Resource Enhancement: concepts, learnings, and future directions

Jon P. Altamirano[1] and Marie Antonette Juinio-Meñez[2]
[1]*Aquaculture Department, Southeast Asian Fisheries Development Center, Tigbauan, Iloilo, Philippines*
[2]*Marine Science Institute, University of the Philippines Diliman, Quezon City, Philippines*
jaltamirano@seafdec.org.ph

Abstract

Fish and fishery products are always in high demand causing pressure on world fish supply. The world's wild capture fisheries resources ultimately reached its peak around the early 90s and plateaued at around 90 million tonnes. The stagnancy in wild fisheries production poses an alarm to the ever-growing human population. Fortunately, at around the same time, aquaculture production has filled some gap in seafood supply with over 100 million tonnes produced annually. However, there are various concerns about aquaculture and its sustainability. This is where the idea of aquatic resource enhancement comes in, not only to increase fish yield for food but also to compensate for losses caused by anthropogenic interventions, while promoting environmental rehabilitation and conservation. Resource enhancement, as a whole, can include various concepts on sustainable development, habitat conservation and improvement, ecological management, and aquaculture-based stock enhancement. This paper highlights the development of some resource enhancement programs worldwide and provide some examples particularly those from the Southeast Asian Region. We will attempt to tackle some successes and failures, as well as review past and recent experiences to extract important learnings. Based on these lessons, future directions of how resource enhancement initiatives can be made more efficient and sustainable. As a general rule, we recommend that in order to increase chances of success for programs on resource enhancement, it has to be science-based, there needs to be inclusive and participatory planning and management involving all stakeholders and adheres to responsible culture practices. Moreover, there should be concurrent efforts in reducing fishing pressures, as well as in protecting and rehabilitating natural ecosystems.

Introduction

Seafood and seafood products are among the top sought-after and expensive food commodities. Because of the apparent abundance of seafood in commercial markets worldwide, it is thought that fish supply can be limitless. The increasing demand for seafood causes more pressure on wild fish supply, especially with the continuous increase in global population that is expected to reach over 8 billion by 2020 (UN, 2019). However, global capture fishery has been recorded to remain at around 90 million metric tons (mt) per year for over two decades now

(**Figure 1**). Some evidence of overfishing is shown to be associated with smaller-sized fish composition in catch, as well as decreasing size-at-maturity of wild fish species (Hunter *et al*., 2015). According to FAO, IUU or illegal, unreported, and unregulated fishing is one of the biggest threats to marine ecosystems that weaken the crucial efforts in sustainably managing fisheries resources while conserving marine biodiversity (FAO, 2016). The sustainability of sea-sourced resources and ecosystems are also more seriously being considered in these modern times. The United Nations established 17 Sustainable Development Goals (SDGs) in 2015, within which SDG14 specifically focuses on "Life Below Water" which aims to sustainably manage and protect marine and coastal resources and ecosystems (UN, 2015).

Aquaculture has been providing volumes of fish and aquatic products since the eighties (**Figure 1**), contributing >50 % of global seafood consumption. However, environmental issues and problems with aquaculture have been raised, pinpointing the negative effects of conversions of mangrove areas to fish ponds (Primavera, 2005), pollution from wastes and effluents (Primavera *et. al*., 2007), and even direct effects on reducing wild fish populations (Naylor *et. al*., 2000). On the bright side, research and development efforts have improved modern aquaculture. Research thrusts are not only in meeting production targets, but also consider health, biosecurity, better-sourced feeds, and environmentally-friendly culture systems. Most of these are being addressed by research institutions like the Aquaculture Department of the Southeast Asian Fisheries Development Center (SEAFDEC/AQD).

Ultimately however, the question is not only on whether or not we will have enough fish to eat in the future, but also whether natural aquatic resources and coastal ecosystems will still be in good condition. This is where the idea of resource enhancement is based upon.

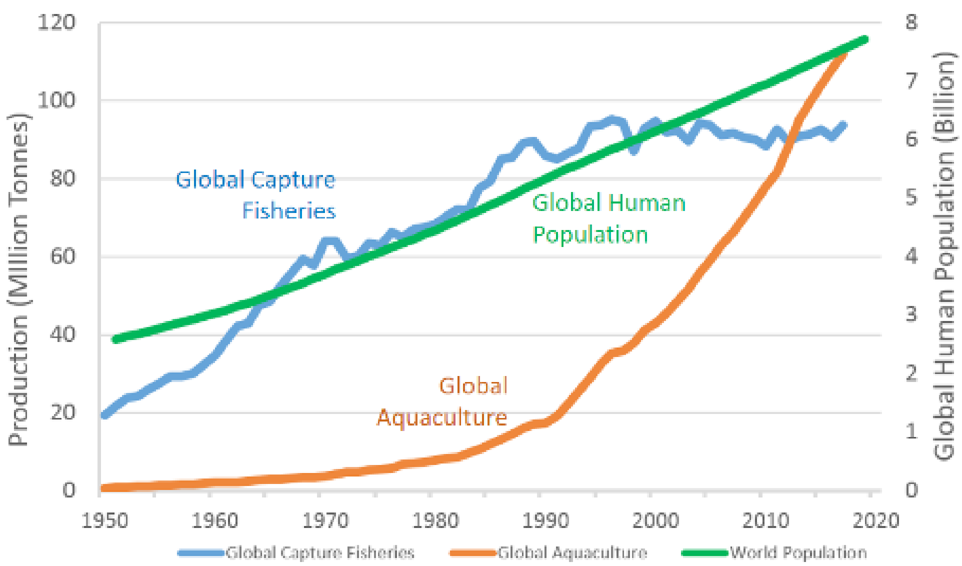

Figure 1. Global trends in capture fisheries and aquaculture (data from FAO, 2019) and world population (data from UN, 2019)

Resource enhancement: concepts, objectives and strategies

Resource enhancement has been called and defined in various ways. Terms like stock enhancement (Harada and Matsumiya, 1992; Ziemann, 2001; Drawbridge, 2002; Bell *et al*., 2006), restocking (Bannister, 1991; Bell *et al*., 2006), sea ranching (Blaxter, 1994; Bartley, 1999; Arnason, 2001; Drawbridge, 2002), coastal mitigation (Cowx, 1994; Bartley, 1999; Radtke and Davis, 2000), augmentation (Bannister, 1991; Cowx, 1994; Bartley, 1999), and addition (Bannister, 1991; Rowland, 1994) have been used interchangeably in the past because of similarity in the general goal of increasing fishery stocks in the sea.

