FISHERY MANIPULATION THROUGH STOCK ENHANCEMENT OR RESTORATION

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Introduction

The continuing advance in the technology associated with the rearing and ongrowing of the early life stages of a number of marine species with commercial importance has resulted in mounting interest in the artificial manipulation of some marine fishery stocks. This manipulation can take two main forms: (1) enhancement of pre-existing or declining stocks and (2) restoration of damaged or extinct stocks.

Enhancement itself can define three forms of fishery manipulation: as being

1. A traditional method of marine ranching for many shellfish species (e.g., oysters or scallops);
2. A method for augmenting existing low volume/high value stocks where the habitat is perceived as being below the potential carrying capacity (e.g., lobster stock enhancement programs); and
3. A reversal of a trend of declining harvests, possibly at reduced catch per unit effort rates, from a fishery which may be recruit-limited (e.g., cod and salmonid stock enhancement programs).

Restoration only occurs where the decline in fishery status is so great that an active fishery no longer exists. Complete fishery collapse has been attributed to natural variation in population shifts but invariably is more often caused, either directly or indirectly, by anthropogenic influence such as nursery habitat destruction or alteration, migratory barriers, overfishing and acute or chronic pollution episodes. In these cases mitigation activities can attempt to reconstruct the previous fishery or replace it with other species of commercial importance that may be better suited to the altered conditions that subsequently exist.

Within both enhancement and restoration programs fishery managers may identify potential benefits associated with basing the manipulation on alternative species to those lost, in decline or to be augmented. These alternative species can be native to the waters of introduction but there are plenty of examples of exotic or closely related marine species being transplanted from different areas of the globe because of the potential for higher yields or better survival potential (e.g., the Pacific oyster, *Crassostrea gigas* (Thunberg)). In addition, artificially increasing the relative numbers of any one species, either naturally occurring or introduced, may alter the ecological balance of an existing ecosystem. Both of these scenarios have been defined previously in the literature as community change marine ranching but, although community change will result, the driving forces for introductions were either enhancement or restoration and so it is not a valid form of manipulation in its own right. **Table 1** summarizes the types and subtypes of fishery manipulation, the reasons for manipulation, the type of stock species used and the key assumptions for artificial fishery intervention. **Table 1** also introduces the concepts of ownership, value, habitat carrying capacity, and recruit limitation which are all contributory factors influencing the scale of the type and value of the intervention.

A Global Perspective of Fishery Manipulation

Over the past few decades, the harvest from the global marine fishery has been maintained with the trend towards a steady but slight increase. However, there have been marked and dramatic declines in some fisheries that have been traditionally exploited possibly caused by overfishing, environmental or ecological change, inadequate fishery management, or combinations of all three. Sometimes the specific fishery or an individual stock have provided a historical basis for the development and maintenance of dependent human communities and so the often sudden reduction in yields can result in significant deleterious socioeconomic degradation.

The history of stock enhancement using hatchery-reared juveniles began in the late 1870s with releases of Atlantic cod (*Gadus morhua* L.) and salmonids principally in the United States and Norway and salmonids only in Japan. Enhancements continued for almost 90 years on varying scales with inconclusive effectiveness. In total it is estimated that 27 countries have been involved with the stocking or ranching of marine species. However, it is Japan that has pursued stock enhancement with long-term vigour. Since 1963, massive stock

Table 1 Summary of the major types of fishery stock manipulation

Type of manipulation	*Subtype*	*Reasons for manipulation*	*Species stocked*	*Key assumptions*
Enhancement	Traditional marine ranching	To improve harvests on a semi-intensive scale through the captive on-growth of juveniles utilizing natural food availability To increase the stock above historical levels	Natives Close relatives Exotics	That the lease of the marine habitat and ownership of the seeded animal is conveyed and thus private commercial status is possible That the natural fishery is low volume/low value[a] That the carrying capacity of the habitat can be significantly increased That the natural fishery is not recruit-limited
	Augmentation of existing stocks	To improve harvests on an extensive scale through noncaptive on-growth of juveniles utilizing natural food availability. To increase the stock above historical levels.	Natives Close relatives	That there is limited access to ownership and cooperative status or government funding is required That the natural fishery is low volume/high value[a] That the carrying capacity of the habitat can be increased. That the natural fishery is not recruit-limited
	Enhancement of declining stocks	To reverse declines in the harvests on an extensive scale through noncaptive on-growth of juveniles utilizing natural food availability. To maintain the stock at historical levels.	Native	That there is no ownership over and above existing regional or national restrictions to the fishery and centralized funding is required That the natural fishery is high volume/low value[a] That the carrying capacity of the habitat can be increased That the natural fishery is recruit-limited
Restoration	Reconstruction of damaged fishery	To re-establish a historical fishery that had declined below levels of sustainability through noncaptive on-growth of juveniles utilizing natural food availability. To return the stock to historical levels	Natives	That there is no ownership over and above existing regional or national restrictions to the fishery and centralized funding is required That the natural fishery is high volume/low value[a] That the carrying capacity of the habitat can be increased That the natural fishery is recruit-limited
	Replacement of damaged fishery	To replace a historical fishery with a new species that can adapt better to the altered conditions through noncaptive on-growth of juveniles utilizing natural food availability. To establish a completely new fishery	Natives Close relatives Exotics	Ownership and volume/value parameters are likely to mimic extinct fishery That the carrying capacity of the habitat can be increased There is no natural fishery

