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Restocking and stock enhancement of coastal fisheries: Potential, problems and progress

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Abstract

The demand for fish is expected to rise substantially by 2020. Although aquaculture must provide much of the additional fish, it remains to be seen whether restored or enhanced capture fisheries can also help fill the projected gap in supply. The key challenges for capture fisheries involve reducing fishing effort, removing excess fishing capacity and building the institutional arrangements needed to restore spawning biomass to more productive levels, and to reverse degradation of the supporting habitats. Two interventions, based largely on hatchery technology, have the potential to reduce the time needed to rebuild some severely over-exploited fisheries, or improve the productivity of other 'healthy' fisheries. These interventions are 'restocking', which involves releasing cultured juveniles to restore spawning biomass to levels where the fishery can once again support regular harvests, and 'stock enhancement', which involves release of cultured juveniles to overcome recruitment limitation. However, despite the potential of these interventions, few restocking and stock enhancement programmes have met expectations. The main problems have been a pre-occupation with bio-technical research at the expense of objective analysis of the need for the intervention, and failure to integrate the technology within an appropriate management scheme that has the participation and understanding of the users. The papers presented at the Special Symposium on this subject at the Seventh Asian Fisheries Forum provide a series of valuable lessons to guide objective assessment of the potential for restocking and stock enhancement. They also show how to implement these interventions responsibly and effectively where they are deemed to add value to other forms of management. Above all, these studies demonstrate that restocking and stock enhancement programmes are applied in complex human–environment systems, involving dynamic interactions between the resource, the technical intervention and the people who use it.

Keywords: Restocking; Stock Enhancement; Fisheries management; Fisheries potential; Spawning biomass; Recruitment limitation

1. Context and rationale for restocking and stock enhancement

The production of fish needs to increase substantially to meet predicted global demand in 2020 (Delgado et al., 2003). Many believe that stagnant production from capture fisheries means that aquaculture will play a major role in supplying this increased demand, albeit with a substantial increase in the use of fisheries resources (Tacon, 2003; Muir, 2005). The potential for improved management of capture fisheries to increase yields, and thus complement aquaculture in filling the supply gap, is controversial (FAO, 2004). The possibility of increased production arises because several coastal fisheries no longer provide their potential benefits for two reasons: spawning biomass has been reduced below optimal levels, and the habitats that support fisheries production have been degraded (FAO, 2004). Reversing this mis-management should improve production from these fisheries, but ecosystem level considerations suggest that management for conservation goals, such as restoring populations of top predators and the historical structure of food webs, will result in lower, rather than higher, overall yields (Jackson et al., 2001; Pauly et al., 2002; Garcia and Grainger, 2005).

Increasing the productivity of capture fisheries in the long-term will involve hard decisions about reducing fishing effort,

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removing excess fishing capacity, and building the enabling institutional arrangements to create property rights and/or other incentives to allow better management (Pauly et al., 2002; Hilborn et al., 2003; Garcia and Grainger, 2005). The hardships involved in such decisions, in terms of loss of livelihoods for fishers, may be offset eventually by the capacity of restored and well-managed stocks to produce higher and more sustainable economic benefits for those remaining in the industry.

The reforms outlined above are easier said than done and remain the key challenges for fisheries managers worldwide. Here, we outline the potential, problems and progress of two additional measures, 'restocking' and 'stock enhancement', that could either reduce the time needed to rebuild certain capture fisheries to more productive levels, or increase the productivity of some 'healthy' fisheries. We base our views on recent literature and the papers in this volume, which were presented at the Special Symposium on "Restocking and Stock Enhancement of Coastal Fisheries: Potential, Problems and Progress" during the Seventh Asian Fisheries Forum, Penang, Malaysia, from 2–3 December 2004.

2. Potential

The potential for restocking and stock enhancement stems mainly, but certainly not entirely, from the development of technology to produce juveniles of a wide variety of coastal fish and shellfish in hatcheries. Although this technology has been directed principally at aquaculture, it has also paved the way for releasing cultured juveniles into the wild with the aim of augmenting fished populations and catches. The availability of large numbers of cultured juveniles provides fisheries managers with potential options to increase productivity in two ways. First, by restoring the spawning biomass of severely depleted populations of fish and shellfish to a level where they can once again provide regular, substantial yields—a process referred to as 'restocking' (Bell et al., 2005). Second, by overcoming the phenomenon of recruitment limitation (Munro and Bell, 1997; Doherty, 1999; Lorenzen, 2005), which occurs when the natural supply of juveniles fails to reach the level that allows optimum use of the carrying capacity of the habitat, even when there are good numbers of spawning adults. The process of releasing cultured animals to increase yields beyond levels supported by natural recruitment is known as 'stock enhancement' (Bell et al., 2005).