Early stock enhancement initiatives dated back to 1867 with shads (*Alosa sapidissima*) in New England (Stickney, 1996) and chum salmon (*Oncorrhynchus keta*) in Japan in 1876 (Oshima, 1993). In 1884–1985, USA and Norway also initiated stock enhancement of finfishes (Liao, 1999). The first salmon hatchery in the United States was established in the 1870s (Blankenship and Leber, 1995) and the release of marine finfish followed, including the Atlantic salmon, flounder, haddock, cod and pollock (Blaxter, 2000; Leber, 2004). Meanwhile, the earliest record of stock enhancement activities in Europe was the release of plaice in Norway and Scotland in 1882 and 1894, respectively and transplants of the same species in the Baltic and North Seas in 1893 (Blaxter, 2000). Since then, many other attempts and programs for stock enhancement followed.

Stock enhancement of invertebrates like mollusks also started as early as 1900s for scallops in Norway, but was more commercially implemented starting 1970 in Europe and Japan (Salvanes, 2001). Specifically, scallops *Patinopecten yessoensis* were produced for release in Japanese waters (Kitada, 1999). Other species released, including some echinoderms, were queen conch *Strombus gigas* (Ray *et. al*., 1994), topshell *Trochus niloticus* (Crowe *et. al*., 2012), abalone *Haliotis assinina* (Salayo *et. al*., 2020), and sea cucumber *Apostichopus japonicus* (Yokoyama, 2013) in Japan and *Holothuria scabra* (Purcell *et. al*., 2012) in the West Pacific. In China, sea ranching of abalone, scallops and sea cucumbers started in the 1980s (Jia and Chen, 2001). Other than as food resource, endangered species were also reseeded for conservation purposes like the giant clams *Tridacna* spp. (Mingoa-Licuanan and Gomez, 2002) and sea horses *Hippocampus* spp. (Okuzawa *et. al*., 2009).

Crustacean stock enhancement programs also started early, like the release of newly-hatched eggs and newly-settled juveniles of the European lobster *Homarus gammarus* in southern Norway in 1889 (Salvanes, 2001). Crabs also had extensive release studies such as the blue crabs *Callinectes sapidus* (Zmora *et. al*., 2005), *Portunus trituberculatus* (Okamoto, 2004), and mangrove crab Scylla species (Le Vay *et. al*., 2008). Shrimp stock enhancement also started since the 1960s in Japan with *Penaeus japonicus* (Kitada, 1999; Fushimi, 2016), and since 1980s in China with *Penaeus chinensis* (Wang, 2006). Unlike other species, however, crustacean stock enhancement programs were relatively few because of various problems in monitoring brought about by tagging difficulty due to molting (Altamirano and Kurokura, 2010).

In general, the release of hatchery-produced juveniles to the wild for whatever objective has been referred to as stock enhancement. However, Bell *et. al*. (2008) proposed only three main categories and definition of marine resources enhancement. "Stock enhancement" is defined as the release of hatchery-produced juveniles to augment natural supply and optimize harvests by overcoming recruitment limitation. This is viewed to have a more public oriented benefit, where the stocks will become part of the common resources that anybody can eventually harvest. "Restocking" is the release of cultured juveniles into wild populations to restore severely depleted spawning biomass and has an environmental-oriented benefit. "Sea ranching" also make use of hatchery-produced juveniles released into unenclosed marine and estuarine environments for harvest at a larger size through a "put, grow, and take" operation. Unlike the former two categories, sea ranching is mainly for private benefit, where those stocks are associated to a defined area, and secured and "cultured" by known operators. Although spill over ecological and public benefits can also be derived from sea ranching (e.g. Juinio-Meñez *et al*. 2013).

In recent decade, programs on stock enhancement, restocking and sea ranching have become more holistic. In many cases, these do not just focus on increasing the target "stocks", but largely encompass concerns of ecological sustainability, as well as, of human's capacity development and socio-economic welfare. In this paper, therefore, we will be referring to the term "Resource Enhancement" that incorporates the general stock enhancement concepts mentioned above of increasing fish and shellfish yield for food, recreation or conservation, but also includes programs for compensating losses caused by overfishing and environmental degradation by promoting resources and habitat conservation, as well as the capacity enhancement of human resources.

Resource enhancement programs vary in objectives and reasons for implementation. Cowx (1994) defined four main reasons for stocking, namely:

(1) mitigation – a voluntary stocking exercise as a fishery protection scheme after some environmental perturbation like dam construction, land drainage works, etc.;

(2) enhancement – a principal method used to maintain or improve stocks where production is actually, or perceived to be, less than the water body could potentially sustain, but where reasons for the poor stocks cannot be identified;

(3) restoration – carried out after a limiting factor to stock recovery or improvement has been removed or reduced, like water quality improvement or habitat restoration; and

(4) introduction – attempts to establish a new stock that was not previously present because of natural barriers or evolutionary isolation, or where new exotic species are introduced into existing fisheries in an attempt to increase diversity or improve yield.

In Southeast Asia, Lebata-Ramos and Doyola-Solis (2016) summarized the main reasons for conducting resources enhancement which are:

(1) to increase in production of target species;

(2) to increase food supply and income;

(3) to revive endemic species;

(4) to conserve endangered species;

(5) to rehabilitate degraded natural habitats;

(6) to restore spawning and feeding grounds;

(7) to enhance fish sanctuaries;

(8) to act as biological control;

(9) to promote aquaculture; and

(10) to develop recreational fishing.

In some cases, however, a resource enhancement program may address a multiple of these objectives.

Alongside these objectives, approaches and strategies for resource enhancement programs also vary. Welcomme and Bartley (1998) mentioned that there are two main strategies for management and enhancement of water resources, and these can be differentiated between strategies implemented in "developed" and "developing" countries (T**able 1**). Stocking strategies in "developed" countries are geared towards ecological goals, particularly the enhancement of recreational fisheries and protection of species diversity. In fact, the preference for sports fishing which are predominantly in developed countries, has led to early adoption of enhancement techniques and these were usually coupled with some form of habitat maintenance and conservation (Welcomme and Bartley, 1998). These programs are also heavily subsidized by the government like in the cases of Japan (Kitada, 1999) and the USA (Leber, 2004). Government hatcheries are capital intensive and the associated aquaculture techniques are also intensive in design, industrialized, and employ latest technology and gearing towards higher returns and profit. On the other hand, such programs in "developing" countries are mostly economically-driven, specifically for food security and income generation which also involve some form of habitat modification and intensive broadcast of seeds (Welcomme and Bartley, 1998). Aquaculture efforts to support resource enhancement in developing countries are extensive but labor-intensive, rural in nature, and lack enough funding for infrastructure development despite adequate physical potential of the area.

