

Approaches to Stock Enhancement in Mangrove-Associated Crab Fisheries

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Over the last decade, hatchery production of mud crabs has become technically and economically more feasible, enabling evaluation of the potential effectiveness of hatchery release in fisheries enhancement. The high growth rates and limited movement of released crabs mean that fisheries' yields in isolated mangrove systems with restricted recruitment can be enhanced within a few months. Thus, a release program may be an effective strategy for short-term enhancement in carefully selected specific areas. To date, results are very promising, with recovery rates up to 50% and increases in fisheries' yield up to 46% over baseline catches. In contrast, mark-recapture studies in more open mangrove system populations show that recruitment success and subsequent stock abundance may be largely determined by habitat availability. For these populations, restoration of lost or degraded mangrove areas has been shown to be effective in promoting stock recovery through natural recruitment, with replanted mangroves supporting fisheries of equivalent economic value to that of natural mangroves, though it may take some years to reach these levels. Thus, a balanced approach to stock management could integrate both hatchery-release and habitat restoration programs, depending on local conditions and over different time scales, with parallel co-management to support effectiveness.

Keywords mangrove, mud crabs, *Scylla*, enhancement, hatchery, replanting

INTRODUCTION

It is generally recognized that stock enhancement by hatchery releases should be evaluated in a multidisciplinary approach including baseline studies of population dynamics and genetics of wild stocks, habitat-stock interactions, fitness of hatchery-produced juveniles, and monitoring of post-release success (Blankenship and Leber, 1995; Bell and Gervis, 1999; Blaxter, 2000; Bell et al., 2005; Le Vay et al., 2008a). Thus, preliminary assessment of enhancement of small-scale mangrove-associated crab fisheries has followed such an integrated approach while, in parallel, alternative habitat management strategies that may be more cost-effective have also been considered. This is particu-

larly relevant in mangrove-associated species where habitat loss may be a major contributor to stock decline. This article summarizes recent progress in the development of stock enhancement for *Scylla* spp. and reviews evidence that stock management could integrate either hatchery-release or habitat restoration over shorter and longer time scales, respectively, depending on local conditions.

The mud crabs, *Scylla* spp. are a group of 4 commercially-important portunid species that are found in intertidal and subtidal sheltered soft-sediment habitats, particularly mangroves, throughout the Indo-Pacific region (Macnae, 1968; Keenan et al., 1998). In much of Southeast Asia, mud crabs are a valuable source of income for coastal communities (Arriola, 1940; Macintosh et al., 1993; Overton and Macintosh, 1997, 2002; Le Vay, 2001; Walton et al., 2006a; Walton et al., 2006b). Unlike in Australia and South Africa, where mature and egg-bearing mud crabs are protected, in most Southeast Asian countries no

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such regulation exists, and mud crabs have traditionally been exploited in fisheries that target all size classes of crabs: seed crabs for pond culture, adult and sub-adult for fattening, for the soft-shelled industry, or for food (Overton et al., 1997; Le Vay, 2001). Mud crab fisheries employ gear such as gill nets, trawls, and traps, while in some areas handpicking in the intertidal is common, sometimes with use of hooks and axes. The most frequently used gear are the baited traps or pots which are common in Australia (Lee, 1992), Indonesia (Cholik and Hanafi, 1992), Philippines (Arriola 1940; Walton et al., 2006a), Thailand (Tookwinas et al., 1992), Bangladesh (Khan and Alam, 1992), Sri Lanka (Jayamanne, 1992), and South Africa (Robertson, 1989). The relatively high value catch, simple fishing gear, and accessibility of intertidal fisheries has led to high levels of fishing pressure (Kosuge, 2001). Varying levels of overfishing or reduced landings have been reported in Australia (Mounsey, 1989), Sri Lanka (Jayamanne, 1992), Thailand (Tiensongrusmee and Pratoomchat, 1999), and throughout Southeast Asia (Overton and Macintosh, 1997), as both national and international markets have developed (Liong, 1995), with resulting decreases in both size and abundance of mud crabs in many fisheries (Angell, 1992; Overton and Macintosh, 1997; Kosuge, 2001). Mud crabs are closely associated with mangrove habitats, and thus populations may be subject to the combined pressures of over-exploitation and habitat loss. In particular, in Southeast Asia, large areas of mangrove have been lost due to over-exploitation and clearance for agriculture, human settlements, and aquaculture (Primavera, 2000). The decline in mangroves has been accompanied by reductions in productivity, biodiversity, and the socioeconomic value of artisanal and inshore fisheries (Costanza et al., 1997; Ronnback et al., 1999).