[a]Volume refers to the proportionate contribution of the fishery to the total national harvest; value refers to the individual animal. Therefore a high volume/low value fishery will have a significantly greater socioeconomic importance compared with a low volume/high value fishery.

Adapted from Barthey (1999).

enhancement schemes in Japan have been supported by the national government. In the 1960s there was widespread destruction of Japanese coastal areas, accelerated by land-reclamation projects and industrial pollution. In addition, overfishing had contributed to seriously low stock levels of major traditional fisheries for red sea bream (*Pagurus major* (Temminck & Schlegel)), kuruma prawn

(*Penaeus japonicus* (Bate)) and swimming crab (*Portunus trituberculatus* (Miers)). A program of stock enhancement was therefore initiated by the Japanese Government in order to improve fishery resources in coastal areas. This program has steadily increased over the years and, at present, there are over 70 national and local government hatchery facilities contributing or developing almost 80 species for stock release (1995 figures: 33 fish species, 13 crustacean, 24 molluscan, six sea urchin, one sea cucumber, and one octopus). The scales of release have been massive in some cases with, for example, 3 billion scallop, 300 million prawns and 70 million crabs released in total since the program was initiated. Over the years there have been marked variations in the effectiveness of this large-scale enhancement program, but long-term results for chum salmon (*Onchorhynchus keta* (Walbaum)) and the scallop (*Patinopecten yessoensis* (Jay)) indicate a proven augmentation of net fishery production at acceptable economic rates. However, distinct positive economic benefits for these programs are not observed routinely. It is notable that the Japanese stock enhancement program co-evolved alongside large artificial reef and seaweed bed restoration programs. Similar enhancement programs for marine vascular plants and seaweeds, some in addition to the construction of artificial reefs, are globally widespread. Habitat restoration or manipulation by itself can have a positive effect on fishery status without the additional requirement of hatchery-reared animal introductions.

The release of Atlantic cod in north Atlantic waters has a long history. Large numbers continue to be released in programs in Norway, but also to a lesser extent in the Faroe Islands and Iceland. Although evidence has been collected to suggest that the condition and growth rates of released cod are better than those of wild stocks on recapture, the overall effect, though variable, was not to produce a significant increase in the fishery and certainly not within any limits of economic viability. Just as enhancement schemes for Atlantic salmon were eventually occluded by intensive aquaculture of that species, there is growing interest in the intensive farming of cod in north temperate waters.

In the 1990s there were widespread releases of microtagged juvenile European lobsters (*Homarus gammarus* (L.)) in Norway. Following the pioneering development work carried out in the UK during the 1970s and 1980s the large-scale production of juvenile European lobsters has become technically straightforward and low-cost. Seven years after initial releases, over 40% of the commercial catches and over 70% of the sublegal-sized catches in south-western Norway were from the released stock. This scale of enhancement was achieved with a total recovery rate of approximately 8% of the released stock. However, even at this rate of return (which approximates to other recapture rates for the European lobster) it is concluded that the continued enhancement of a depleted lobster population in Norway is economically feasible.

There are many other examples of manipulation programs occurring over the globe at varying levels of size and success. Some concentrate on enhancement, others on restoration. In all cases, the measurement of success is complex. For example, a large fishery of significant social importance can be maintained at an economic loss through stock enhancement schemes, but can still be measured as a success by the funding agency if the losses sustained through enhancement outweigh the socioeconomic costs of societal collapse. In another case, enhancement or restoration may not increase the numbers of animals harvested but could increase the unit price through improved quality. In a similar way, there have been examples of artificially moving the fishery closer to the market, thereby increasing the unit price and restoring an economically viable fishery even though catch volumes were not improved.