Table 1. Differing strategies for resource enhancement programs between developed and developing countries (after Welcomme and Bartley, 1998)

	Developed Countries	**Developing Countries**
Objectives	Conservation	Provision of food
	Recreation	Income generation
Mechanisms	Sport fisheries	Food fisheries
	Habitat restoration	Habitat modifications
	Environmentally-sound stocking	Intensive restocking
Economic	Intensive, modern aquaculture	Extensive, rural aquaculture
	Capital-intensive	Labor-intensive
	Profit	Production

Some resource enhancement initiatives

Volume and number of species

As a positive fisheries management tool and to boost fishing production, scientists and fisheries managers have been looking at ways of enhancing fish stocks for more than a century (Liao, 1999; Blaxter, 2000). Since then, well over than 300 species were estimated to have been used for release worldwide (Welcomme and Bartley, 1998), and >290+ of these are freshwater (Welcomme, 1992), signifying that marine restocking is relatively uncommon (Brown and Day, 2002). Similarly, there are more species released in freshwater bodies than in the sea of various countries in Southeast Asia. Freshwater species like the Nile tilapia (*Oreochromis niloticus*) has been the major commodity for release in small waterbodies in Savannakhet Province in Laos PDR since 1994, although the government has been recently promoting the enhancement of the Indian major carps (*Cirrhinus mrigala* and *Labeo rohita*) as well (Garaway *et. al*., 2006). In the whole Southeast Asia, the most common are barbs, particularly the silver barb *Barbonymus gonionotus*, and tilapia *Oreochromis niloticus* with Malaysia and Thailand leading the most number of freshwater species targeted for enhancement (see summary table in Lebata-Ramos and Doyola-Solis, 2016). On the other hand, the Philippines ranked first for the most number of marine species released for resource enhancement, including various species of high value finfishes, crustacean, mollusks and echinoderms. In comparison, about 80 species are being ranched or researched for eventual stocking in Japan alone (Fushimi, 2001; Salvanes, 2001).

A recent systematic review of the global marine stock enhancement reported a total of 187 species comprised mainly of marine fish, salmon, crustaceans, mollusks and other species was released by 20 countries between 2011 and 2016 (Kitada, 2018). Japan released the largest number of species (72) followed by Taiwan (24 marine fish species only), USA (22 species), China and South Korea (14 species) and Australia (seven species). Other countries released only one or two species in considerable quantities. Salmon hatchery release is the largest release program in the world. Five countries (USA, Canada, Russia, South Korea and Japan) released seven species of salmon in the millions. The US alone was reported to release 2 billion juveniles in 2016 (Kitada, 2018).

Recovery and enhanced catch

Although stock enhancement activities have been done more than a century ago, the approach during those early times can be categorized as being focused on "production" where the main concern was achieving higher release volume and magnitude (Leber, 1999). Especially for developing countries, the anticipated increase in stock volume is viewed to have direct impact in terms of increasing sales from catch. A specific example for this benefit is shown by the stock enhancement activities of sea bream *Pagrus major* in Japan (Fujii, 2016). Sequential releases of red sea bream stocks since 1983, resulted in detectable increase of harvests since 1990, and even recorded abundance of wild recruits since year 2000 (see Fujii, 2016; Kitada *et. al*., 2019). In another species, the Japanese flounder *Paralichthys olivaceus* stock enhancement in Fukushima Prefecture, Japan has achieved a 30% recapture rate, and the cost-benefit ratio is estimated to be more than 300% (Masuda and Tsukamoto, 1998). Through purely theoretical calculations, Yulianto *et al*., (2019) estimated the potential benefit of stock enhancement of grouper *Epinephelus fuscoguttatus* in Karimunjawa Islands, Indonesia to be 1.27–1.69 USD (based on 1000 released fish, 10–15 cm size), but can be highly variable depending on weather conditions.

In terms of general recovery, a recent review by Kitada (2018) from 37 studies covering 24 species, revealed that the overall weighted mean recovery rate was only at 8.1 ± 8 %. In general, recovery rates for fish species (e.g. cod, sea bream, halibut, mackerel) can be between 10–15 %, while crustacean species (e.g. shrimp, lobster, crabs) achieved a recovery rate of less than 6 %, with mangrove crabs at only 0.9 % (Kitada, 2018). Experimental releases of the tiger shrimps *Penaeus monodon* in Aklan, Philippines showed promising results whereby quantitative evaluation of recovery was recorded, even conservatively, at 8 % (Altamirano *et al*., 2016) (**Figure 2**). Shrimp releases in China since the 1980s had evaluated recovery of 0.001–1.88 % (Jia and Chen, 2001).

Unfortunately, the low recovery and negative economic returns for resource enhancement programs have been more common (Kitada, 2018). In Norway, releases of juvenile Atlantic cod (*Gadus morhua*) in 1980s and 1990s did not significantly increase cod production and catches (Svåsand *et. al*., 2000). Very high mortality of hatchery-bred juvenile topshell *Trochus niloticus* released in Australia, Indonesia and Vanuatu was recorded, which was mainly associated with predation (Crowe *et. al*., 2002). Mortality and high variation in recovery were also limited by the carrying capacity of the release sites, as in the case of red sea bream *Pagrus major* and the Japanese flounder *Paralichthys olivaceus* in Japan, whereby "cautious approach" to stock enhancement is recommended (Kitada and Kishino, 2006).

More than just enhancing catch

While there have been numerous efforts on resource enhancement, the major gap is in evaluating their impacts. Economic gain in terms of fishery production is often the intended target of large-scale efforts of long-term culture-based enhancements. However, smaller-scale community-based restocking and sea ranching efforts were also undertaken for conservation of species and at the same time development of supplemental

Figure 2. A local fisher (left) helps in monitoring the sizes of tiger shrimps caught daily, taking special note of tags (right) to indicate samples of released shrimps

sources of livelihood, as well as capacity building of local communities (Fushimi, 2016; Juinio-Meñez, 2016). Unintended impacts such as development of tourism attractions, ecotourism learning sites and community empowerment related to improve environmental/ecological conditions have also been realized in some cases particularly in Southeast Asia.

Efforts for the stock enhancement of the Japanese kuruma prawn *Penaeus japonicus* in Hamana Lake, Shizuoka, Japan was not quick and easy. It took some awareness molding among seven collaborating villages around the lake to realize some success in increased catch. Capacitated local communities were then able to implement shrimp releases and environmental monitoring by themselves since 1985 (Fushimi, 2016). In Thailand, capacity building and awareness campaign was implemented in Sriboya Island, Krabi Province, where various stakeholders of dog conch *Strombus canarium* were informed of its sustainable management and habitat conservation in 2013 (Manajit *et. al*., 2016). Through various public awareness activities, permanent dog conch conservation sites were established by local communities in the region where sustainable harvesting and management are now in place.