In the late 1990s, as interest in aquaculture of mud crabs was increasing throughout Asia, commercial-scale hatchery production of *S. serrata* was not yet economically viable (Mann et al., 1999), so that all forms of mud crab culture depended on collection of natural seed (Overton and Macintosh, 1997). Lack of technology for hatchery production of juveniles has not only hindered development of the mud crab grow-out industry but has also meant that unregulated fishing in many areas targets all life stages from first recruits to mature females (Le Vay et al., 2001; Walton et al., 2006b). However, recent developments suggest that commercial hatcheries will be operational in the near future (Fushimi and Watanabe, 1999; Mann et al., 1999; Qunitio et al., 2002; Qunitio and Parado-Estepa, 2003; Wang et al., 2005), and the technology to produce juveniles in hatcheries may lessen fishing pressure on wild stocks by decreasing demand on juveniles for use in aquaculture. However, as human populations continue to grow, particularly in coastal rural areas, the need to derive income from fishing is unlikely to be lessened by the increase in aquaculture production, which mainly benefits pond owners. Thus, harvesting wild populations will continue, especially by low-income fishers who mainly depend on fishing for their livelihood.

Whereas the ability to produce juveniles in the hatchery is not in itself sufficient rationale to undertake restocking or stock

enhancement efforts (Bell and Nash, 2004), the development of technology for hatchery production of mud crabs opens up the possibility of improvement of small-scale fisheries through release of hatchery-reared juveniles (Le Vay et al., 2001). The rapid growth rates and the limited post-recruitment movement of mangrove-associated species, such as the mud crabs (Hyland et al., 1984; Lebata, 2006; Le Vay et al., 2007b) have made stock enhancement an attractive option for localized fisheries enhancement due to the potential for high recapture rates in a restricted area (Le Vay, 2001).

Selection of Species for Stock Enhancement

Assessment of the potential for stock enhancement of mud crab species in Southeast Asia was initially hampered by the limited amount of species-specific biological and ecological information available. This was compounded by reservations about the identity of species studied before the revision of the genus by Keenan et al. (1998). Thus, before stock enhancement trials, long-term monitoring of fisheries' landings was established in a range of selected mangrove habitats in the Mekong Delta, Vietnam, and Panay, Philippines. These studies provided estimates of fishery yields and patterns of recruitment for the 2 more abundant species in these areas, *S. olivacea* and *S. paramamosain*, and more limited information on *S. serrata* and *S. tranquebarica* (Le Vay et al., 2001; Ut, 2002; Lebata, 2006; Walton et al., 2006a; Walton et al., 2006b). A series of mark-recapture studies collected more detailed data on abundance, movement, growth, and mortality in natural crab stocks (Ut, 2002; Lebata, 2006; Le Vay et al., 2007a). Estimates of growth rates in the wild have been very encouraging in terms of restocking and stock enhancement, but appear to vary among species. In *S. paramamosain*, mean growth rates of approximately 2 cm carapace width month⁻¹ indicate that wild crabs will attain reproductive maturity (median size 10.2 cm carapace width) after 5 months from recruitment (Ut, 2002; Walton et al., 2006b; Le Vay et al., 2007b), while growth in wild *S. olivacea* appears to be much slower at around 1 cm month⁻¹, with maturity at 8.8 cm CW, (Moser et al., 2002; Lebata, 2006; Walton, 2006). The same studies confirm that *S. olivacea* is less free-ranging, with the majority of the population typically occupying burrows within the mangrove (Estampador, 1949; Oshiro, 1991; Moser et al., 2002; Lebata, 2006; Walton et al., 2006a), suggesting that despite slower growth rates, this species may be more suitable for stock enhancement.