In the restocking of depleted populations, release of juveniles is combined with large reductions in fishing effort to help rebuild the natural spawning stock. In stock enhancement, releases may be combined with relatively high levels of fishing effort, allowing high yields to be sustained by a combination of natural recruitment (from wild spawners and spawners derived from releases of hatchery-reared juveniles) and direct recapture of stocked animals. 'Sea ranching' can also be used by managers to increase productivity from fisheries habitats. In sea ranching systems, animals are released for harvest at a larger size in 'put and take' operations, i.e., there is no intention of allowing them to augment spawning biomass. Sea ranching is usually applied when natural recruitment is low or absent owing to very intensive fishing or lack of spawning or nursery habitat. All three approaches have advantages and disadvantages, and their overall suitability will depend on management objectives and specific biological and economic conditions (Lorenzen, 2005).

Releases of cultured juveniles are not the only interventions with potential to replenish severely depleted fisheries, or enhance the production of recruitment-limited fisheries. Restocking could also be achieved by aggregating and relocating adults for some species (Purcell, 2004; Bell et al., 2005). Stock enhancement may also be achieved by the collection, grow-out and release of spat; provision of settlement habitat where it is limiting; redistribution of settled juveniles from areas with high densities to places were abundances are low; and relocation of adults from areas where growth or survival is low to more productive parts of the coast (Bell et al., 2005; Uki, 2006; Gardner et al., 2006).

It also follows that restocking and stock enhancement will not be suitable for managing many of the world's marine fisheries. For example, hatchery production can never be expected to make more than a trivial contribution to the supply of juveniles for large, demersal finfish fisheries (Blaxter, 2000). On the other hand, restocking and stock enhancement are likely to be effective for some coastal invertebrate fisheries because the shallow inshore distribution, and sessile or sedentary behaviour of the species involved, can create self-replenishing populations on a relatively small spatial scale. In such cases, releases of cultured juveniles can have a reasonable chance of augmenting population size significantly (Bell et al., 2005). Even so, a different approach is needed for each species, and often for populations of the same species at different locations. Of course, restocking and stock enhancement must be placed within a fishery management system that integrates releases with appropriate control of fishing effort and habitat protection. There are no shortcuts to the research needed to identify whether hatchery releases will be a technically effective and economically viable management option for each situation.

3. Problems

Regrettably, many enhancement initiatives have been conducted without consideration of wider fisheries management aspects, and with little or too narrowly focused research. Often, the main aims of research have simply been to reduce the cost of producing environmentally fit, hatchery-reared juveniles, and to increase the survival of juveniles released into the wild, in the expectation that improvements in these areas will eventually make restocking and stock enhancement viable (Munro and Bell, 1997; Howell et al., 1999; Blaxter, 2000; Leber et al., 2004; Bell et al., 2005). As a result, few release programmes can claim success as fisheries management interventions. Many have either failed to produce any measurable impact on stock abundance and yield, or led to negative impacts on wild populations (Travis et al., 1998; Hilborn, 1998). The stock enhancement of scallops in northern Japan is one of the exceptions. There, the release of wild spat, cultured to a size where predation is reduced, has produced annual harvests that consistently exceed maximum historical yields (Uki, 2006). This success is attributable to a management system that combines effective juvenile production and release technology with tailored management of harvests, all conducted and supported financially by fishers.

Many restocking and stock enhancement endeavours have been aware of the pitfalls that can beset efforts to produce fit, cultured juveniles at low cost, and to release them in ways that increase overall levels of recruitment. There has also been a concerted effort to apply a responsible approach to restocking and stock enhancement following the seminal paper by Blankenship and Leber (1995). The attempts to overcome problems such as the risks of changing the genetic diversity of wild populations, introducing diseases or changing the abundances of other valuable species in the ecosystem through careless release of juveniles have been heartening (Bell et al., 2005; Bartley et al., 2006; Ward, 2006). But there has been a pre-occupation with such research at the expense of the main game.