In the Philippines, the communal sea ranching of the sandfish *Holothuria scabra* was piloted in a small 5-ha area in Bolinao, Pangasinan as a means to help rebuild local population and provide a supplemental source of income to small fishers (Juinio-Meñez *et. al*., 2012). The sea ranch is managed by some members of a local small fishers' association (Samahan ng Malililit na Mangingisda ng Victory) and are responsible for guarding, maintenance and providing assistance in the monitoring. They share in the sales of harvested and processed sandfish from the sea ranch (**Figure 3**). A spawning population is maintained in the area because sandfish are not harvested until they reach >300 g, which is greater than the average size of sandfish that attain sexual maturity (>180 g) (Juinio-Meñez *et. al*., 2013). Increase in landed catch of sandfish is attributed by collectors to the efforts of the local managers in maintaining the sandfish sea ranch.

Restocking efforts for endangered species are also being carried out in the Philippines for giant clams whose natural populations have been depleted while the largest species, *Tridacna gigas*, was virtually extinct (Juinio *et. al*., 1989). Tens of thousands of cultured juveniles of the different species (*Tridacna gigas*, *T. derasa*, *T. squamosal*, *T. maxima*, *T. crocea*, *Hippopus hippopus*) have been produced in the hatchery, reared in the ocean nurseries, and restocked in over 40 locations throughout the Philippines (Gomez and Licuanan, 2006). Indication of natural recruitment from the restocked clams have been documented in at least two of these sites (Cabaitan and Conaco, 2017). Moreover, the projects also had

Figure 3. Local fishers participating in the communal sea ranching of sandfish in Bolinao, Pangasinan, Philippines

the unintended long-term impact of enhancing coastal ecotourism activities and revenues, where giant clam gardens have become part of tourist attractions in restocking sites that were well maintained, in partnership with the private sector and local government. Meanwhile, a theoretical study on the benefit of stock enhancement of grouper *Epinephelus fuscoguttatus* in Karimunjawa Islands, Indonesia, estimated a projected positive contribution to tourism around the islands by potentially generating 550,000 USD annually (Yulianto *et. al*., 2019).

Some problems and concerns

Stock enhancement studies were conducted extensively in many countries, mostly unscientifically, for more than a century but the success of these programs were apparently absent and unquantifiable (Welcomme and Bartley 1998; Cowx, 1999; Liao *et. al*., 2003; Bell *et al*., 2006). The long-lived constraint of stock enhancement or restocking activities is not only the lack of proof of success in terms of harvest and ultimate production, but also in terms of natural ecology, and effects on social dynamics of local fishing communities.

The case of abalone *Haliotis asinina* enhancement in Sagay, Negros Occidental, Philippines demonstrated the success of fishery recovery, but also highlights the role of aquaculture in mass-producing the seeds required for repopulating degraded target species and improve catch of beneficiary fishers (Salayo *et. al*., 2020). In many cases, however, release of stocks in the wild was done because of surplus in supply of hatchery-bred and reared individuals originally for aquaculture, like for shrimps in Japan and China (Fushimi, 1999; Wang, 2006). This has become a popular method of supplementing depleted stocks. However, the capability to produce abundant seeds from hatcheries and aquaculture farms is not enough reason to release juveniles and call it stock enhancement (Bell and Nash, 2004). Moreover, hatchery operation often only accounts for large quantities of seed production, rather than producing good quality and ecologically viable individuals (Fushimi, 2001; Brown and Day, 2002). Without careful considerations, these haphazard releases would eventually result in critical loss of stock fitness through ecological impacts and genetic introgressions (Kitada, 2018), negative interactions of released stocks with wild species and alter trophic dynamics (Cowx, 1994), possible transfer of diseases (Bartley *et. al*., 2006), and socio-cultural impacts on the local human communities (Garaway *et. al*., 2006; Altamirano *et. al*., 2015).

The limited number of broodstock, which were often spawned multiple times, to produce seeds for release may result in many anomalous genotypic and phenotypic traits. Kitada (2018) summarized the genetic risks of artificial propagation that may include:

(1) loss of genetic diversity;

(2) loss of fitness and performance;

(3) change in population composition,; and

(4) change in population structure.

This is why, as a precautionary approach, it is recommended to use only local stocks of wild broodstock to maintain genetic integrity of local populations, as in the case of the sandfish *H. scabra* that showed highly defined regional genetic structures in the Philippines (Ravago-Gotanco and Kim, 2019).

Problems with the local fishing communities can also arise because fisheries management programs, including stock enhancement, entail some kind of social modification like fishing limitations (Altamirano *et al*., 2015). Often, the success of the resource enhancement program can be largely dependent on the presence of a strong local community leadership, and that the community members have direct access to the benefits while being agreeable and able to adapt the technology required (Garaway *et al*., 2006). There is also that inherent danger of dependency by the benefiting community on the stock enhancement activity. Lenanton *et al*., (1999) reported that should the artificial releases be successful in increasing catch and income, there might be the desire to continue such activity over longer periods, while creating the tendency to overlook the original subtle causes of the decline.

In this case, the local communities will continue to rely on this artificial and virtual solution, rather than pursuing the ultimate goal of having naturally sustainable aquatic resources. Therefore, stock enhancement or sea ranching should not be seen as a substitute for the long-term conservation and management of valuable aquatic resources (Liao et al., 2003). Blankenship and Leber (1995) summarized that to effectively recondition depleted stocks, fishing effort must first be regulated; second, degraded nursery and spawning habitats must be restored; and third, only then can stocks be replenished through stock enhancement or restocking.

Future considerations for responsible resource enhancement

Science-based and systematic

The common approach during the early times of stock enhancement can be categorized as being focused on "production" where the main concern was achieving higher release volume and magnitude (Leber, 1999). Moreover, the advent of stock enhancement activities was started with the simplistic idea that production could be increased by releasing eggs or larvae of a certain species into coastal or marine waters (Welcomme and Bartley, 1998). The period governed by this simplistic notion was branded as the "denial phase" by fisheries scientists and it is only in the late 90s, where the "science" of stock enhancement began when critical thinking emerged and scientific objectives and hypotheses were formulated (Leber, 1999).

Whatever the purposes and strategies defined for stock enhancement, it is most important to consider various scientific aspects to ensure the applicability and feasibility of such programs in achieving those goals. In contrast with the way release programs were conducted in the past, modern stock enhancement activities need to be more scientific in approach. Given the long history of questionable stocking practices, and because of the rapidly expanding interest worldwide in starting new programs, it is essential to apply a substantial amount of science towards solving several key constraints to responsible application of stock enhancement technology (Blankenship and Leber, 1995). To develop an effective and sound stock-enhancement tool, the integration and coordination of research and expertise in several essential sub-disciplines of natural science and social science are imperative. For a successful resource enhancement program, the biology and ecology of target species must be thoroughly understood from production of seed stocks until monitoring and assessing the efficiency of release, as well as the conditions of the environment for release, carrying capacity of the habitat, wild populations and diversity, factors that may contribute to mortality, and existing fisheries and social conditions (Fushimi, 2001; Liao *et al*., 2003; Garaway *et. al*., 2006).

