# Chapter 13. Fish Stock Propagation

**Contributors:** Kai Lorenzen, Stephen Smith, Michael Banks, Chang Ik Zhang, Zacharie Sohou, V. N. Sanjeevan, Andrew Rosenberg (Lead Member)

## 1. Definition

Fish stock propagation, more commonly known as fisheries enhancement, is a set of management approaches involving the use of aquaculture technologies to enhance or restore fisheries in natural ecosystems (Lorenzen, 2008). "Aquaculture technologies" include culture under controlled conditions and subsequent release of aquatic organisms, provision of artificial habitat, feeding, fertilization, and predator control. "Fisheries" refers to the harvesting of aquatic organisms as a common pool resource, and "natural ecosystems" are ecosystems not primarily controlled by humans, whether truly natural or modified by human activity. This places enhancements in an intermediate position between capture fisheries and aquaculture in terms of technical and management control (Anderson, 2002).

The present chapter focuses primarily on enhancements involving releases of cultured organisms, the most common form of enhancements often described by terms such as 'propagation', 'stock enhancement', 'sea ranching' or 'aquaculture-based enhancement'.

## 2. Enhancements in marine resource management

Enhancements are developed when fisheries management stakeholders or agencies take a proactive, interventionist approach towards achieving management objectives by employing aquaculture technologies instead of relying solely on the protection of natural resources and processes. Enhancement approaches may be used effectively or ineffectively in resource management. To understand how enhancement initiatives can give rise to such different outcomes, it is important to consider not only the technical intervention but the management context in which the initiative has arisen, including ecological and socioeconomic factors as well as the governance arrangements (Lorenzen, 2008).

### *2.1 Effective enhancements*

Enhancement approaches may be employed towards different ends commonly referred to as sea ranching, stock enhancement and restocking (Bell et al. 2008). Sea ranching entails releasing cultured organisms to maintain stocks that do not recruit naturally in the focal ecosystem. This may involve stocks that once recruited naturally but no longer do so due to loss of critical habitat, or it may involve creation of fisheries for desired "new" species for which the focal system provides a habitat suitable for adult stages but not for spawning or for juveniles. Stock enhancement is the practice of releasing cultured organisms into natural stocks of the same species on a regular basis, with the aim of increasing abundance or harvest beyond the level supported by natural recruitment. Restocking entails temporary releases of cultured organisms into wild stocks that have been depleted by overfishing or extreme environmental events, with the aim of accelerating recovery or enabling recovery of stocks "trapped" in a depleted or declining state. The use of enhancement approaches represents a spectrum from strongly production/catch-oriented applications to strongly conservation/restoration-oriented ones, and entails quite different management practices (Section 13.5; Table 2).

The technical intervention of enhancements interacts synergistically with governance arrangements. Stakeholders or management agencies invest in enhancements when they have incentives to do so, either because they stand to gain material benefits (e.g. increase in harvests) or because engaging in enhancement activities increases the perceived legitimacy of management arrangements or agencies (for example, stakeholders may be more supportive of a management agency that engages in fisheries enhancement activities than of one that only regulates fishing). Enhancements require a reasonable level of governance control to emerge at all (they are unlikely to emerge under unregulated open access), and they tend to further strengthen governance control when implemented (Anderson, 2002; Drummond, 2004; Lorenzen, 2008). By helping to strengthen and transform governance arrangements, enhancement initiatives can sometimes generate fisheries management benefits beyond those directly attributable to the technical intervention.

Economic and social benefits of enhancements may arise from biological outcomes such as increased catches or maintenance of fisheries and other ecosystem services in highly modified environments. Successful enhancements often have further, more derived benefits. Pinkerton (1994), for example, describes economic benefits of Alaska salmon enhancements that result from greater consistency and quality of harvests, as well as greater volume. Enhancements can make economic and social benefits from aquaculture technologies available to stakeholders, such as traditional fishers who may lack the assets, skills or interest to engage in conventional aquaculture.

In addition to direct management benefits, enhancements provide opportunities for advancing basic knowledge of ecology, evolution and exploitation dynamics of marine resources (Lorenzen 2014).