A new approach to restocking and stock enhancement is needed to identify the potential of these interventions to increase the productivity of selected coastal fisheries (Bell et al., 2005). The basic steps to this approach are:

1. Recognise that the interventions should be applied to self-replenishing populations.
2. Assess each population to see if there is a need for restocking or stock enhancement.
3. Model the potential benefits of investments in restocking and stock enhancement to determine whether they are likely to add value to other forms of management.
4. Proceed with releases of cultured juveniles only when substantial benefits are predicted.
5. Integrate restocking or stock enhancement within an appropriate management scheme that has the participation and understanding of users.

Responsible methods for reducing the cost of producing fit juveniles, optimising survival of animals released in the wild, and minimising the effects of releases on conspecifics and other species in the ecosystem remain key elements of this approach, and need concerted research. However, greater emphasis is placed on the integration of releases with other fisheries management measures, and their contribution to wider management goals. Also, quantitative assessment and modelling of biological and economic dynamics of the enhanced fishery is increasingly seen as crucial to the rational evaluation of stock enhancement and alternative or additional management measures. Models and assessment methods for enhanced fisheries are becoming widely available, providing powerful and general tools for the evaluation of stock enhancement programmes, from early planning to full-scale operation (Lorenzen, 2005; Ye et al., 2005; Medley and Lorenzen, 2006). Preliminary assessments can and should be carried out before significant investment in experimental research or production facilities, and before any alternative management options are dismissed or delayed in favour of stock enhancement. Combining population dynamics and bio-economic modelling with participatory planning will promote a broad-based assessment of alternatives, and reduce the influence of unrealistic expectations and partisan views on decisions (Lorenzen, 2005).

4. Progress

The papers in this volume add to a growing number of books, conference proceedings and major reviews in the field in the past decade that have been instrumental in highlighting the technology and approaches needed to apply restocking and stock enhancement in an environmentally and socially responsible way (Blankenship and Leber, 1995; Munro and Bell, 1997; Travis et al., 1998; FAO, 1999; Howell et al., 1999; Blaxter, 2000; Caddy and Defeo, 2003; Molony et al., 2003; Bartley and Leber, 2004; Leber et al., 2004; Bell et al., 2005; Taylor et al., 2005). In particular, the papers from the Seventh Asian Fisheries Forum provide several new lessons for scientists and managers involved in assessing the potential for restocking and stock enhancement of coastal fisheries. The papers fall into three broad categories: cross-cutting themes, restocking, and stock enhancement. Below we comment briefly on the nature of each paper, and the lessons they provide. We begin with the four papers involving cross-cutting themes, proceed to the two papers on restocking and then handle the seven papers dealing with stock enhancement.

4.1. Cross-cutting themes

The cross-cutting themes cover the use of population genetics to delineate separate stocks within a fishery; analysis of release experiments using population modelling approaches to predict recapture rates and yields at different levels of releases and harvests; a framework for assessing the disease risks that attend releases of cultured juveniles; and an analysis of the social benefits and drivers of stock enhancement. The last paper comes from long-term studies of freshwater systems, but many of the lessons will also apply to coastal fisheries.

Ward (2006) presents the mechanisms and evidence for spatial structuring of marine fish and invertebrate populations. Although his main aim is to demonstrate that much care is needed to manage broodstock and the release of juveniles to maintain the gene frequencies of wild populations, there is a clear application for this body of research to the approach to restocking and stock enhancement advocated above. That is, population genetics should also be used to identify the number and distribution of any self-replenishing populations comprising a fishery, which should be the management units for restocking and stock enhancement programmes. However, Ward (2006) cautions that, although population genetics is a key method for identifying spatial structure within fisheries, even the most recent tools may lack the power to delineate self-replenishing populations. The basic problem is that rates of gene exchange as low as 1% ($F_{ST} \simeq 0$) in some analyses do not falsify the null hypothesis that separate populations have no differences in their gene frequencies. In reality, however, such genetically homogeneous populations may be biologically isolated, i.e., there may be little or no scope for a severely overfished population to be replenished from an adjacent one. Clearly, where population genetic analyses reveal significant differences in gene frequencies between samples from different locations, there is unequivocal evidence for separate self-replenishing populations. However, where the null hypothesis is not rejected, other methods are needed to determine the extent of spatial structuring within a fishery. Such methods include analysis of geographic features and current patterns likely to create boundaries, tagging, and assessing variation in parasite loads, morphometrics and otolith microchemistry. The challenge is to develop ways of acquiring this information at reasonable cost, especially for data-poor fisheries operated by small-scale fishers.