One key in ensuring successful stock enhancement and restocking programs is following some pre-determined guidelines for systematic planning, implementation, monitoring and management. Blakenship and Leber (1995) have made a 10-point system for a responsible approach to developing, evaluating and managing marine stock enhancement programs. This system includes the following:

1. prioritize and select target species;
2. develop a species management plan that identifies harvest opportunity, stock rebuilding goals, and genetic objectives;
3. define quantitative measures of success;
4. use genetic resource management to avoid deleterious genetic effects;
5. use disease and health management;
6. consider ecological, biological, and life-history patterns;
7. identify released hatchery fish and assess stocking effects;
8. use an empirical process for defining optimum release strategies;
9. identify economic and policy guidelines; and
10. use adaptive management.

Integrated, holistic, participatory and sustainable

Scientific studies on resource enhancement have been done in the recent years, but are only mostly aimed towards reducing cost of producing ecologically fit juveniles from hatcheries and to increase survival of released stocks, hoping that only these aspects can make stock enhancement or restocking viable (Howell *et. al*., 1999; Blaxter 2000; Bell *et al*., 2004; Leber *et. al*., 2004). However, current progress in research also involves various other concerns from basic biology and ecology of target species (Fushimi, 2001), health management (Bartley *et. al*., 2006), risk assessments, socio-economic studies, as well as social science perspectives (Garaway *et al*., 2006). Perhaps, equally important are the roles of fisheries managers, local governments, and especially the local fishing communities for effective and responsible stocking program (Liao, 2003; Garaway *et al*., 2006; Altamirano *et al*., 2015; Fushimi, 2016; Juinio-Meñez, 2016). Bell *et al*., (2006) highlighted that "restocking and stock enhancement programs are applied in complex human–environment systems, involving dynamic interactions between the resource, the technical intervention and the people who use it." In Laos, increases in catch of Nile tilapia in enhanced lakes was not realized immediately. The success was mostly dependent on the characteristics of the benefited community and on how they manage the resource available to them, making the resource users the most crucial factor in the determination of ultimate outcome of the resource enhancement programs (Garaway *et al*., 2006). Lorenzen *et al*., (2010) also emphasized the need for looking at the broader picture even at the earliest phase of the project development and defining about the purpose, identifying the players, and specifying alternative measures. This also means that all players and stakeholders should actively participate, be scientifically informed, and therefore accountable for the planning, implementing and assessment of the potential contribution of enhancements.

The potential success of the enhancement program can be largely magnified when various phases and aspects of the production chain is considered. This was exemplified by the case of the scallop stock enhancement program in Japan where consideration was not only on ensuring the high quality of seedlings, but also in the improvement of the scallop general habitat, implementing proper farming management like crop rotation, and making sure that the marketing system was strong (Matsuda and Tsukamoto, 1998). It is also important to put in place some suitable and acceptable management interventions even before the release activities. Experiences in Laos for the enhancement of Nile tilapia exemplified that "the combination of access restrictions and stocking had a strong positive effect on total standing stocks" (Lorenzen *et al*., 1998). The authors also reported that releasing of stocks alone will not necessarily increase yields unless some "optimal management regimes can be identified and implemented by the management institutions."

The varying levels of success in stock enhancement programs around the world have resulted in various research concerns and scientific information generated has emphasized the importance of physiological, biological, morphological, and ecological attributes of the hatchery-reared juveniles (Fushimi, 2001) and their behavior, adaptations, and survival in the wild (Bell, 2005), as well as the social dimensions of the community (Garaway *et al*., 2006). All of these available information may already be harmonized to form part of policies and management arrangements, particularly in areas that were well-studied. At the present generation, it may be considered as a crucial crossroad for resource enhancement – from an "exploratory, research-oriented endeavor" to becoming a more useful set of tools in the "fisheries management tool box" (Lorenzen *et al*., 2013).

Culture and stock enhancement has to be incorporated within an integrated management framework that includes harvest regulation and protection of ecosystems and critical habitats. On a broader scale, a multi-criteria science-based approach can be used to delineate ecologically meaningful management units for resources as illustrated in the Philippines for sea cucumbers (**Figure 4**, UPMSI-DOST project). This includes understanding of biophysical and genetic connectivity, and distribution of habitats coupled with local governance capacity. The holistic framework for policy decision support can guide resource enhancement efforts to conserve genetic diversity and productivity in the long-term. In addition, priority areas for conservation and restocking has to take a wider ecosystem and trans-boundary approach to further ensure applicability and success (see example from Siriraksophon (2016) on regional trans-boundary refugia in Southeast Asia).

Conclusion

Resource enhancement is a century-old concept that has been ever evolving. Since its inception, some recurring themes of problems and concerns have become evident. Early stock enhancement programs

1. were focused on "production" and release volume which were considered to be not scientific;

2. made use of eggs and larvae which were eventually not measureable;

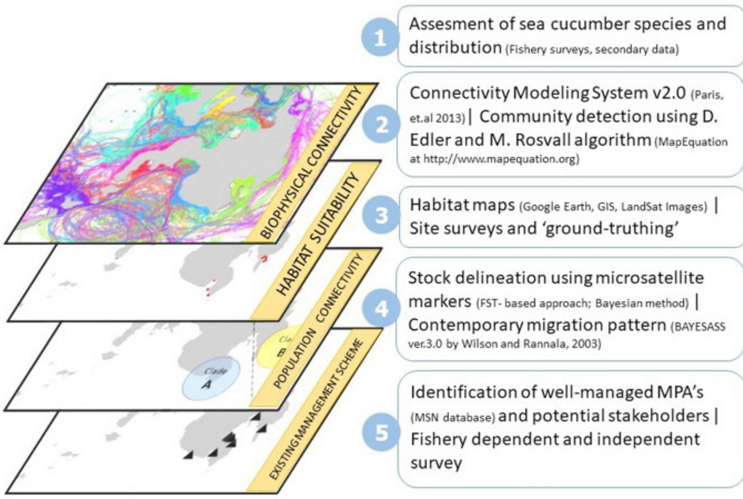

Figure 4. Integrated multidisciplinary approach to identify ecologically meaningful management units (UPMSI-DOST project)

3. used wild larvae or juveniles which may be considered to be not sustainable;

4. used of non-indigenous species which may not be ecologically-healthy;

5. lack coordination with other sector and not holistic; and

6. lack follow-through management and not integrated.