Quality and Survival of the Release Stock

The anticipated proportion of released individuals recruiting to the fishery and eventually to harvest will differ between species and the intended type of manipulation. However, an essential objective in the production of hatchery-reared animals is that they should possess similar physical and behavioral capabilities to their wild counterparts in order to minimize differences that would compromise their survival in a natural environment. Many stock enhancement programs have reported high mortality rates in released individuals over timescales of days post-release. Through subsequent laboratory experimentation significant progress has been made into identifying approaches to the ways the enhancement stocks are cultured, prepared for release, and eventually liberated.

There are a significant number of marine species that, when reared artificially, present differences in structure and coloration compared with wild individuals. Examples of this are hatchery-reared halibut (*Hippoglossus hippoglossus* (L.)) where a significant proportion of the cultured individuals are nonpigmented, and physical jaw deformities characteristically caused during the rearing of Atlantic cod and herring (*Clupea harengus* L.). Many of these abnormalities can be corrected for through dietary improvement. In addition abnormal colorations are sometimes a result of being reared in bare unnaturally colored culture tanks and only a short prerelease exposure period to simulated natural conditions is sufficient to improve coloration. The culture environment itself is likely to lack many of the physicochemical attributes of the wild. Numerous fish species depend on tidal and diel variations in parameters such as light and pressure to drive short-term migratory patterns that may be essential in optimizing foraging and antipredation behaviors. The ability to learn potentially inherent rhythmic behavior cycles over relatively short conditioning periods has been shown to reduce initial levels of postrelease vulnerability.

In intensive fish farming the removal of many natural behavioral traits that can potentially result in intraspecific damage can be advantageous. However, the retention of aggressive, predatory and antipredatory behavior is essential in many species that are intended for wild-release in manipulation programs. A number of studies have shown that cultured juveniles rarely possess the same abilities as wild fish of similar age to detect and/or react to potential predators or prey, or react in the same way to different environmental cues and clues. Systematic approaches have been taken to dissipate the effects of hatchery culture including prerelease exposures to predators, prey organisms (weaning hatchery-reared individuals from artificial to live diets), and simulated natural environments. Some of the juvenile cod intended for release in the Norwegian cod enhancement program were cultured in extensive systems that potentially preconditioned the juveniles to a suite of behavioral and physical conditions that were similar to those expected in the wild. The same enhancement program also produced 0-group juveniles that at the time of liberation had achieved a higher growth rate and were in a higher condition than their wild counterparts. It was considered that this advanced growth and condition allowed the culture animals to withstand a period of poor feeding after release.

The actual methodological approach to the practical task of liberation of the reared stock will vary considerably between species. However, it is essential that release is based on a sound knowledge of the biology, environmental requirements, and stocking densities of each species. Some release strategies are plainly obvious; significant mortality levels would be expected if rock-dependent fish were released onto a sand-dominated habitat and vice versa. Detailed knowledge of the animal's life history may indicate that a range of habitats may be required for the successful on-growth of the released juveniles. One method of optimizing the habitat requirements of ranched species may be to deploy artificial habitats at, or in the vicinity of, the site of release. As well as potentially improving survival, artificial habitats can increase the carrying capacity of an environment and help in designating ownership within an open system environment (see below).

The method of release also has to consider the stocking density, the early life-history tendencies and any ontogenic shifts in habitat utilization. Research has indicated the benefits of introducing shoaling species initially into cages so that the individuals can recover from the stresses associated with release and develop strong shoaling tendencies prior to eventual liberation. Conversely, dispersal methods are essential in species that are strongly territorial and potentially cannibalistic. Ontogenic changes in habitat requirements may also have to be considered if maintenance of the species within set geographical limitations is an objective of the enhancement program.

Genetic Considerations and the Introduction of Exotics

The maintenance of native gene pools and the preservation of genetic variation and adaptive gene combinations in natural populations have the potential to be compromised through the deliberate release of hatchery-reared fishery stocks of different or restricted genetic profiles. Conserving natural genetic variation is important for continued evolution in wild stocks, but also has direct economic implications for use in aquaculture. However, genetic variability also represents an opportunity to improve stocks for enhancement or restoration by selective breeding. Selective breeding is at one end of a scale of genetic modification that could potentially result in the released animals out-competing the natural stocks and eventually completely replacing, rather than augmenting, the target fishery. A cautionary approach has always been urged with regard to improving strains for eventual release by selection.