Lorenzen (2005) developed a generic population dynamics model for enhanced fisheries by extending the dynamic pool theory of fishing. In this volume, Lorenzen (2006), shows how release experiments may be analysed to provide key information for the quantitative assessment of population management in fisheries enhancement. The core element of this approach is to use a size-dependent natural mortality model (Lorenzen, 2000) to estimate natural and fishing mortality rates. This information may then be used to predict yields under alternative release and harvesting regimes. Such assessments need to be a key feature of evaluations of future proposals for releasing cultured juveniles to augment self-replenishing populations within coastal fisheries.

The paper by Bartley et al. (2006) deals with risk analysis in regard to the transfer of diseases to conspecifics and other species associated with releases of hatchery-reared juveniles. They advocate a systems approach that involves consideration of: the source of animals to be released, the populations to be managed, hazard identification, risk assessment, risk management, quarantine, diagnostic and treatment procedures, mitigation measures, monitoring, reporting the disease status of hatchery and wild populations, and the establishment of aquatic animal health standards. Bartley et al. (2006) also describe the information and support available to complete a responsible risk analysis, and the internationally accepted guidelines and protocols that apply to the various components of the framework. They conclude that, with appropriate management, restocking and stock enhancement of coastal fisheries can be done with minimal losses due to disease, and minimal impacts on other species.

Garaway et al. (2006) issue a timely wake up call that past restocking and stock enhancement research has focused too heavily, often exclusively, on biological and technical aspects. They stress that restocking and stock enhancement is done in complex human–environment systems, involving dynamic interactions between the resource, the technical intervention and the people who use or manage it. In their experience, technical research alone cannot predict or explain the outcomes of releasing cultured juveniles—integrated, interdisciplinary studies are crucial. The key points from their research in the small freshwater bodies in Lao, that can also be expected to hold for coastal fisheries, are: (1) The rights of ownership, control and use of enhanced resources need to be determined and understood by the wider institutional, social, economic and political environment. (2) Stock enhancement can catalyse institutional change and influence how and by whom living aquatic resources are used, thereby significantly affecting the distribution of benefits, the costs of releasing fish, and the scope for success. (3) Resource users are not the recipients of enhancement technology, they drive it—they determine whether it is adopted, the technical outcomes that are achieved, and how the benefits are distributed. The message is clear; future evaluations of the potential roles of restocking and stock enhancement in managing coastal fisheries need to strive for a more integrated understanding of how these interventions will affect both the biological and social components of the resource system. The importance of this point is also illustrated by other papers in this volume, notably those by Gomez and Mingoa-Licuanan, Uki, and Wang et al. Appropriate and well-designed restocking and stock enhancement programmes will combine responsible technology and fisheries management within institutional arrangements that enable these interventions to meet a range of production, environmental, economic and social objectives.

4.2. Restocking initiatives

The two papers in this section both deal with a key issue in the management of restocking projects—the need to protect the released animals while they replenish the target population(s). Gomez and Mingoa-Licuanan (2006) report the results of their concerted efforts over the past 20 years to restock giant clams in the Philippines. The key lessons from their work, which has so far placed 46 cohorts of juvenile giant clams across >40 sites in >20 coastal provinces, centre around the importance of involving local communities in restocking programmes. They found that adequate survival of even the limited numbers of clams released at each site depended on in-depth participation of communities in: selecting the sites for release of juveniles; husbandry of the clams until they reached ‘escape’ size from predation; and the arrangements to protect the adult clams from poaching and typhoons. It is credit to the authors that many of the local collaborators involved in the restocking programme were willing to shoulder the costs involved in the training needed to equip them with the necessary husbandry skills.