However, releases of juvenile fish and shellfish into freshwater or marine waters did increase seafood production to some extent, although monitoring were very well in place for most cases. Resource Enhancement has also evolved from doing haphazard releases, to being more holistic by incorporating habitat restoration and conservation. More and more has resource enhancement programs have engaged various stakeholders, especially the concerned local communities in developing countries, while promoting capacity building and awareness enhancement.

Although there are various and extensive experiences on resource enhancement demonstrated worldwide, whether for large commercial scale or for smaller experimental and community-based scale, resource enhancement will still need to evolve some more. The major challenges include:

(1) scaling-up production using scientific, holistic and responsible approach;

(2) sustaining production and engagement of partners while ensuring long-term ecological and socio-economic benefits;

(3) maintaining effective management and governance systems that are tailor-fit and acceptable to all stakeholders.

Resource enhancement programs need to be carefully planned. Bell *et al.* (2006)

emphasized that preliminary assessments should be carried out before investments on research and construction of facilities, and the need to have clear and specific objectives before any alternative management options are dismissed or delayed in lieu of stock enhancement. Additionally, Lorenzen (2005) promoted that studies on population dynamics and bioeconomic modeling in combination with participatory approaches in planning and implementation can provide a broad-based assessment of alternatives and help avoid unrealistic expectations and biased views and decisions.

Resource enhancement approach alone will not solve the problems of fisheries overexploitation. Programs should be integrated with other management approaches, that may already be in place (e.g. MPAs, effort control, etc.), and should be cognizant of long-term changes (e.g. effects of climate change), and should be aligned with sustainable development goals. Sustainable resource enhancement should be harmonized with responsible fishery practices and at broader scales to have real impact. For long-term sustainability, we reiterate that resource enhancement programs should be science-based, systematic, integrated, transdisciplinary, multi-sectoral, ecosystem-based and transboundary, participatory, responsible and sustainable.

If there is to be enough seafood in the future, resource enhancement must be practiced collaboratively and responsibly.

References

Altamirano, J.P. and Kurokura, H. 2010. Marking of tiger shrimp *Penaeus monodon* (Fabricius) juveniles: Comparison among inexpensive tagging options. La Mer 47(4): 33-45.

Altamirano, J.P., H. Kurokura, N. Salayo, D. Baticados, J.G. Suyo, S. Ishikawa. 2015. Community-based shrimp stock enhancement for coastal socio-ecological restoration in the Philippines. In: Romana-Eguia, M.R.R., F.D. Parado-Estepa, N.D. Salayo, & M.J.H. Lebata-Ramos (Eds.). Resource Enhancement and Sustainable Aquaculture Practices in Southeast Asia: Challenges in Responsible Production of Aquatic Species. SEAFDEC/AQD. pp 159-167.

Altamirano, J.P., Salayo, N., Kurokura, H., Fushimi, H., Ishikawa, S. 2016. Aquaculture-based restoration and stock enhancement of tiger shrimps in the Philippines. In: Kawamura H., Iwata T., Theparoonrat Y., Manajit N., and Sulit V.T. (Eds). Consolidating the Strategies for Fishery Resources Enhancement in Southeast Asia. SEAFDEC/TD. pp. 166-170.

Arnason, R. 2001. The economics of ocean ranching: experiences, outlook and theory. FAO Fisheries Technical Paper 413, 45pp.

Bannister, R.C.A. 1991. Stock Enhancement. ICES Mar. Sci. Symp. 192, 191-192.

Bartley, D.M. 1999. Marine ranching: a global perspective, In: Howell, B.R., Moksness, E., Svasand, T. (Eds.), Enhancement and Sea Ranching. Fishing News Books, Oxford, pp. 79-90.

Bartley, D.M., Bondad-Reantaso, M.G., Subasinghe, R.P. 2006. A risk analysis framework for aquatic animal health management in marine stock enhancement programmes. Fisheries Research 80, 28-36.

Bell, J.D., Bartley, D.M., Lorenzen, K., Loneragan, N.R. 2006. Restocking and stock enhancement of coastal fisheries: Potential, problems and progress. Fisheries Research 80(1):1-8.

Bell, J.D., Leber, K.M., Blankenship, H.L., Loneragan, N.R., Masuda, R. 2008. A new era for restocking, stock enhancement and sea ranching of coastal fisheries resources. Reviews in Fisheries Science. 16, 1-9.

Bell, J.D., Nash, W.J. 2004. When should restocking and stock enhancement be used to manage sea cucumber fisheries? In: Lovatelli, A., Conand, C., Purcell, S., Uthicke, S., Hamel, J.F., Mercier, A. (Eds.), Advances in Sea Cucumber Aquaculture and Management, FAO Fisheries Technical Paper No. 463. FAO of the United Nations, Rome, Italy, pp. 173-179.

Blankenship, H.L., Leber, K.M. 1995. A responsible approach to marine stock enhancement. American Fisheries Society Symposium 15, 167-175.

Blaxter, J.H.S. 1994. Summary of symposiumon sea ranching of cod and other marine fish species. Aquacult. Fish. Manage. 25, 259-264.

Blaxter, J.H.S. 2000. The Enhancement of Marine Fish Stocks. In: Southward, A.J., Tyler, P.A., Young, C.M., Fuiman, L.A. (Eds.), Advances in Marine Biology. Academic Press, London, pp. 1-54.

Brown, C., Day, R.L. 2002. The future of stock enhancements: lessons for hatchery practice from conservation biology. Fish and Fisheries 3, 79-94.

Cabaitan, P.C. and C. Conaco. 2017. Bringing back the giants: juvenile *Tridacna gigas* from natural spawning of restocked giant clams. Coral Reefs 36:591.

Cowx, I.G. 1994. Stocking strategies. Management Ecology 1, 15-30.

Crowe, T.P., Lee, C.L., McGuinness, K.A., Amos, M.J., N'Guyen, F., Tetelepta, J., Dangeubun, J., Dwiono, S.A.P., Makatipu, P.C., Manuputty, J., N'Guyen, F., Pakoa, K., Tetelepta, J. 2002. Experimental evaluation of the use of hatchery-reared juveniles to enhance stocks of the topshell *Trochus niloticus* in Australia, Indonesia and Vanuatu. Aquaculture. 206, 175-197.

Drawbridge, M.A. 2002. The role of aquaculture in the restoration of coastal fisheries, In: Costa-Pierce, B.A. (Ed.), Ecological Aquaculture, The Evolution of the Blue Revolution. Blackwell Science, Oxford, pp. 314-336.

FAO. 2016. Illegal, unreported and unregulated fishing. FAO Document I6069E/1/09.16 (http://www.fao.org/3/a-i6069e.pdf)

FAO. 2019. Fishery and Aquaculture Statistics. Global capture production 1950-2017 (FishstatJ). In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 2019

Fujii, T. 2016. Potentials and Limitations of Stock Enhancement Programs in Japan. In: Kawamura H., Iwata T., Theparoonrat Y., Manajit N., and Sulit V.T. (Eds). Consolidating the Strategies for Fishery Resources Enhancement in Southeast Asia. SEAFDEC/TD. pp. 136-139.

