Responsible marine stock enhancement as a solution to the problem of depleted or declining fish stocks - A review

R.P.P.K. Jayasinghe* and K.H.K. Bandaranayake

National Aquatic Resources Research and Development Agency (NARA), Crow Island, Colombo 15, Sri Lanka.

Abstract

Stock management and enhancement are very important techniques to positively deal with the world fish demand. It allows fisheries to recover from overexploitation and thereafter maintain stock in a sustainable manner. Stock enhancement, however, is not a simple procedure as it is closely linked with all the ecosystem parameters. Many authors have described the stepwise criteria needed to develop such programs and achieve successful enhancement. Each stock enhancement program is case specific and exceptional; therefore, it is difficult to generalize the processes. Japan has a good history for stock enhancement practices and there are several examples of successful stock enhancement programs which provide unique examples to the world. Modern aquaculture techniques and advanced expertise are the key factors behind the success in Japan. On the other hand, Sri Lanka has little experience in stock enhancement and management in the sea and the country needs to urgently develop a successful enhancement program.

Keywords: Stock enhancement, Sustainable fisheries management

*Corresponding author – Email: prabath_jayasinghe@yahoo.com

Introduction

The global demand for fish and fisheries related products is increasing year by year and fishery managers are continuously searching for sustainable ways to extend fisheries resources. Most of the stocks of the top ten species which account in total for about 30% of the world marine capture fisheries production in terms of quantity are, however, already over exploited (FAO, 2010). Even though aquaculture gives good support in meeting the world's rising fish demand, recent statistics show that the growth rate of aquaculture production is slow due to the impacts of a wide range of factors (FAO, 2010). In such a situation, fisheries managers and scientists have the responsibility to find urgent solutions to meet the increasing demand for fish.

In some situations, it is possible to combine both capture fisheries and aquaculture in an integrated manner (Muir and Young, 1998) in order to increase the fish supply. In this sense, Bell *et al.*, (2008) stated that releasing of hatchery reared fish juveniles to some coastal fisheries would be advantageous for both capture fisheries and aquaculture. Here the main task is producing fish juveniles in hatcheries to release them to natural habitats with the aim of enhancing the wild fish stocks. Stock enhancement was defined by Stottrup and Sparrevohn (2007) as "multiple releases of fish to a stock chronically suffering from poor recruitment with the aim of increasing both fishery recruits and spawning biomass". Marine stock enhancement is therefore considered to be one of the best potential strategies to replenish depleted stocks and manage fishery yields (Blackenship and Leber, 1995).

The efficacy of using stock enhancement to replenish fisheries, however, is still being debated among scientists (Coronado and Hilborn, 1998), mainly due to the lack of a reliable method to determine whether such hatchery releases were successful and achieved the desired increase in stock (Blackenship and Leber, 1995). A responsible approach, therefore, is essential in stock enhancement programs in order to ensure success.

This review examines aspects of responsible marine stock enhancement practices with specific examples from Japan, and considers their applicability in Sri Lanka to enhance the fish production.

Responsible marine stock enhancement

Stock enhancement is not a program of simply releasing fish larvae or juveniles to the sea. Planning of effective stock enhancement program is more complex and should be carried out to address possible biological and economic failures in the future. By reviewing a range of stock enhancement programs, Taylor *et al.*, (2005) proposed that all the uncertainties behind stock enhancement should be addressed by stepwise small scale research projects to reveal the underlying mechanisms of stock dynamics and to resolve any effects stocking may have. It should be carried out in a scientific manner taking account major environmental and genetic aspects, socio-economic and management aspects and implications for the particular species within the ecosystem (Blankenship and Leber, 1995).

Blankenship and Leber (1995) proposed a ten-step responsible approach to marine stock enhancement which is shown below together with the comments by Taylor *et al.*, (2005) in their review. Due to the nature of the variability in the marine environment, these steps should be individually tested in each application for better performances.