### *2.2 Ineffective enhancements*

Often, enhancements are initiated under conditions that are fundamentally unsuitable for their effective use, or designed inappropriately. Such ineffective enhancements can nonetheless persist for a considerable time and sometimes do considerable ecological and economic damage. Incentives for stakeholders or management agencies to engage in enhancement activities can exist even in the absence of evidence of their technical effectiveness, and once investments have been made and stakeholders have become vested, it becomes increasingly difficult to discontinue such initiatives. These issues point to the need for constructive science and management engagement with the development of new, and the reform of existing, enhancements (Section 13.4).

### *2.3 Examples of enhancement efforts*

The following examples illustrate the potential for well-managed enhancements to contribute to fisheries management goals and the interactions between the technical and governance dimensions of such initiatives.

Very large-scale enhancement efforts are undertaken in the Pacific Northwest of the United States of America (Naish et al., 2007). These efforts include enhancements to support commercial and recreational fisheries (Knapp et al., 2007), enhancement and restocking initiatives to meet tribal treaty obligations (Smith, 2014), and restoration efforts for endangered populations (Kline and Flagg, 2014). Pacific Northwestern habitats once hosted a tremendous biomass of salmon that comprised a significant component of food and nutrient webs linking ocean and freshwater biomes. For example, it is estimated that the Columbia River once hosted returns of 10-16 million wild salmon (Johnson et al., 1997). Historical overharvest, irrigation withdrawals, hydropower dams and other factors have reduced returns. Of the current returns of around 1 million, hatchery fish make up around 80 per cent (95 per cent of the coho, 70 to 80 per cent of the spring and summer chinook, 50 per cent of the fall chinook, and 70 per cent of the steelhead) (NMFS, 2000)). In Oregon, Nicholas and Hankin (1989) estimated that 21 of 36 coastal stocks of spring and fall chinook salmon were almost entirely comprised of wild fish. In the remaining stocks, the percentage of hatchery fish in the runs ranged from 10 to 75 per cent. Oregon's hatchery programme annually releases 74 million salmonids: 60.4 million salmon, 6.4 million steelhead and 7.6 million trout (ODFW, 1998). Such hatchery programmes can maintain fisheries when essential habitats are degraded or inaccessible and help conserve or restore endangered populations, but they also pose ecological and genetic risks to wild populations. A major scientific review of Columbia River hatchery programmes successfully used population modelling to identify hatchery operation and harvest policies that simultaneously improve the conservation status of wild populations and provide moderate increases in harvest (Paquet et al., 2011). In Alaska, large-scale salmon enhancements are run by community-based Aquaculture Associations. Since the mid-1970s, Aquaculture Associations produce and release juvenile salmon and, in return, gain exclusive rights to a share of the harvest in the form of "cost-recovery fish". The associations have since become engaged in many aspects of salmon fisheries management, effectively creating a co-management system with the State of Alaska.

The world's largest marine invertebrate fisheries enhancement is the scallop enhancement operation run by fishing cooperatives in Hokkaido, Japan (Uki, 2006). Development of an effective spat collecting, on-growing and releasing technology in the mid-1960s created the opportunity to seed scallop grounds with high densities of juveniles. Fishing cooperatives adopted rotational seeding and harvesting of fishing grounds, combined with predator control, and increased regional production from an average of 40,000 tons to around 300,000 tons per year. The success of this enhancement has been attributed to a combination of factors including suitable habitat, the species' biology (young optimal harvest age, low post-release dispersal), integration of spat releasing with predator control and rotational harvesting, and devolution of management to a fishing cooperative with exclusive rights over the resource (Uki, 2006).

In New Zealand, the Japanese scallop enhancement technology was adapted to revive the Southern Scallop Fishery in what became a restocking initiative combined with far-reaching changes in governance. Adoption of aquaculture technology allowed the fishery to opt out of the fisheries management framework of the time and transition to an individual quota-based regime and rotational seeding and harvesting. Cultured juveniles contributed strongly to initial recovery but natural recruitment became dominant as the fishery was rebuilt (Drummond, 2004). More recently, low spat survival has led to a sharp reduction in catches and to the closure of some of the main grounds (Williams et al. 2014). This decline in survival may be related due to changes in productivity due to increasing sedimentation in the area.