Fushimi, H. 2001. Production of juvenile marine finfish for stock enhancement in Japan. Aquaculture 200, 33-53.

Fushimi, H. 2016. Improvement of Stocking Efficiencies. In: Kawamura H., Iwata T., Theparoonrat Y., Manajit N., and Sulit V.T. (Eds). Consolidating the Strategies for Fishery Resources Enhancement in Southeast Asia. SEAFDEC/TD. pp 18-24.

Garaway, C.J., Arthur, R.I., Chamsingh, B., Homekingkeo, P., Lorenzen, K., Saengvilaikham, B., Sidavong, K. 2006. A social science perspective on stock enhancement outcomes: Lessons learned from inland fisheries in southern Lao PDR. Fisheries Research. 80, 37-45.

Gomez E.D., Mingoa-Licuanan S.S. (2006) Achievements and lessons learned in restocking giant clams in the Philippines. Fish Res 80:46–52.

Harada, Y., Matsumiya, Y. 1992. A theoretical study on resource enhancement by stocking, with special reference to its intergenerational effects. Nippon Suisan Gakkaishi 58, 1833-1842.

Howell, B.R., Moksness, E., Svasand, T. 1999. Stock Enhancement and Sea Ranching. Fishing News Books, Oxford, United Kingdom.

Jia, J. S., and J. X. Chen. 2001. Sea farming and sea ranching in China. FAO Fish. Tech. Paper, 418.

Juinio, M.A.R., Menez, L.A.B., Villanoy, C.L., Gomez, E.D. 1989. Status of giant clam resources in the Philippines. J. Mollus. Stud. 55, 431–440.

Juinio-Meñez, M.A. S. Paña, G.M. de Peralta, T.O. Catbagan, R.D. Olavides,C.A. Edullantes, B.D. Rodriguez. 2012. Establishment and management of communal sandfish (*Holothuria scabra*) sea ranching in the Philippines. In: C.A. Hair, T.D. Pickering, D. Mills, eds. Asia-Pacific tropical sea cucumber aquaculture. Proceedings of an International symposium held in Noumea, New Caledonia, 15-17 February 2011. ACIAR Porc. No. 136. Australian Center for International Agricultural Research, Canberra. 121-127.

Juinio-Meñez, M.A., J.C. Evangelio, R. D. Olavides, M.A. Paña, G. M. de Peralta, C. M. Edullantes, B. D. Rodriguez, I.L. Casilagan. 2013. Population dynamics of cultured *Holothuria scabra* in a sea ranch: Implication for Stock Restoration. Rev. in Fish. Sci. 21(3-4): 424-432.

Juinio-Meñez. M.A. 2016. Approaches in rebuilding sea urchin and sea cucumber populations in the Philippines. In: Hajime, K., *et al*. (Eds.) Consolidating the Strategies for Fisheries Enhancement in Southeast Asia. SEAFDEC/TD. pp 161-164.

Kitada, S. 1999. Effectiveness of Japan's stock enhancement programmes: Current perspectives. In: Howell, B.R., Moksness, E., Svasand, T. (Eds.), Stock Enhancement and Sea Ranching. Fishing News Books, Oxford, United Kingdom, pp. 103-131.

Kitada, S., and Kishino, H. 2006. Lessons learned from Japanese marine finfish stock enhancement programmes. Fisheries Research. 80, 101-112.

Kitada, S. 2018. Economic, ecological and genetic impacts of marine stock enhancement and sea ranching: A systematic review. Fish and Fisheries. 19, 511-532.

Kitada, S., Nakajima, K., Hamasaki, K., Shishidou, H., Waples, R.S., Kishino, H. 2019. Rigorous monitoring of a large-scale marine stock enhancement program demonstrates the need for comprehensive management of fisheries and nursery habitat. Scientific Reports. 9, 5290

Le Vay, L., Lebata, M.J.H., Walton, M., Primavera, J., Quinitio, E., Lavilla-Pitogo, C., Parado-Estepa, F., Rodriguez, E., Ut, V.N., Nghia, T.T., Sorgeloos, P., Wille, M. 2008. Approaches to stock enhancement in mangrove-associated crab fisheries. Reviews in Fisheries Science 16, 72-80.

Lebata-Ramos M.J. and Doyola-Solis E. 2016. Fishery Resource Enhancement: An Overview of the Current Situation and Issues in the Southeast Asian Region. In: Kawamura H., Iwata T., Theparoonrat Y., Manajit N., and Sulit V.T. (Eds). Consolidating the Strategies for Fishery Resources Enhancement in Southeast Asia. SEAFDEC/TD. pp. 124-128.

Leber, K.M. 1999. Rationale for an experimental approach to stock enhancement. In: Howell, B.R., Moksness, E., Svåsand, T. (Eds.), Stock Enhancement and Sea Ranching. Fishing News Books, Oxford, pp. 63–73.

Leber, K.M. 2004. Marine stock enhancement in the USA: status, trends and needs. In: Leber, K.M., Kitada, S., Blankenship, H.L., Svasand, T. (Eds.), Stock Enhancement and Sea Ranching: Developments, Pitfalls and Opportunities. Blackwell Publishing Ltd., Oxford, United Kingdon, pp. 11-24.

Lenanton, R.C., Ayvazian, S.G., Dibden, C., Jenkins, G., Sarre, G. 1999. The use of stock enhancement to improve the catch rates of black bream, *Acanthopagrus butcheri* (Munro) for Western Australian recreational fishers. In: Howell, B.R., Moksness, E., Svasand, T. (Eds.), Stock Enhancement and Sea Ranching. Fishing News Books, Oxford, United Kingdom, pp. 219–230.

Liao, I.C. 1999. How can stock enhancement and sea ranching help sustain and increase coastal fisheries? In: Howell, B.R., Moksness, E., Svasand, T. (Eds.), Stock Enhancement and Sea Ranching. Fishing News Books, Oxford, pp. 132-149.

Liao, I.C., Su, M.S., Leano, E.M. 2003. Status of research in stock enhancement and sea ranching. Reviews in Fish Biology and Fisheries 13, 151-163.

Lorenzen, K., Agnalt, A.-L., Blankenship, H.L., Hines, A.H., Leber, K.M., Loneragan, N.R., Taylor, M.D. 2013. Evolving context and maturing science: Aquaculture-based enhancement and restoration enter the marine fisheries management toolbox. Reviews in Fisheries Science. 21, 213-221.

Lorenzen, K., Garaway, C.J., Chamsingh, B., Warren, T.J. 1998. Effects of access restrictions and stocking on small water body fisheries in Laos. Journal of Fish Biology. 53, 345-357.