Development of Hatchery Production for Mud Crabs

Clearly the cost-effective production of high-quality juveniles is a prerequisite of any release program, and until recently this has presented a bottle-neck in stock enhancement for the *Scylla* spp. The culture of mud crab zoea to crab instar started in the early 1970s but was mostly confined in the laboratory (Brick, 1974; Hill, 1974; Heasman and Fielder, 1983). Partly due to the problems in the shrimp industry, coupled with declining mud

crab fisheries in Southeast Asia (Le Vay, 2001), interest in mud crab seed production started to peak in the 1990s. A series of research studies was conducted to further investigate the biology (Robertson and Kruger, 1994; Li et al., 1999; Zeng and Li, 1999), nutrition (Williams et al., 1999; Millamena and Qunitio, 2000), diseases (Kaji et al., 1991; Hamasaki and Hatai, 1993b; Hamasaki and Hatai, 1993a; Li et al., 1998; Chen et al., 2000; Lavilla-Pitogo et al., 2001), and live-food production methods (Parado-Esteva and Qunitio, 1999; Williams et al., 1999; Hamasaki et al., 2002). Application of the results of these tests led to successful production of crab instars in the Philippines, Japan, Vietnam, and Australia in larger tanks, with survival rates of up to 15% from zoea to crab instar (Fielder and Allan, 2003). More recent developments include improvement of broodstock and larval nutrition (Alava et al., 2007; Nghia et al., 2007a; Qunitio et al., 2007); zoo-techniques (Nghia et al., 2007b), health management (de Pedro et al., 2007; Lavilla-Pitogo et al., 2008); nursery production (Mann et al., 2007; Rodriguez et al., 2007; Ut et al., 2007b). Future viability of hatchery production for both aquaculture and large-scale stock enhancement will depend on further refinement of larviculture technology to ensure economic viability. However, hatchery production is now sufficiently advanced to support experimental releases and localized enhancement programs.

Selection of Release Sites

Abundance of mud crabs in mangroves can vary considerably among species and study sites, from high values of 1100 ha⁻¹ for *S. paramamosain* in the Mekong Delta (Le Vay et al., 2007b) and 1228 ha⁻¹ for *S. serrata* in East Africa (Barnes et al., 2002), to lower values of 14–38 ha⁻¹ for *S. olivacea* in Thailand (Moser et al., 2005). Comparison of *S. olivacea* abundance at closely adjacent sites on Panay Island in the Philippines, using mark-recapture studies, was used to support identification of an appropriate area for experimental stock enhancement trials (Lebata, 2006; Walton et al., 2006a). Mapping of the site finally selected at Bugtong-Bato, Aklan, indicated a 70-ha area mangrove, of which approximately 50 ha of natural mangroves were identified as suitable mud crab habitat (Lebata, 2006; Langdown, 2005). A single narrow entrance from the sea with no mangroves present on open shoreline suggested potential recruitment limitation. This was also indicated by baseline mud crab fisheries yields ha⁻¹ that were lower than at comparable sites elsewhere (Lebata et al., 2007) and estimated abundance of only 14–34 crabs ha⁻¹ compared to 38–138 crabs ha⁻¹ in a nearby fringing replanted mangrove system (Walton et al., 2006a). Replacement of mud crabs by non-commercial crab species, mainly *Baptozius vinosus* and *Thalamita crenata* which occupy a similar niche in