In the Republic of Korea, the National Fisheries Research and Development Institute (NFRDI) developed seed production technology to release healthy juveniles of rockfish and sea bream. Since 1998, seed production and fish release have successfully enhanced fishery resources and increased the income of fishermen. In the early stages of seed production, national facilities took the lead to develop techniques, but currently private companies produce the seed. Between 1986 and 2012, 46 marine species including abalone, various flatfish, sea bream and sea slugs were targets for production and 1,410 million juveniles of fish and shellfish species were stocked in the sea in the Republic of Korea. In the Republic of Korea, habitat restoration tools are also widely applied together with fish release in situations where habitat has been identified as the primary factor limiting production. These tools refer to the increase in available habitat and/or access to key habitat for at least some stages of the life history of a target species. Although artificial habitats are currently popular in some areas and widely used, scientific evaluation of the effectiveness of habitat restoration is incomplete. In the Republic of Korea, construction of artificial reefs is aimed at improving productivity of devastated fishing grounds by providing fish resources with habitats, and spawning and nursery grounds. Since 1971, about 3,000 fishing grounds have been augmented, with artificial reefs covering a total area of 216 kha as of 2012. Fifty-five per cent of the area with artificial reefs is utilized as fishing grounds and the other 45 per cent is preserved as spawning and nursery grounds of fish resources. Enhanced fisheries are managed cooperatively with fishing communities and marine enhancement in the Republic of

 

Korea is becoming integrated into a comprehensive ecosystem-based fisheries management approach (Zhang et al., 2009).

In India, efforts with regard to stock enhancement of Penaeid prawns along the Kerala coast have not met with the desired success. This probably reflects heavy mortality of hatchery grown post larvae on their release to the sea, as they are neither acclimatized to the stress conditions of the sea nor have they acquired adequate predator avoidance skills. An additional effort in India is intended to revive depleted marine snail species along the coast of Tamil Nadu; *Xancus pyrum* (sacred chank), *Babylonia spirata* (whelk), *Hemifusus pugilinu*s (spindle shells), *Chicoreus ramosus* (murex) and *C. virgineus*. Wild stocks of all of these species are heavily exploited for their meat (India exports 700 to 900 tons of frozen whelk meat every year), shells (used as a trumpet in temples and for the manufacture of ornaments) and opercula (which have medicinal value and are exported to Australia, France, Germany, Italy, Japan). About 10,000 juveniles and 0.5 million larvae of the above species were sea-ranched in the Gulf of Mannar in October 2010. It is premature to comment on the success of this experiment, but regular surveys of the-grow out site show only a few dead organisms.

### *2.4 Global extent of enhancements*

Marine fisheries enhancement is a widespread activity. Between 1984 and 1997, 64 countries reported stocking over 30 billion individuals of over 180 species in marine environments (Born et al., 2004). The global contribution of enhancements to marine fish production is difficult to quantify exactly, but is unlikely to exceed one to two million tons per year (around 1-2 per cent of global marine fisheries and aquaculture production) (Lorenzen 2014). This modest contribution to global production should not distract from the fact that considerable efforts and monetary investments are expended on enhancement initiatives, and that enhancements contribute substantially to several high-value fisheries as well as to restoration efforts for various species of conservation concern.

### *2.5 Developing or reforming enhancements*

According to the reviewed assessments, enhancements are often initiated or promoted by fisheries stakeholders, but require scientific and management engagement in order to assess the potential of such initiatives, to develop effective enhancement systems where the potential exists, and to discontinue initiatives that are likely to be ineffective or harmful. Constructive science and management engagement with enhancements may be guided by the widely used and recently updated "responsible approach" (Blankenship and Leber, 1995; Lorenzen et al., 2010). The updated responsible approach consists of 15 recommended actions, divided into three stages of development or reform (Table 1). A staged approach ensures that the basic potential of enhancements is assessed (Stage I) prior to investment in technology development and pilot studies (Stage II), which in turn precede operational-scale implementation(Stage III). Qualitative and quantitative modelling are crucial in Stage I, and experimental (adaptive) management is central to assessing enhancement capacity and ecological impacts in later stages. This requires monitoring of temporal and spatial controls where fisheries are not enhanced and possibly not exploited (Caddy and Defeo 2003; Leleu et al., 2012; Costello, 2014). The most systematic and rigorous application of many ideas summarized in the responsible approach can be found in the Hatchery Reform process being applied to Pacific salmon hatchery programmes (Mobrand et al., 2005; Paquet et al., 2011).