(i) Prioritize and select target species for enhancement

- Initial workshop to define and rank selection criteria
- Community survey to solicit opinions on selection criteria and identify candidate species
- Rank candidate species with respect to selection criteria and seek consensus from stakeholders on most appropriate species

The needs of stakeholders of the community, available aquaculture technology, the duration needed and fund availability should be considered during the selection of a target species. Some suggested criteria for selecting species are given in Fig. 1. and ranking of primary goals should be done according to each situation.

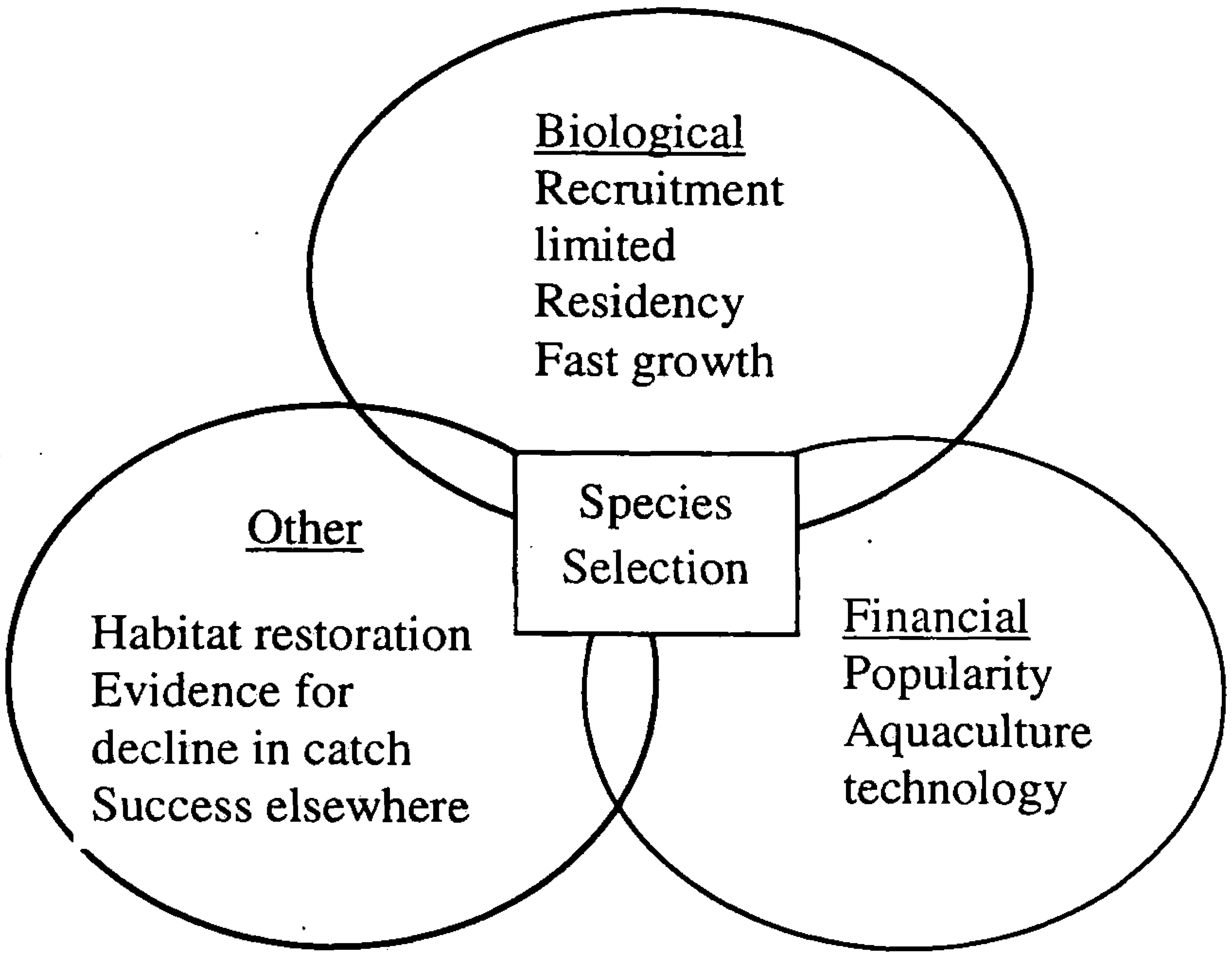

Fig. 1. Suggested criteria for selecting species for stock enhancement (modified from Taylor *et al.*, (2005)).

(ii) Develop a species management plan

- Identify harvest opportunity, stock rebuilding goals and genetic objectives
- Consider goals and objectives in the context of the management plan for candidate species
- Evaluate strategies to use in conjunction with stock enhancement

The development of individual species management plans will evaluate the uncertainties, assumptions and expectations with regard to the performance of the enhancement program and such plans may include habitat restoration to assist stocking efforts (Blankenship and Leber, 1995).

(iii) Define quantitative measures of success

- Develop benchmarks against which enhancement success can be measured
- Benchmarks should be related to stock rebuilding goals and genetic objectives

Carrying capacity is a measure of biomass of a given population that can be supported, in terms of available food and habitat in the ecosystem (Cooney and Brodeur, 1998). This should be very carefully evaluated as exceeding carrying capacity of an ecosystem can lead to the displacement of other individuals that share the resources or shift in the ecosystem (Molony *et al.*, 2003; Kitada and Kishino, 2006).

(iv) Use of genetic resource management

- Identify the genetic risks and consequences of enhancement
- Define enhancement strategies
- Outline research needs and objectives
- Develop a feedback mechanisms
- Implement genetic controls in the hatchery and monitoring and evaluation programs of wild stocks