The genetical ethics involved with the deliberate release of fish into the wild have received a lot of attention and most large-scale, public-funded release schemes have in place guidelines for the selection of broodstock, release sites and the health status of the released fish. Unfortunately, what is largely lacking in many programs is genetic information tracking the interactions of released and wild stocks, and so the analysis of the potential risks posed by large-scale releases is largely incomplete. What is known is that selective breeding can result in improved return rates and is, therefore, of significant economic importance in manipulation programs. In general, most proposals for minimizing genetic pollution within selective breeding programs suggest using local broodstock where possible to produce the juveniles at each release point and preserving genetic diversity through the maintenance of large broodstock numbers.

The process of fishery replacement often occurs where, for a variety of potential reasons, the historical fishery has become extinct. Often in these cases it is identified that the re-establishment of the fishery using the same species would not be successful. In this situation, and where an identified basis for a new fishery to replace the failed one exists, introductions of different native species or in some cases nonnative species, or exotics, has taken place. Often the greatest care is taken with such introductions and many countries have strict laws governing the movement and introduction of nonnative species in order to minimize risks of disease transfer, to which native wild populations may have no resistance, and to prevent adverse competition or interbreeding. Clearly such introductions, and on scales likely to be economically viable, create special concerns. As a consequence large-scale introductions of non-natives are unlikely to form a significant proportion of future manipulation programs. Current practices do involve important safeguards to protect the ecological integrity of systems in which enhancement or restoration efforts are carried out. However, many such programs were initiated at a time when modern environmental ethics were unrecognized. As a consequence, irreversible changes have occurred in some systems.

Ecological Balance and Carrying Capacity

Crucial to any form of fishery manipulation is the question of whether or not the ecosystem that hatchery-reared fish are being introduced to can sustain and support the new introductions. Quite often it is assumed that because stocks of the main commercially relevant species are in decline, the ecosystem can support reintroduction with the aim of at least attaining historical levels. However, this ignores how the total biomass has changed and whether there is a concomitant decline. A decline in the density and abundance of one species can result in one or more other species increasing in volume because there is now spare capacity in the system. So, if the commercial species has declined to a level at which manipulation is being considered, but the spare capacity in the system once occupied by that species has now been filled by expansion from other species, the carrying capacity may be limited and, irrespective of the numbers of introductions, the target species entering the fishery will not increase.

Measurement of total biomass may, therefore, give indications as to the potential success of a fishery manipulation program. However, estimating total biomass is very difficult in what are usually dynamic trophic situations and rarely in manipulation programs do total biomass estimates exist prior to the measured decline in the target species. A potentially more practical methodology is to examine the ecosystem as a whole and identify what species are inhabiting the trophic niche that the target species would be expected to occupy on introduction. If there is a possibility of interspecific competition occurring with the target species being successful against trophic niche competitors then an introduction may be successful. This is, of course, an extremely simplistic approach and totally ignores the questions of food supply and higher order predation. If a manipulation is taken to the extreme then enhancements of food supply, reductions in predators, reductions in competitors, and increased habitat availability should also be considered. Artificial reef deployments that are designed to optimize habitat requirements, enhance lower order productivity, and minimize higher order predation and interspecific competition have proved successful in small-scale localized manipulations.

Recapture and Monitoring Performance

All fishery manipulations will require some degree of performance auditing. As well as yielding feedback as to how well the manipulation has worked there will be real economic data to be obtained in order to assess the socioeconomic and commercial validity of the manipulation. In addition, fishery managers will also obtain an indication as to any additional manipulations that may be required. Performance monitoring usually takes the form of recapture. Simple ratios of wild compared with introduced individuals give an initial indication of how the manipulation has worked, though these can be further modified through condition indices and age/growth functions. The criteria against which a successful manipulation can be assessed will vary markedly between target species and the economic reasons for the initial intervention. In most cases it is the target stock mass that will be of central importance with the objective of maximizing conversion rates of food to flesh in order to produce maximum sustainable yield. However, increasing numbers may have equal importance particularly in cases where the target species are for sport fishing.

The methods for recording the incidence of released individuals will also vary between fisheries. Large-scale introductions will invariably have to rely on return information gathered from the commercial fishery. Often these data can be obtained through a reward system to the fishermen if the method of tagging is visible enough to be identified easily. Manipulations that have employed the use of small microtag injections have required a much more active role for the assessors who have to monitor all or parts of the fishery landings in order to estimate the efficacy of the manipulation. Where intervention has occurred on a smaller scale, the active fishery may be small enough to allow for all catches to be assessed.