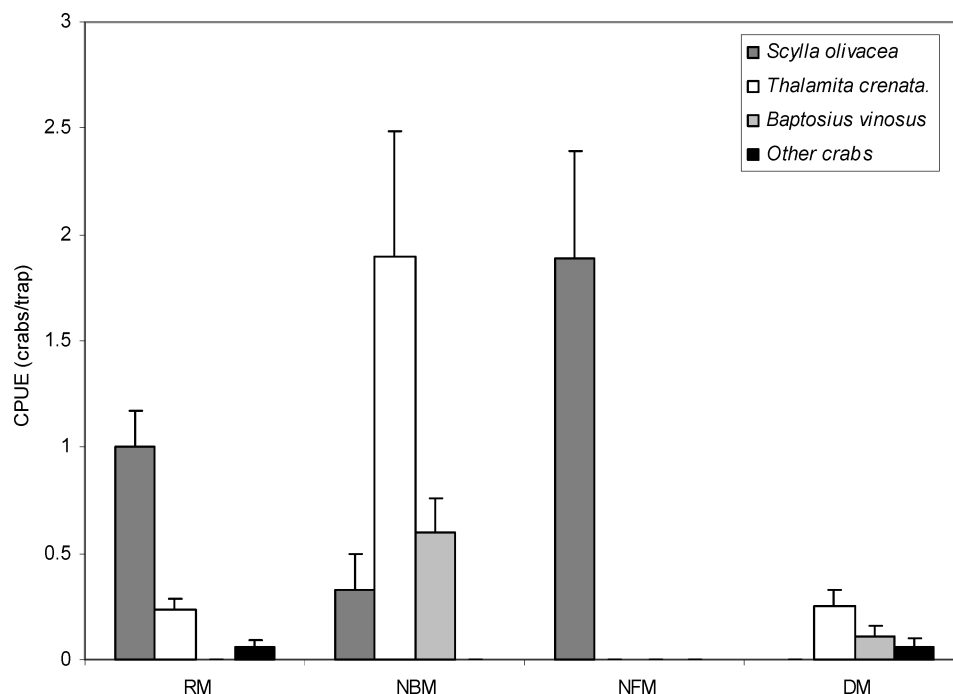


Figure 1 Catch per unit effort for crab species sampled in standardised tapping grids in 4 mangrove areas on Panay Island, Philippines; a replanted mangrove (RM), a natural basin mangrove (the selected release site, NBM), natural fringing mangrove (NFM), and a degraded natural mangrove (DM) (adapted from Walton, 2006).

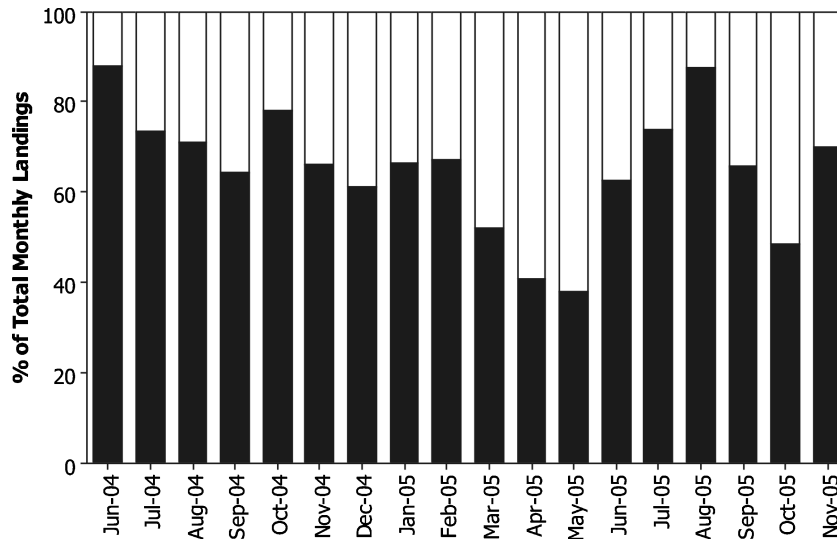


Figure 2 Percent (%) contribution of stocked and wild *Scylla* spp. in total monthly landings of mud crabs from the mangroves of Naisud and Bugtong Bato, Ibaday, Aklan, Philippines, June 2004–November 2005. Black bars represent percent of wild *Scylla* spp., white bars represent released crabs. Release of crabs was continuous, on a monthly batch basis, in 4 release areas within the study site from June 2004–October 2005. (Adapted from Lebata, 2006).

mangrove benthic communities (Figure 1), also indicated capacity in the mangrove system to support greater numbers of mud crabs (Walton, 2006).

Hatchery-Release Trials

In a series of enhancement trials (Lebata, 2006), batches of wild and hatchery-reared *Scylla* spp. were released into the Bugtong-Bato mangrove system. All released crabs were marked using internal microwire tags (Northwest Marine Technology, Inc., Shaw Island, WA, USA) to allow identification of batch, initial size, and date of release (Ut, 2002; Ut et al., 2007b). Wild *S. olivacea* were translocated from nearby replanted mangroves (Walton et al., 2006a). Hatchery production was conducted at the Southeast Asian Fisheries Development Center Aquaculture Department using methods described in detail by Quintino et al. (2002) and Quintino and Parado-Estapa (2003). Hatchery-reared (HR) crabs were either released directly from the hatchery into the mangroves without conditioning or were first transferred to earthen ponds and reared for 1–1.5 months prior to release (HR-conditioned). A total of 2,235 wild and 4,949 HR crabs were released overall in 30 batches: 16 batches (14 wild, 2 HR-conditioned) of *S. olivacea*, 12 batches (7 HR-unconditioned, 5 HR-conditioned) of *S. serrata*, and 2 batches (1 HR-unconditioned, 1 HR-conditioned) of *S. tranquebarica*. The contribution of released *Scylla* spp. to total monthly fishery catches ranged from 11.9% (June 2004) to 62.3% (May 2005) (Figure 2), resulting in increases in fisheries yield by up to 46% over baseline catches.