## 3. Management considerations

### *3.1 The fisheries system and management context*

Enhancements enter into existing fisheries systems and it is crucial to gain a broad-based understanding of the system prior to defining management objectives and assessing possible courses of action. At a minimum the following should be considered: the biology and status of the target fish stock (biological resource), the supporting habitat and ecosystem, the aquaculture operation, stakeholder characteristics (of fishers, aquaculture producers and resource managers), markets for inputs and outputs, governance arrangements, and the linkages between these components. A framework for enhancement-fisheries system analysis is outlined in Lorenzen (2008).

### *3.2 Stakeholder involvement*

Stakeholder involvement is central to effective scientific and management engagement with enhancement initiatives because stakeholders tend to have a large influence on the initiation and development of such initiatives. Only when stakeholders are constructively involved in the assessment and decision-making process is the enhancement initiative likely to develop towards a beneficial conclusion (which may be an effective enhancement or the discontinuation of an ineffective or damaging initiative). Stakeholder involvement also makes the often considerable knowledge and experience of stakeholders accessible to the scientific and management process.

### *3.3 Identifying appropriate biological and technical system designs*

Different enhancement strategies, such as sea ranching, stock enhancement and restocking, involve quite different management approaches and considerations (Utter and Epifanio, 2002; Naish et al., 2007 and Lorenzen et al., 2010; Lorenzen et al., 2012). Table (2) outlines the different practices involved with regards to aquaculture, stock and genetic management (based on Lorenzen et al., 2012).

 

### *3.4 Stock dynamics and management*

Quantitative assessment of stock dynamics and the potential of enhancement as well as alternative management options, such as harvest restrictions to contribute to stock management objectives, is important at all stages of enhancement initiatives (Caddy and Defeo, 2003; Walters and Martell, 2004; Lorenzen, 2005). Different considerations apply to ranching, stock enhancement and restocking systems (Table 2). In ranching systems where maintaining natural recruitment is not a management goal, stock structure could be manipulated to maximize biomass production in food fisheries or to maximize abundance of 'catchable' size fish in put-and-take recreational fisheries. In stock enhancements where cultured fish are released into wild populations, it would be desirable to manage stocking and harvesting activities so as to limit negative impacts on naturally recruiting stock components which may arise from compensatory ecological responses to stocking or from overfishing of the natural spawning stock (Hilborn and Eggers 2000; Lorenzen, 2005). Such effects may reduce or eliminate net benefits from enhancement and pose conservation threats to wild stocks. Impacts of enhancements on wild stocks could be reduced by separating the cultured and wild population components as far as technically possible at the point of stocking, and through differential harvesting and possibly induced sterility of cultured fish (Lorenzen, 2005; Naish et al., 2007; Mobrand et al., 2005). According to these authors, restocking is likely to be advantageous over natural recovery only for populations that have been depleted to a very low fraction of their carrying capacity and requires concomitant reductions in fishing effort (Lorenzen 2005). Fisheries models and assessment tools are now available to conduct such quantitative assessment at all stages in the development or reform of enhancements (Lorenzen, 2005; Michael et al. 2009).

### *3.5 Aquaculture production for enhancements*

Rearing of marine organisms in culture facilities subjects them to domestication processes that have strong and almost always negative impacts on their capacity to survive, grow, and reproduce in the wild (Le Vay et al., 2007; Lorenzen et al., 2012). A variety of measures, such as rearing in near-natural environments, environmental enrichment, life-skills training and soft release strategies, can counteract such domestication effects, but none are likely to be wholly effective (Olla et al., 1998; Brown and Day, 2002). Aquaculture production for release into natural ecosystems may benefit from culture practices that differ from those normally employed in facilities producing organisms for on-growing in aquaculture facilities and may also require different genetic management.