Due to frequent use of cultured brood stocks for production of larvae, long term stock enhancement programs often encounter genetic effects on wild populations (Kitada *et al.*, 2009). Attempts should be made to minimize such effects in order to keep the natural stocks healthy.

(v) Proper management of disease and health

- Adopt responsible hatchery practices
- Certify fish are free from viral, parasitic and bacterial infections

Every measure should be taken to avoid stocking of diseased fish into the wild as it may cause contamination of wild stocks and will lead to low survival rates of released fish (Johnson and Jenson, 1986).

(vi) Formulate enhancement objectives and tactics

- Evaluate stock enhancement in an ecological context

The status of the environment should not be altered due to the enhancement program. The food-web structure, marine biological diversity and water quality status should be maintained.

- Evaluate behavioral and physiological deficiencies that may be present in stocked fish

This is a very vital factor to be considered since it can directly affect the success of the growth, development and reproduction of fish. There are several studies that have been carried out to correlate the special behavioral changes, to stock enhancement (Fushimi, 2001; Tsukamato *et al.*, 1997).

(vii) Identify released fish and assess stocking effects

- Develop efficient methods for marking fish
- Evaluate interactions between hatchery fish and wild stocks and competitors

Recognizing stocked fish is essential to assess the effectiveness of stock enhancement, as natural fluctuations of fish stocks can mark successes or failures and stocked fish must be tagged to distinguish from the wild fish and the tagging must not interfere with behavior, biological functions and survival rates (Blankenship and Leber, 1995). In addition, the tags should be cheap, simple and effective (Taylor *et al.*, 2005).

(viii) Use an empirical process to define optimum release strategies

- Optimize stocking strategies through pilot-scale releases
- Use empirical data from pilot releases to control enhancement impacts

Leber *et al.*, (1996) pointed out that although it is logistically difficult to quantify survival of stocked fish in a coastal environment, this information is vital to a successful implementation and evaluation of the stock enhancement program (Blankenship and Leber, 1995).