Ownership, Exploitation Rights and Operational Controls

Fundamental to the form and viability of any manipulation program is the legal framework on which the ownership rights to the resource and its exploitation are based. Unless traditional rights to the existing or damaged fishery exist or legal provisions are successfully made to the contrary, the default position is usually open-access exploitation. Unlimited access to the resource, within possible national or international quota controls, means that ownership of the released stock cannot be retained and, therefore, the instigation of such an enhancement or restoration program can only come from supraregional, national, or international initiatives. Only in programs where ownership of the released stock is conveyed and can be managed will private or cooperative programs be assured. In a similar way, the pattern of exploitation rights will influence heavily the investment procedures in the manipulation program. There is an established history of private, cooperative, and centralized public funding in fishery enhancement and restoration programs where, in general, private and cooperative investment only occurs where some legally protected proprietary rights exist. A fishery that remains open-access will only ever attract centralized public investment.

The source of investment will also dictate the type of fishery that is to be enhanced or restored. Centralized public funding has traditionally targeted fisheries that have large socioeconomic impacts. These fisheries are invariably ones of high volume but where the unit value of the fishery is low. Invariably these high volume/low value fisheries are ones with significant historical resonance but are declining through recruit limitations. Stock enhancement in these cases will be as much to maintain social structure and tradition than to rescue the fishery *per se*. Private and cooperative investment will be on a smaller scale and will, therefore, be attracted to low-volume fisheries, where the unit value of the fishery is high. This latter form of fishery also tends to be the type where ownership and exploitation rights are more easily established because of the smaller areas involved. In cases of private restricted ownership the ability to identify and retain the released stock is important. Also through artificial fishery manipulation the location of the fishery can be altered to the advantage of the fishermen by, for example, bringing the fishery closer to the markets or moving it to more protected waters. Location manipulation, retention of the released stock, habitat optimization, and fishery identification have all been achieved through the construction of artificial structures, that either mimic the habitat provided by a natural reef or act as fish attraction devices. In many countries the deployment of artificial structures in association with fishery enhancement, although potentially advantageous for the above reasons, can, in itself, carry a high level of legal burden even before the legal provisions for ownership regulation of the released stock are attained.

Conclusions

The manipulation of some marine fisheries has been considered to be an important tool available to fishery managers to prevent or reverse declining fisheries, or to restore or replace lost ones. However, many manipulation schemes have attracted both controversy and critisism and it has not always been possible to quantify the efficacy of all programs. It has been proposed that future manipulation programs follow a two-staged approach. This approach suggests that managers should firstly quantify the existing status of the fishery and the environment (to include other species present and the ecological carrying capacity) prior to considering manipulation and then undertake a detailed premanipulation study that estimates the expected returns (numbers and value), identifies the expected beneficiaries, assigns ownership, and introduces a legal framework of regulation. Once manipulation is embarked on then a precautionary approach should be adopted. This entails adherence to agreed and planned manipulation protocols and the continuing evaluation of potential impacts with contingency plans to either adapt or end the manipulation if adverse impacts are detected. In addition, there are now case studies from around the world that highlight decades of past manipulation research, dozens of species released and many fisheries targeted. In general, there does appear to be a trend emerging, which is that successful manipulation tends only to occur where the species is not migratory on a large scale, is part-contained by habitat availability, and is dependent on relatively low levels of recapture in order to be economically or socially viable. These type of criteria are best represented by low volume, high value fisheries where environmental carrying capacity can be increased. In addition, manipulations that have been undertaken in parallel with habitat enhancement schemes (for example, artificial reefs, nursery ground restoration or protection) have been among the most successful.

See also

Coral Reef and Other Tropical Fisheries. Crustacean Fisheries. Demersal Species Fisheries. Marine Fishery Resources, Global State of. Molluskan Fisheries. Open Ocean Fisheries for Deep Water Species. Open Ocean Fisheries for Large Pelagic Species. Salmon Fisheries: Atlantic. Salmon Fisheries: Pacific. Seabirds and Fisheries Interaction. Small Pelagic Species Fisheries. Southern Ocean Fisheries.

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FISHING METHODS AND FISHING FLEETS

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Introduction

Since the early days of mankind fishing has been an important source of food supply. The means to collect fish and other aquatic animals evolved from very simple tools to the present, often sophisticated, fishing methods. Nevertheless, many of the ancient fishing gears are still in use today, in one form or another. Even if their contribution to the total world catch is negligible, they are often very important for the economy of local communities. The efficiency of a limited number of fishing methods, such as trawling and purse seining, has become