Purcell and Kirby (2006) add to the growing body of information on the potential for using restocking programmes to manage severely overfished populations of the valuable tropical sea cucumber, *Holothuria scabra*. They re-iterate that no-take zones (NTZs) are needed to protect the released animals until they and their progeny have replenished the target population, and show that modelling is a practical way of identifying the area needed to protect released sea cucumbers as they disperse throughout their lifespan. The individual-based model they used predicts that NTZs of 19–40 ha will be needed to protect juvenile *H. scabra,* released initially at a density of 1 individual m^{-2} over an area of 1 ha, as they disperse and reproduce over a 10-year period. Their analysis is based on realistic levels of current hatchery capacity (i.e., multiple releases of ~10,000 juveniles) and provides clear guidance for managers planning to use restocking to restore local fisheries. Their approach can also be applied easily to other sedentary species where basic data on movement and growth are available. Questions remain about the average "footprint" of larval dispersal that can be expected from such reservoirs of spawners, and therefore the minimum distance between NTZs required to ensure distribution of larvae to all available habitat within the range of the target self-replenishing population. Recommended distances between NTZs can be expected to differ depending on local geography and currents. There is also the question of how many individuals to release within an NTZ to prevent 'allee effects' and maximize spawning potential. Modelling to answer this question will need to combine dispersal, behaviour, and survival of hatchery-reared juveniles.

4.3. Stock enhancement initiatives

The seven papers on stock enhancement contain reviews of some of the largest and most successful forms of marine stock enhancement to date.

Uki (2006) provides a brief history of what is undoubtedly the greatest success story in marine stock enhancement—the augmentation of the scallop fishery in Hokkaido, Japan, to create consistent annual harvests of ~300,000 t p.a. These regular harvests represent a four-fold increase over the historical maximum catch. The success of scallop stock enhancement in Hokkaido is attributed to: simple and effective methods for catching and rearing massive numbers of spat; ideal habitat for growth of scallops; survival rates for released spat >30%; development of a broader stock enhancement management system involving rotational fishing regimes that allow scallops to reproduce before harvest, and removal of predators; and devolution of management to local fisheries cooperatives. A particularly remarkable feature of this fishery is the development of methods to catch, grow and release >2 billion wild-caught juveniles each year. Use of wild spat not only bypasses the need for hatcheries, it removes the risks of introducing genetically modified animals to the population. The costs of collecting and rearing the spat to the necessary release size are borne by the fishermen themselves. They also organize the monitoring of scallop populations and the environment at 200 points across the fishing grounds, adapt the catches of spat each year to meet the estimated need for released juveniles, remove starfish predators, and rigourously train new members of co-operatives entering the fishery. Interestingly, however, the basic methods used to enhance scallops in Hokkaido have not succeeded in other places, except the south island of New Zealand (Drummond, 2004; Bell et al., 2005). In other places, it has not been possible to meet all the pre-requisites of a good supply of spat, low levels of predation, currents that retain larvae, and incentives for fishermen to invest in the capture, rearing and release of spat and implementation of rotational fishing. There may well be other places where these conditions exist, but it will take substantial biological and socio-economic research to identify them.

Wang et al. (2006) describe 20 years of releases of juvenile shrimp *Penaeus chinensis* in China. The immense scale of these releases, peaking at >5 billion juveniles p.a. in 1993, was made possible only through the use of infrastructure for shrimp aquaculture, and considerable financing from government. With such assistance, the releases of shrimp in China have achieved a 7–10-fold return on investment (although the extent of savings made through the use of the existing aquaculture infrastructure is not clear). However, due to economic reforms, local governments are now responsible for administering the production and release of juveniles, and are expected to recover the full costs from the beneficiaries. In the Bohai Sea region, it has not be easy to identify the beneficiaries because the contributions of released juveniles to local fisheries were not uniform across the three provinces involved and 'user-pay' mechanisms could not be defined clearly. Difficulties in collection of funds by the different bureaucracies, viral disease outbreaks and the continuous decline in catches resulted in closure of the stock enhancement programme in the region in 1994. In contrast, the releases at the Haiyangdao and Qinghai fishing grounds are operated by local fishermen and the beneficiaries can be identified clearly. There, the user-pay charges are collected successfully and releases of ~600 million juvenile shrimp p.a. continue. The major lesson here echoes the views of Garaway et al. (2006), i.e., that the biological and social aspects of stock enhancement, including appropriate and practical institutional arrangements, must be integrated for the successful application of feasible technology.

