine resources than regulations that restrict exploitation. Regulations are likely to be imposed if the trade is not made sustainable. Legal restrictions on the collection of MOF in some areas have already been imposed by management agencies within source countries such as Australia, Indonesia and the Philippines. Moreover, the United States, the single largest market for marine ornamentals, has considered restrictions at the import end of the trade (CRTF 2000). In the absence of alternative livelihoods, restrictions on the collection or trade of target species often simply lead to the targeting of new species that are no better able to withstand exploitation. This is exacerbated by the marine ornamentals industry encouraging new and different species to enter the trade, and a lack of understanding of the biology and abundance of many of the species being exploited (e.g. Kolm and Berglund 2003). Community-based aquaculture would break the vicious cycle of shifting from resource to resource, as well as meet market demand.

Sustainable development and community-based marine ornamental aquaculture

Community-based marine ornamental fish aquaculture must be economically viable if it is to contribute to the sustainable development of coastal communities. The likelihood of MOF culturing being commercially viable is high. The global trade in marine ornamentals is estimated to be worth between 200 and 330 million US dollars (USD) per year at the retail level (Baquero 1999; Wabnitz et al. 2003). By unit weight, MOF are worth on average USD 247 kg^{-1}, a value substantially greater than that for fish species exploited in capture fisheries or aquaculture generally (Table 1). The value of the trade is especially great in some countries. In the Maldives, for example, MOF were worth almost USD 500 kg^{-1} in 2000 (Wabnitz et al. 2003). As supplies of marine ornamentals become ever more constrained due to high exploitation rates and the use of destructive fishing techniques, the market value for cultured species can only increase with time, with greater benefits to those communities producing cultured individuals.

Marine ornamental fish are valuable at young ages and small sizes, which further increases the economic potential of MOF aquaculture. Juveniles and subadults are preferred for many species (Wabnitz et al. 2003). Juvenile blue tangs (*Paracanthurus hepatus*), for example, are highly sought after even at sizes as small as 2.5 to 5 cm in (total) length, and can command between USD 2.50 and 4.00 each at this size (freight-on-board (FOB) prices from Indonesia, S. Job unpublished data). Juveniles of species such at the pomacanthids (angelfish) can be even more valuable (USD 12–14 per fish FOB from Bali). The high value at young age is a key advantage of marine ornamentals aquaculture as the time taken to reach market size is short in comparison to most food fish species. Many MOF species reach market size within 4 to 6 months. This reduces the risk inherent in any community-based aquaculture initiative from events such as storms, theft, vandalism, and so forth. Furthermore, the short time to market facilitates batch culturing by local communities. This allows culturing effort to be intensified during those times of the year when livelihoods such as wild capture fishing are less productive.

The small size of most marine ornamental fish species increases the feasibility of developing small-scale aquaculture operations in coastal communities. Effective integration of all levels of the culturing operation, from hatchery production to grow-out to marketing, is possible even in small-scale MOF operations as space and infrastructure requirements are much smaller than for most high value food fish species. The costs involved in establishing and operating aquarium fish aquaculture operations are, therefore, also substantially smaller. The reduced space, infrastructure and cost requirements facilitate local communities engaging in marine aquarium fish aquaculture as an alternative livelihood.

Challenges

The first key challenge is to develop aquaculture techniques that are suitable for coastal communities in the region. Current aquaculture production of MOF is largely based in developed countries such as the United States and the United Kingdom. The use of expensive high-technology methods and equipment in these operations restricts their applicability to fishing communities in tropical Indo-Pacific nations. The focus in the region should be on developing techniques that meet the needs of

Table 1. Global annual volumes landed, total annual economic value and price per kilogram for the capture fisheries, aquaculture and ornamental fish sectors. Data sources and calculations indicated by footnote. Marine capture and aquaculture values are based on prices received by fishers and fish farmers. Marine ornamentals values are based on source country export prices (FOB).

Sector	Volume landed (metric tons)	Total value (million USD)	Unit value (USD kg^{-1})
Capture fisheries	93,021,000[2]	80,123[2]	0.86
Aquaculture	33,213,429[2]	48,229[2]	1.46
Marine ornamental fish	80[3]	20[4]	246.88

2. Estimates for capture fisheries and aquaculture are based on United Nations FAO data averaged from 1996 to 2002, and include all aquatic animals. Source: http://www.fao.org
3. The landings estimates of 80 metric tons (mt) and 12.5 million fish are based on Baquero's (1999) ranges of 60 to 100 mt and 10 to 15 million fish; these correspond to an average weight of 6.4 grams $fish^{-1}$.
4. The mean price per fish was estimated from data presented in Wood (2001) as USD 1.58 $fish^{-1}$. This was multiplied by the number of fish traded (12.5 million fish) to obtain an estimate of total value.

local fishing communities and that address their constraints. The use of high-technology methods in more developed countries does not imply that such techniques are absolutely necessary. Indeed, much of the need for high-technology equipment is a result of culturing tropical coral reef fish in non-tropical locations. Adverse climatic conditions in these places and distance from clean seawater necessitate the use of more advanced equipment. Coastal communities in the region, in contrast, have favourable climatic conditions for much of the year and have access to high quality seawater in many places. With the development of suitable techniques, MOF aquaculture could provide fishers in the region with a much-needed alternative livelihood option.

The second challenge for developing countries is to identify species that are economically viable in their circumstances. The value of the various aquarium fish species varies from country to country as a result of factors such as differences in air-freight costs to the major markets, perceived quality of fish and species diversity and abundance. For example, fish from countries with more expensive freight costs (and generally also more limited air transport links) may have to be sold at lower prices to remain competitive with other countries that export the same species but have lower transport costs (everything else being equal). Thus, the economic viability of culturing various species may vary from country to country. Countries with higher freight costs, for example, may have to focus largely on high value species (Bell and Gervis 1999), while countries with lower freight costs may be able to viably produce a broader range of species of moderate to high value.