### *3.6 Genetic management*

Genetic management is important for maximizing post-release fitness and enhancement effectiveness, and for minimizing risks to the genetic integrity of wild stocks. Three main sets of issues need to be considered: (1) potential disruption of neutral and adaptive spatial population structure due to translocation; (2) impacts of hatchery spawning and rearing on the genetic diversity of stocked fish and the enhanced, mixed stock; (3) impacts of hatchery rearing on the fitness of released fish and their naturally recruiting offspring; and (4) hybridization between stocked and wild species (Utter and Epifanio, 2002; Tringali et al., 2007; Araki et al., 2008). Appropriate sourcing and management of brood stock, possibly combined with rearing practices that minimize domestication selection are key genetic management actions and it may also be necessary to limit the contribution of cultured fish to the naturally spawning population (Miller and Kapuscinski, 2003; Tringali et al., 2007; Baskett and Waples, 2013). Different genetic management approaches may apply in sea ranching systems or “separated” stock enhancement programmes where direct genetic interactions between stocked and wild fish are absent and where, for example, selective breeding may be used to improve the post-release performance of hatchery fish (Table 2; Jonasson et al., 1997).

### *3.7 Pathogen interactions*

Impacts on wild stocks from pathogen and parasite interactions that may cause disease may occur via three mechanisms: (1) introduction of alien pathogens, (2) transfer of pathogens that have evolved increased virulence in culture, (3) changes in host population density, age/size structure, or immune status that affect the dynamics of established pathogens. It is therefore important to implement an epidemiological, risk-based approach to managing disease interactions that accounts for ecological and evolutionary dynamics of transmission and host population impacts (Bartley et al., 2006).

### *3.8 Governance*

Enhancements require governance systems that are effective at restricting exploitation and ensuring that those who invest in the resource through stocking can reap at least a sufficient share of the benefits. Depending on the wider governance framework, such arrangements can be based on individual or communal use rights (e.g., individual quotas or territorial use rights) or on government regulation (and taxation to recoup costs). A second important requirement of governance systems for enhanced fisheries is coordination of the fisheries and aquaculture components in terms of stock, genetic and health management.

### *3.9 Impacts on marine ecosystems*

Potential impacts of enhancements on marine ecosystems differ between types of enhancement system. Impacts on non-target species are of the most concern in ranching systems where organisms that do not recruit naturally in the receiving ecosystem may be released in high numbers and harvested intensively. Species introduced outside their native range pose particular risks (many have minimal impacts, but a small proportion become invasive and inflict massive ecological and economic damage). In stock enhancement systems, ecological and genetic impacts on the wild stock component tend to be of the most concern. Restocking initiatives will have broadly positive impacts on marine ecosystems as long as good stock and genetic management approaches are in place. Although potential impacts of marine enhancement activities are well understood, empirical evidence for such impacts is limited except for the large-scale salmon enhancements in the Pacific Northwest and the Laurentian Great Lakes of North America (Naish et al., 2007; Crawford, 2001). This paucity of information likely reflects the limited scale of marine enhancements to date.

### *3.10 Interactions with other sectors*

Aquaculture technologies enable enhancements in the first place and availability of cultured organisms from the commercial aquaculture sector can greatly reduce the barriers for fisheries stakeholders to engage in enhancements. Interactions with fisheries may occur in terms of access conflicts or impacts on wild target or non-target species and such interactions may increase as marine enhancements become more common. Market interactions between products from enhancements and from aquaculture and capture fisheries can be significant where enhancements account for substantial market share as in the case of salmon (Knapp et al., 2007). However, the market share of enhancements is small for most species and products, so that enhancements are more often impacted through the market by developments in the aquaculture and capture fisheries sectors than vice versa.

### *3.11 Technical and economic performance*

As discussed previously, the technical and economic performance of marine enhancements is highly variable. Reviews by Hilborn (1998) and Arnason (2001) concluded that only a small proportion of documented enhancements are demonstrably economically successful, but for many information is insufficient to assess economic viability, and some are demonstrably unsuccessful. Further assessments and comparative analyses are urgently required.

## 4. International agreements and guidelines

There are currently no international agreements pertaining directly to fisheries enhancements. Some FAO instruments, including the FAO Technical Guidelines for Responsible Fisheries, deal with issues associated with fisheries enhancements (e.g., FAO, 2008). In addition, eco-labelling of products from enhanced fisheries has been considered at the Expert Consultation on the Development of Guidelines for the Ecolabelling of Fish and Fishery Products from Inland Capture Fisheries held in 2010 (FAO, 2010). The FAO Committee on Fisheries adopted these Guidelines in 2011 (FAO, 2011). The *ICES Code of Practice on the Introductions and Transfers of Marine Organisms* (ICES, 2005) is widely accepted and applies to introductions carried out for the purpose of fisheries enhancements.