A second major lesson from the comprehensive efforts to produce and release shrimp in China is that care is needed to obtain the full range of benefits available from releasing juveniles. Although returns on investment appear to be attractive, the release of shrimp in China has essentially been limited to 'put and take' sea ranching because the shrimp are caught before they spawn. Indeed, the fishery at Haiyangdao, where >90% of the catch consists of released shrimp, would scarcely exist if not for the hatchery programme. Allowing released hatchery-reared shrimp to contribute to spawning biomass, restoration of degraded habitats and short-term reduction in fishing effort promise to be a more cost-effective approach to increasing production than sea ranching alone. In short, hatchery releases should be dovetailed with other forms of management to provide fishing communities with a robust and resilient suite of measures to create and maintain the desired spawning biomass and obtain optimum yields regularly.

Hamasaki and Kitada (2006) review 40 years of stock enhancement of the kuruma prawn (shrimp) *Penaeus japonicus* in Japan. This substantial, long-term programme, which has released up to ∼300 million juveniles p.a. across seven areas of Japan, provides a different but equally telling lesson for all managers considering the use of stock enhancement—investments in releases of hatchery-reared juveniles will not bear fruit unless the problems that caused the decline in catches have been rectified. In the case of kuruma prawns, decreases in catches were due in large part to degradation of nursery habitats. The analyses by Hamasaki and Kitada (2006) show that despite a marked trend to release larger juveniles, and the development of reliable tagging methods, only 5 of 40 recent releases were economically beneficial due to low recapture rates. They attribute the low survival to the poor quality of nursery habitats. However, they did identify a promising interaction between release size and habitat quality—recapture rates were greater at smaller release sizes in areas with larger nursery grounds. The findings from Japan underscore two important points: (1) the quality and quantity of release habitats can be expected to affect the success and cost of releases; and (2) releases should be targeted at local populations where stock enhancement is predicted to be cost-effective. Because kuruma prawns have continued to decrease since the mid 1980s throughout much of their range, it is clear that stock enhancement no longer merits priority as a management tool. The imperative is restoration of nursery habitats. Once increased catches of kuruma prawns due to improvements in habitat have stabilized, the potential for stock enhancement to overcome any recruitment limitation can then be re-assessed.

Loneragan et al. (2006) provide valuable insights from a different approach to shrimp stock enhancement for *Penaeus esculentus* in Exmouth Gulf, Western Australia. Unlike the situation in China and Japan, where massive numbers of juvenile prawns have been available as the by-product of aquaculture, assessments of the feasibility of shrimp stock enhancement in Exmouth Gulf have needed to include much higher costs for hatchery production (Loneragan et al., 2004; Ye et al., 2005). Consequently, a bio-economic modelling approach has been used to assess the likely profitability of stock enhancement involving the production and release of ca. 24 million juveniles p.a., with the aim of increasing catch by 100 t (Ye et al., 2005). Key aspects of the modelling have been predictions about the survival of juvenile prawns released in nursery habitats of different quality: high biomass (∼100 g m^{-2}) seagrass, low biomass (∼10 g m^{-2}) seagrass and bare substrata. The modelling showed that survival of prawns of 2 mm carapace length (CL) to the size at emigration from the nursery habitat was ∼1.9 times higher for individuals associated with seagrass of high biomass than for those in seagrass of low biomass. Survival was predicted to be 19 times higher for prawns in high biomass seagrass than for those on bare substratum. However, the differences in survival between habitats were reduced greatly when the releases of much larger prawns (10 mm CL) were simulated. These findings not only highlight the importance of research to develop optimal release strategies for prawns in stock enhancement programmes, they reinforce the conclusions of Hamasaki and Kitada (2006) that the quality of nursery habitats can have a major impact on the fisheries production of some species of penaeid shrimp.