Lorenzen, K., Leber, K.M., Blankenship, H.L. 2010. Responsible approach to marine stock enhancement: An update. Reviews in Fisheries Science. 18, 189-210.

Manajit, N., Theparoonrat, Y., Amornpiyakrit, T., Yingyuad, W. 2016. Habitat conservation and resources enhancement in seagrass beds in Sriboya Island, Krabi Province, Thailand. In: Kawamura H., Iwata T., Theparoonrat Y., Manajit N., and Sulit V.T. (Eds). Consolidating the Strategies for Fishery Resources Enhancement in Southeast Asia. SEAFDEC/TD. pp 117-120.

Masuda, R., Tsukamoto, K. 1998. Stock enhancement in Japan: Review and perspective. Bulletin of Marine Science. 62, 337-358.

Mingoa-Licuanan, S.S. and E. D. Gomez. 2002. Giant clam conservation in Southeast Asia. Tropical Coasts. 9(2): 24-56.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H., Troell, M. 2000. Effect of aquaculture on world fish supplies. Nature. 405, 1017-1024.

Okamoto, K. 2004. Juvenile release and market size recapture of the swimming crab *Portunus trituberculatus* (Miers) marked with coded wire tags. In: Leber, K.M., Kitada, S., Blankenship, H.L., Svasand, T. (Eds.), Stock Enhancement and Sea Ranching: Developments, Pitfalls and Opportunities. Blackwell Publishing Ltd., Oxford, United Kingdom, pp. 181-186.

Okuzawa, K., Maliao, R., Quinitio, E., Buen-Ursua, S., Lebata, J., Gallardo, W., Garcia, L., Primavera, J. 2008. Stock enhancement of threatened species in Southeast Asia. Reviews in Fisheries Science. 16, 394-402.

Oshima, Y. 1993. History of technical development in stock enhancement and aquaculture. Midori Shobo, Tokyo, Japan.

Primavera, J.H. 2005. Mangroves, fishponds, and the quest for sustainability. Science. 310, 57-59.

Primavera, J.H., Altamirano, J.P., Lebata, M.J.H.L., delos Reyes, A.A., Pitogo, C.L. 2007. Mangroves and shrimp pond culture effluents in Aklan, Panay Is., Central Philippines. Bulletin of Marine Science. 80, 795-804.

Purcell, S.W., Hair, C.A., Mills, D.J. 2012. Sea cucumber culture, farming and sea ranching in the tropics: Progress, problems and opportunities. Aquaculture. 368–369, 68-81.

Radtke, H.A., Davis, S.W. 2000. Economic feasibility of salmon enhancement propagation programs, in: Knudson, E.E., Steward, C.R., MacDonald, D.D., Williams, J.E., Reiser, D.W. (Eds.), Sustainable Fisheries Management: Pacific Salmon. CRC Press, Boca Raton, pp. 381-392.

Ravago-Gotanco, R., Kim, K.M. 2019. Regional genetic structure of sandfish *Holothuria* (Metriatyla) *scabra* populations across the Philippine archipelago. Fish Res. 209, 143-155.

Ray, M., Stoner, A.W., O'Connell, S.M. 1994. Size-specific predation of juvenile queen conch, *Strombus gigas*: iImplications for stock enhancement. Aquaculture 128, 79-88.

Rowland, S.J. 1994. Stocking of freshwater fishes and policy in New South Wales,. In: Prokop, F. (Ed.), Translocation Issues in Western Australia. Fisheries Department of Western Australia, Fisheries Management Paper 83, pp. 50-62.

Salayo, N.D., Azuma, T., Castel, R.J.G., Barrido, R.T., Tormon-West, D.H.M., Shibuno, T. 2020. Stock enhancement of abalone, *Haliotis asinina*, in multi-use buffer zone of Sagay Marine Reserve in the Philippines. Aquaculture. 523, 735138.

Salvanes, A.G.V. 2001. Ocean ranching. In: Steele, J., Turekiane, K.K., Thorpe, S.A. (Eds.), Encyclopedia of Ocean Sciences, Academic Press, pp. 1973-1982

Siriraksophon, S. 2016. Fisheries refugia: A regional initiative to improve the integration of fisheries and habitat management. In: Kawamura H., Iwata T., Theparoonrat Y., Manajit N., and Sulit V.T. (Eds). Consolidating the Strategies for Fishery Resources Enhancement in Southeast Asia. SEAFDEC/TD. pp 80-92.

Stickney, R.R. 1996. Aquaculture in the United States: A historical survey. John Wiley and Sons, New York, USA.

Svåsand, T., Kristiansen, T. S., Pedersen, T., Salvanes, A. V., Engelsen, R., Naevdal, G., Nødtvedt, M. 2000. The enhancement of cod stocks. Fish and Fisheries, 1, 173–205.

United Nations. 2019. World Population Prospects 2019: Highlights (ST/ESA/SER.A/423). United Nations, New York.

United Nations. 2015. Transforming Our World: The 2030 Agenda for Sustainable Development (A/RES/70/1). United Nations, New York.

Wang, Y.G., Haywood, M.D.E. 1999. Size-dependent natural mortality of juvenile banana prawns *Penaeus merguiensis* in the Gulf of Carpentaria, Australia. Marine and Freshwater Research 50, 313-317.

Wang, Q.Y., Zhuang, Z.M., Deng, J.Y., Ye, Y.M. 2006. Stock enhancement and translocation of the shrimp *Penaeus chinensis* in China. Fisheries Research 80, 67-79.

Welcomme, R.L., 1992. A history of international introductions of inland aquatic species. FAO Fisheries Technical Paper No. 294. FAO, Rome, p. 318 pp.

Welcomme, R.L., Bartley, D.M. 1998. Current approaches to the enhancement of fisheries. Fisheries Management and Ecology 5, 351-382.

Yokoyama, H. 2013. Growth and food source of the sea cucumber *Apostichopus japonicus* cultured below fish cages - Potential for integrated multi-trophic aquaculture. Aquaculture. 372-375, 28-38.

Yulianto, I., Hammer, C., Wiryawan, B., Palm, H.W. 2019. Cost-benefits of grouper *Epinephelus fuscoguttatus* (Forsskål, 1775) stock enhancement and sea-ranching in Indonesia. Asian Fisheries Science. 32, 124-130.

Ziemann, D.A. 2001. The potential for the restoration of marine ornamental fish populations through hatchery releases. Aquar. Sci. Conserv 3, 107-117.

Zmora, O., Findiesen, A., Stubblefield, J., Frenkel, V., Zohar, Y. 2005. Large-scale production of the blue crab *Callinectes sapidus*. Aquaculture 244, 129-139