Species that are of high conservation concern should also be a priority focus as a complementary mechanism to restrictions on collection and/or trade. This is sensible from an economic viability perspective, as species that are of conservation concern are likely to be those for which overexploitation has led to reduced supply or that are naturally rare. Such species frequently command high prices. Furthermore, such species are more likely to come under trade restrictions and/or monitoring (e.g. seahorses), which may further restrict supply of wild-caught animals. Judicious species selection is key to establishing an economically and ecologically sustainable marine ornamental fish aquaculture industry in the region.

The third challenge is to ensure that participation in culturing activities is open to fishers rather than restricted to local elites. This is challenging as fishers are often among the most marginalised within already marginalised communities. They seldom own land or have access to capital or other resources that would facilitate participation in culturing activities. Community-based culturing initiatives must be designed to facilitate the fishers' involvement by developing protocols that accommodate the constraints within which they function. Technical training, the development of village-based cooperatives, and creative start-up support may be necessary to facilitate the shift of fishers to aquaculture.

The fourth challenge is to restructure the aquarium fish trade in the region to ensure the equitable distribution of benefits derived from culturing. In developed countries such as Australia and the US, aquarium fish collectors generally export their fish themselves or, at worst, supply fish directly to exporters or in-country wholesalers. In contrast, the aquarium trade in most developing countries in the region consists of multiple levels, each level taking a share of the profit (Wood 2001). Typically, fishers receive the smallest profit share, even considering their lower costs and cost of living. Such whittling away of profits by each level reduces the value of each fish to the fisher. Unless this imbalance is addressed, fishers and aquaculturists will remain impoverished. The development of village-based co-operatives may facilitate fishers and aquaculturists obtaining fairer prices for their fish (Rubec et al. 2001). Such cooperatives for fishers are already being developed in a few areas in the region, and the development of similar initiatives amongst aquaculturists should be encouraged and facilitated as the industry develops.

Future directions

Marine ornamental fish aquaculture holds great promise as an alternative livelihood option for fishers in the region. Full-cycle aquaculture currently accounts for only approximately 1 per cent of the global trade in marine aquarium fish (Wood 2001). Approximately forty species are routinely produced commercially. These species are primarily anemonefish, dottybacks, gobies and seahorses. A broader range of species has been bred by both commercial facilities and research institutions, but they are not routinely produced yet (e.g. Job et al. 1997; Job et al. 2002). Species that are produced commercially almost invariably are demersal egg layers or mouth/pouch brooders, have relatively large larvae, and can be bred in small tanks.

Techniques have, however, recently been developed for a number of pelagic spawning species with small larvae, such as the angelfish. The flame angelfish, *Centropyge loriculus*, for example, has recently been produced commercially in Hawaii (Baensch 2002; Baensch 2003). This species has long been one of the holy grails of MOF aquaculture due to its high value and high demand. The successful production of a copepod species as the first food has enabled key breakthroughs in the rearing of this and other angelfish species. Provision of an appropriate first food has long been a major constraint in the aquaculture of MOF species (e.g. Nagano et al. 2000). The recent success with angelfish species is exciting, as the same techniques should allow a broad range of hitherto difficult or "impossible" species to be produced commercially.

The development of a viable marine ornamental fish aquaculture industry in the region needs to be encouraged. Most of the current full-cycle commercial production is based in developed countries outside the region. Existing efforts within the region have focused primarily on collecting post-larval coral reef fish from the wild and then rearing them to market size (Hair and Doherty 2003; Durville et al. 2003). Full-cycle aquaculture production within the region would have some significant competitive advantages compared to countries such as the US and UK. Almost all the costs involved in full-cycle MOF aquaculture are substantially lower in the region. Furthermore, the ideal climatic conditions and access to clean tropical seawater makes the use of low-cost extensive techniques possible (Rubec et al. 2001). The most significant disadvantages are the comparatively high transport costs to the major markets (Bell and Gervis 1999), and the high cost of imported materials and equipment. The high value of most aquarium fish species and the presence of existing trade networks, however, offset the high cost of transport and imported materials. Full-cycle aquaculture would complement techniques based on the collection of post-larval fish by providing a reliable production base. Developing a viable MOF aquaculture industry in the region will promote the conservation of marine biodiversity while facilitating sustainable development in coastal communities.

Tank-bred aquarium fish are in high demand by hobbyists in the major markets. Tank-bred marine aquarium fish in the United States, for example, currently command prices 25% higher than those for equivalent wild-caught fish (S. Job and J. Meeuwig unpublished data). This is primarily a result of successful long-term efforts by commercial producers to promote tank-bred fish as both "conservation-friendly" and better suited to the aquarium environment than wild-caught fish. Early challenges with poor colouration and physical anomalies have been overcome through the development of better culturing techniques. As a result, tank-bred fish are now generally recognised to be of superior quality to wild-caught fish. Increased awareness of coral reef degradation issues amongst hobbyists will continue to ensure that tank-bred fish remain in high demand and command a premium price.

Preventing overexploitation remains a central issue in global coral reef conservation efforts. The presence of high numbers of fishers in the region in the face of declining marine resources will ensure that levels of fishing effort remain high unless alternative livelihoods are available. Marine ornamental fish aquaculture will provide another much-needed livelihood option for fishers in the region. Its development, however, needs to be guided carefully in order to ensure that fishers indeed benefit from shifting to aquaculture. This requires a multifaceted approach that combines the development of suitable techniques with socioeconomic initiatives such as the development of community-based cooperatives, and sound business strategies such as the "eco-labelling" of cultured fish.

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