The recovery rates, expressed as percentage of animals released, for translocated and HR crabs were generally high, with best results recorded for translocated *S. olivacea* (55.9 ±

22.4%) and similar values for one batch of HR-conditioned crabs of the same species (48.1%). In contrast to previous studies that have shown that *S. olivacea* is the slowest growing of the mud crab species, growth rates of translocated and hatchery-reared *S. olivacea* were significantly higher than those exhibited by either of the *S. serrata* and *S. tranquebarica*. Data from baseline fisheries and experimental trapping surveys previously showed that *S. olivacea* constituted over 95% of mud crabs naturally present at this site, indicating the importance of selecting appropriate habitat for release of even closely-related species.

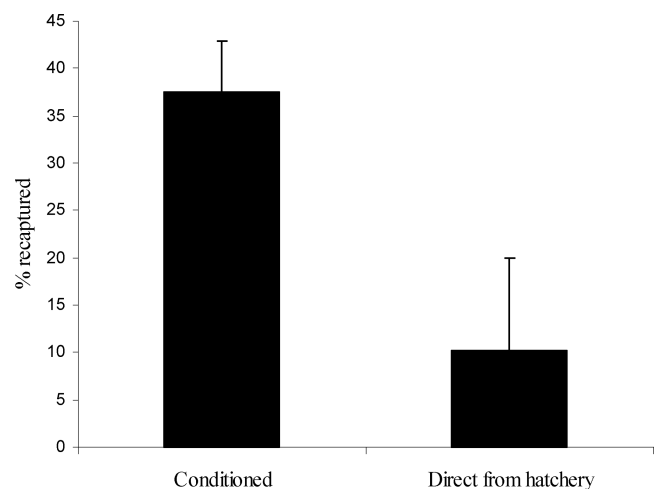


Figure 3 Recapture of released hatchery-raised mud crabs, *Scylla serrata*, from a mangrove fishery in Panay, Philippines. Prior to release, crabs from the same cohort were either held for a conditioning period in groups in ponds for one month (conditioned), or held individually for the same period in the hatchery, without experience of foraging or intraspecific competition (direct from hatchery). (Adapted from Lebata, 2006).

While recovery rates for HR-conditioned *S. serrata* ($36.8 \pm 4.4\%$) were not significantly different to that of translocated wild *S. olivacea*, they were 3 times greater than for HR-unconditioned crabs held individually in the hatchery before release without experience of foraging for food or intraspecific competition (Lebata, 2006) (Figure 3). A similar lack of adaptation to the natural environment has been observed in other hatchery-reared crustacean species (Wickens, 1986; van der Meeren, 2001; Davis et al., in press) and confirms the considerable scope for increasing the fitness of hatchery-reared juveniles before release. Overall mortality in translocated and HR-conditioned *S. olivacea* was similar to that observed in the wild population during baseline studies and to values from previous studies of *S. paramamosain* in other areas (Le Vay et al., 2007b). In the latter case, fishing was a very minor component of overall mortality, but for *S. olivacea* in the Bugtong-Bato mangrove system, 76% of total mortality was due to fishing, as reflected in the high recovery rates of released and translocated animals. For this species, which tends to live in intertidal burrows and feed on the rising tide, use of baited traps deployed within the mangrove prior to the onset of high tide may be particularly effective. In addition, the relatively low population density and the restricted fishing area at the study site may also have resulted in development of a more effective fishery. In both cases, the lack of any regulation of the fishery means that all size classes are targeted, resulting in relatively short periods between release and recapture, high recovery rates, and hence higher estimates of fishing mortality than might be observed in a fishery where minimum landing sizes are enforced.