## 5. Future trends

Enhancements are likely to become more widespread as burgeoning demand for seafood and increasingly severe human impacts on the coastal oceans create greater demand for proactive management, aquaculture technologies become available for an ever-increasing number of marine species, and governance arrangements for many fisheries move towards rights-based systems that provide strong incentives for investment in resources (Lorenzen et al., 2013). Greater scientific and management attention to enhancements is required to aid the development of potentially effective initiatives and to avoid widespread investment in ineffective or damaging enhancements (Lorenzen, 2014).

## 6. State of scientific knowledge, application and recommendations

Rapid progress has been made in the scientific understanding of marine enhancements over the past 20 years (Leber, 2013). Unfortunately, the scientific knowledge and tools now available to aid the development or reform of enhancements are not widely applied (Lorenzen 2014). Reasons may include that mainstream fisheries and aquaculture scientists are often unaware of developments in this interdisciplinary area or not adequately trained to conduct the necessary assessments. Research providers and management agencies need to build capacity for engaging with enhancement initiatives using current science. Improved reporting on enhancement initiatives and outcomes at national and international level is also important. Currently, harvests from enhanced fisheries tend to be lumped into either capture fisheries or aquaculture production figures in national and international statistics (Born et al., 2004; Klinger et al., 2012).

Table 1. Elements of the updated "responsible approach" to fisheries enhancement (Lorenzen et al., 2010).

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| <u>Stage I: Initial appraisal and goal setting</u> |
| (1) Understand the role of enhancement within the fishery system |
| (2) Engage stakeholders and develop a rigorous and accountable decision-making process |
| (3) Quantitatively assess contributions of enhancement to fisheries management goals |
| (4) Prioritize and select target species and stocks for enhancement |
| (5) Assess economic and social benefits and costs of enhancement |
| <u>Stage II: Research and technology development including pilot studies</u> |
| (6) Define enhancement system designs suitable for the fishery and management objectives |
| (7) Design appropriate aquaculture systems |
| (8) Use genetic resource management to avoid deleterious genetic effects |
| (9) Use disease and health management |
| (10) Ensure that released hatchery fish can be identified |
| (11) Use an empirical process for defining optimal release strategies |
| <u>Stage III: Operational implementation and adaptive management</u> |
| (12) Devise effective governance arrangements |
| (13) Define a stock management plan with clear goals, measures of success and decision rules |
| (14) Assess and manage ecological impacts |
| (15) Use adaptive management |

Table 2. Design criteria for biological-technical components of marine enhancement fisheries systems serving different objectives (adapted from Lorenzen et al., 2012).

| | Sea ranching | Stock enhancement | Re-stocking |
|---|---|---|---|
| **Aim of enhancement** | Increase fisheries catch | Increase fisheries catch while conserving or increasing naturally recruiting stock | Rebuild depleted wild stock to higher abundance |
| **Wild population status** | Absent or insignificant | Numerically large<br>Possibly depleted relative to carrying capacity | Numerically large or small<br>Depleted relative to carrying capacity |
| **Aquaculture management** | Production-oriented<br>Partial domestication<br>Conditioning for release<br>Possibly induced sterility | Integrated programmes:<br>as for re-stocking<br>Separated programmes:<br>as for sea ranching | Conservation-oriented<br>Minimize domestication<br>Conditioning for release |
| **Genetic management** | Maintain genetic diversity<br>Selection for high return | Integrated programmes:<br>as for re-stocking<br>Separated programmes:<br>as for sea ranching;<br>also selection to promote separation | Preserve all wild population genetic characteristics |
| **Population management** | Stocking and harvesting to create desired population structure | Integrated programmes:<br>restricted stocking and harvesting to increase catch while conserving naturally recruiting stock<br>Separated programmes:<br>as for sea ranching;<br>also measures to promote separation | High stocking density over short period; temporarily restricted harvesting or moratorium |

 

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