Kitada and Kishino (2006) bring us a range of lessons from 40 years of stock enhancement programmes for finfish (excluding salmon) in Japan. Although cultured juveniles of 37 species of finfish are currently released in Japan, they have focused their analysis on two species, the red sea bream *Pagrus major* and flounder *Paralichthys olivaceus*. They demonstrate that, at the scale of individual bays, releases of hatchery-reared juveniles can have significant effects, e.g., in Kagoshima Bay, where 50% of the variation in catches of red sea bream was explained by the capture of hatchery-reared fish. However, macro-analyses of the impact of releases over larger scales showed that the global dynamics of wild populations of these species were not affected significantly by stock enhancement. They conclude that marine stock enhancement should be targeted at local populations with limited recruitment and high commercial and/or recreational fishing pressures. They also identify the need for the modelling proposed in Section 3, and reiterate that the effects of local releases can be predicted from the numbers of juveniles released and the survival rate of released juveniles. However, rather than being concerned whether local releases can be organized on a scale that is large enough to enable significant effects to be achieved, Kitada and Kishino (2006) provide evidence of density dependence and replacement of wild individuals by hatchery-reared fish. They conclude that the magnitude of releases must be considered carefully and determined for each area by taking into account the status of the wild stock and the local carrying capacity. They also demonstrate for red sea bream how density-dependent interactions between wild and hatchery-reared fish have been exacerbated by massive reductions in the extent of eelgrass (*Zostera marina*). Clearly, the importance of maintaining and restoring essential habitats needs much greater attention in stock enhancement programmes. Stock enhancement will be of no effect in situations where recruitment limitation is due to lack of sufficient nursery areas.

Obata et al. (2006) provide a very useful contribution to the important issue of tagging animals to assess the contributions from stock enhancement to population size and catches (see Blankenship and Leber, 1995; Munro and Bell, 1997; Bell et al., 2005). Faced with the difficulty of using a physical tag to mark large numbers of juvenile mud crabs *Scylla paramamosain*, they developed a genetic tag based on a low frequency haplotype. The tag allowed them to assess recapture rates for released crabs, and the economic efficiency of stock enhancement. Nevertheless, the precision estimates they obtained were low and could be improved only through the release of greater numbers of juveniles. Obata et al. (2006) caution that although statistical power increases with greater releases of animals with minor alleles or haplotypes, the risk of long-term deleterious effects from such manipulations on the wild population also increases. They do not generally recommend genetic tagging to estimate recapture rates of released juveniles in stock enhancement programmes; they favour other efficient non-genetic marking methods. As there are no alternatives to genetic tags for assessing the inter-generational contributions of animals released to rebuild a target spawning biomass in restocking programmes, more research is urgently needed on the risks involved.

Gardner et al. (2006) describe how plans to develop an aquaculture industry based on the capture and culture of puerulus larvae of the rock lobster *Jasus edwardsii* in Australia are expected to enhance the fishery through release of juveniles grown-on for 1 year. The scheme promises to serve the twin goals of providing ‘seed’ for aquaculture, and for stock enhancement, because survival of puerulus in culture is ∼90% whereas survival in the wild during the first year is thought to be much lower than 25%. This still remains to be quantified but survival during the first benthic year is <5% for two other species of spiny lobsters, *Panulirus argus* from the Caribbean, and *Panulirus cygnus* from Western Australia. An attractive feature of the proposed stock enhancement of *J. edwardsii,* as a way of compensating the fishing industry for the removal of puerulus for aquaculture, is that it creates new options for spatial management. In particular, on-grown juveniles could be returned to sites where puerulus were harvested, or to other areas within the range of the self-replenishing population where abundances are of concern to managers. This paper also highlights that hatchery technology is not the only form of aquaculture that facilitates restocking and stock enhancement projects—capture and culture of wild juveniles has also provided major opportunities, e.g., scallops in Japan, and can be expected to continue to do so.

5. Final remarks

In addition to providing a rich set of lessons for scientists and managers interested in assessing the potential for restocking and stock enhancement of the species covered within this volume, or applying these tools to other fisheries, the papers assembled here also deliver an unexpected but important outcome. Releases of hatchery-reared juveniles have raised awareness of the key management problems facing fisheries. For example, the ‘put and take’ nature of shrimp stock enhancement in China, which does not make the most of the investment because the released shrimp are caught before they spawn, highlights the need to change management arrangements to increase spawning biomass to more productive levels. Similarly, releases of shrimp and red sea bream in Japan illustrate the futility of stock enhancement where there is insufficient nursery habitat for additional juveniles. Rather, the first priority for management must be to restore and maintain larger nursery areas for these two species. As research continues to provide robust information on survival of cultured juveniles in the wild for the modelling needed to determine whether restocking and stock enhancement add value to other forms of management, we can expect to gain further insights into other biological processes that will help to improve management.

We commend the papers from the Seventh Asian Fisheries Forum to you. We trust that the lessons they provide will assist in designing research that promotes cost-effective decisions about how to restore and enhance the productivity of coastal fisheries to help meet the increasing demand for fish.

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