Stock Enhancement through Habitat Restoration

It is generally recognized that mangroves contribute to coastal fisheries production through a variety of mechanisms, including acting as a direct or indirect source of primary production and provision of sheltered complex habitats (see reviews by Hogarth, 1999; Kathiresan and Bingham, 2001). Extensive mangrove replanting has been undertaken in some regions, with the goal of rehabilitating cleared or degraded areas (Field, 1998; Kaly and Jones, 1998; Alongi, 2002). Where replanted mangroves have matured, associated fauna recovered by a process of recruitment and colonization (Macintosh et al., 2002; Bosire et al., 2004; Huxham et al., 2004; Walton et al., 2006a), though there have been few studies of commercially exploited species. As in many marine decapods, *Scylla* spp. have a reproductive strategy of high fecundity and broadcast larval dispersal. Mark-recapture studies in wild populations of *S. paramamosain* and *S. olivacea* have shown that settlement into natural mangrove habitats is followed by rapid growth to maturity with high mortality/emigration ($z = -0.90$ to -1.35 month⁻¹) (Lebata, 2006; Le Vay et al., 2007b). This life history suggests that recruitment success and subsequent stock abundance may largely be determined by habitat availability (Bell and Nash, 2004) rather than supply of recruits (Caley et al., 1996; Holbrook et al., 2000). The association

between *Scylla* spp. and mangroves has long been recognized (Arriola, 1940; Estampador, 1949; Macnae, 1968; Sasekumar, 1974), and the habitat fidelity exhibited by some of the *Scylla* spp. suggests that restoration of lost or degraded mangrove areas may be an alternative or complementary strategy for promoting stock recovery through natural recruitment. In parallel to release trials, comparison of mud crab fisheries and populations in replanted and natural mangroves in the Philippines has shown that yields and abundance of *Scylla olivacea* in replanted mangrove areas (186–401 crabs ha⁻¹) can be equivalent to or higher than that supported by healthy natural mangrove environments, and substantially higher than in those areas subject to structural anthropogenic disturbance such as tree-felling (Walton et al., 2007). Compared to stock enhancement by a hatchery release program, habitat rehabilitation offers the potential advantages of a lower technical barrier to implementation and a wider range of benefits, including enhanced fisheries for a broader range of species and the additional ecological services provided by mangroves, such as timber production and coastal protection (Badola and Hussain, 2005; Dahdouh-Guebas et al., 2005; Walters, 2005; Barbier, 2006; Walton et al., 2006a; Walton et al., 2006c). The need for community-based cooperation in any replanting program also presents additional opportunities for introduction of co-management of fishing effort. Socioeconomic analysis of the costs and benefits accruing to coastal communities participating in a successful cooperative mangrove replanting initiative shows direct economic benefits of US\$564–2317 ha⁻¹ yr⁻¹, including contribution from timber products, mangrove fisheries, and adjacent catches of mangrove-associated species (Walton, 2006c). Importantly, for such community-based initiatives, this income accrued directly to community members and a survey of attitudes of fishers indicated that they valued the benefits of mangrove restoration very highly, including less-tangible elements such as protection from erosion and storm damage.

CONCLUSIONS

Bell et al. (2005) and Leber et al. (2004) differentiate between “stock enhancement” (increasing productivity of operational fisheries by overcoming recruitment limitation) and “restocking” (rebuilding spawning biomass of severely depleted populations to levels where the fishery can once again support regular harvest). Life history strategies of mud crabs suggest that restocking is unlikely to be a viable proposition for these species in open mangrove systems, as, typically, in natural populations, high levels of recruitment are followed by high rates of mortality. However, as hatchery technology continues to improve and mass-production becomes more cost-effective, such a mass-release approach may yet become feasible. The trials conducted so far confirm the fidelity of these mangrove-associated mud crab species to restricted areas. They also demonstrate that releases of hatchery-reared animals to enhance localized fisheries in selected mangrove habitats may be appropriate where recruitment is relatively low. The rapid growth rate of mud crabs means

that significant increases in fisheries' yields can be achieved within a few months. In more open systems, where recruitment is less likely to be limiting, enhancement or recovery of mangrove-related fisheries may be achieved by a nonspecific approach of habitat restoration and management, with natural recruitment and restoration of the ecological function of mangroves supporting longer-term fisheries' enhancement. Techniques for the restoration of mangrove habitats are well-developed and may be undertaken over extensive areas. Such an approach has been shown to yield a broad range of benefits to fishing communities where there is a cooperative approach to rehabilitation and management of the habitat. However, these benefits may accrue over a relatively long time scale (7–10 years) and hatchery releases in suitable areas may also be used as a complementary approach to generate more rapid enhancement in fisheries. However, determination of the range of situations where hatchery releases will prove to be cost-effective requires further pilot programs. Ideally, these should be integrated with co-management of both stocking activities and fishing effort to further increase benefits in terms of yield.

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