(ix) Identify economic and policy guidelines

- Assess the value of enhancement in terms of costs and benefits

The ultimate objective is to gain economical benefits by enhancing the natural stocks. It is helpful to record all the economic values and build up economic models and carry out cost benefit analyses for each system. Similarly, policy makers also have to play an important role in reporting, price controlling and legislation.

(x) Use adaptive management

- Adopt a continuing assessment process that allows improvement over time
- Allow integration of new ideas and strategies into the management process

Adaptive management is a process for changing both production and management to control the improvements of enhancement, thus allowing better results over time (Blankenship and Leber, 1995). Effective and adaptive management process may be difficult when many different stake holders are involved in a stock enhancement program. A single body should be appointed by stakeholders to oversee and manage the program, especially if the program operates across state or national boundaries (Taylor *et al.*, 2005).

Stock enhancement practices in Japan

The new pioneers in marine enhancement are fisheries scientists and fishermen working together on a shared but carefully allocated resource, as exemplified in Japan (Kitada *et al.*, 1992). The history of the development of modern techniques begins in Japan in the late 1800s to the beginning of 1900s, with the successful larviculture of red sea bream, *Pagrus major*, carried out in Okayama prefecture by Kajiyama and Nishioka in 1930 (Fushimi, 2001). This initial success was followed by giant steps in stock enhancement practices in the country. The Japan Fisheries Agency (JFA), Japan Sea-Farming Association (JASFA) and Seto Inland Sea fish Farming Association (SISFA) supported the industry by developing various technical aspects in stock enhancement such as brood stock management, induced spawning, egg incubation and rearing fry and juveniles. With the continuous production of larvae, Japanese stock enhancement program commenced in 1963 with 32 different species of fish, shellfish and other invertebrates (Imamura, 1999). Kitajima (1991) stated that 63 million individuals of red sea bream were produced in hatcheries for stock enhancement and aquaculture purposes. With the rapid growth in technology, by 1997, seed production for stock enhancement was performed for 88 species with a total production of 14 billion individuals for 85 species including natural seeds (Takebe, 1999).

Intensive larviculture is one of the main and important aspects of stock enhancement. In Japan with the development of the finfish hatchery technologies the quality of the larvae improved together with the reduction in cost, labour and space. At the same time, the technology associated with nutritive feed production was developed. For example, Fukusho (1986) describes the detailed requirements of successful culture of red bream larvae as follows: a concrete tank with a volume of 27 -200 m^3, depth of 1-2.5 m is usually used. The density of fry introduced to the tank is 12,000- 72,000 individuals/m^3 with a survival rate of 40-50% at 12-13 mm in total length. Larvae then grow up to 25-30 mm in total length in the net cages with survival rates over 90%. Further advances included the rapid development of intensive mass culture systems, mechanization - such as an automatic collecting and feeding system for live foods - and an automatic bottom sweeping system for the larviculture tanks (Fushimi, 2001).

The technologies associated with live feed culture are also important in stock enhancement. Most commonly, rotifers are used as they can be cultivated easily and are of high nutritional value. Most rotifer cultures are based on *Nannochloropsis oculata* at densities of 100 to 400 cells/ml (Fushimi, 2001). Red sea bream is the model case of commercialized stock enhancement of finfish in Japan, including the applied quantitative assessment methods for stocking effectiveness (Kitada, 1999). Japanese flounder (*Paralichthys olivaceus*) is another example in stock enhancement accounting, on average, for the production and release of 30 million and 22 million individuals, respectively, on an annual basis during the period 1993 to 1997. Furthermore, black sea bream (*Acanthopagrus schlegeli*), ocellate puffer (*Takifugu rubripes*), striped jack (*Psedocaranx dentex*) are also good demersal candidates (Fushimi, 2001) for this purpose.

Tsukamato *et al.*, (1997) described three main factors which contributed to the effectiveness of stock enhancement practices in Japan, namely, the quality of the fish, environmental conditions and the releasing techniques (Fig. 2).

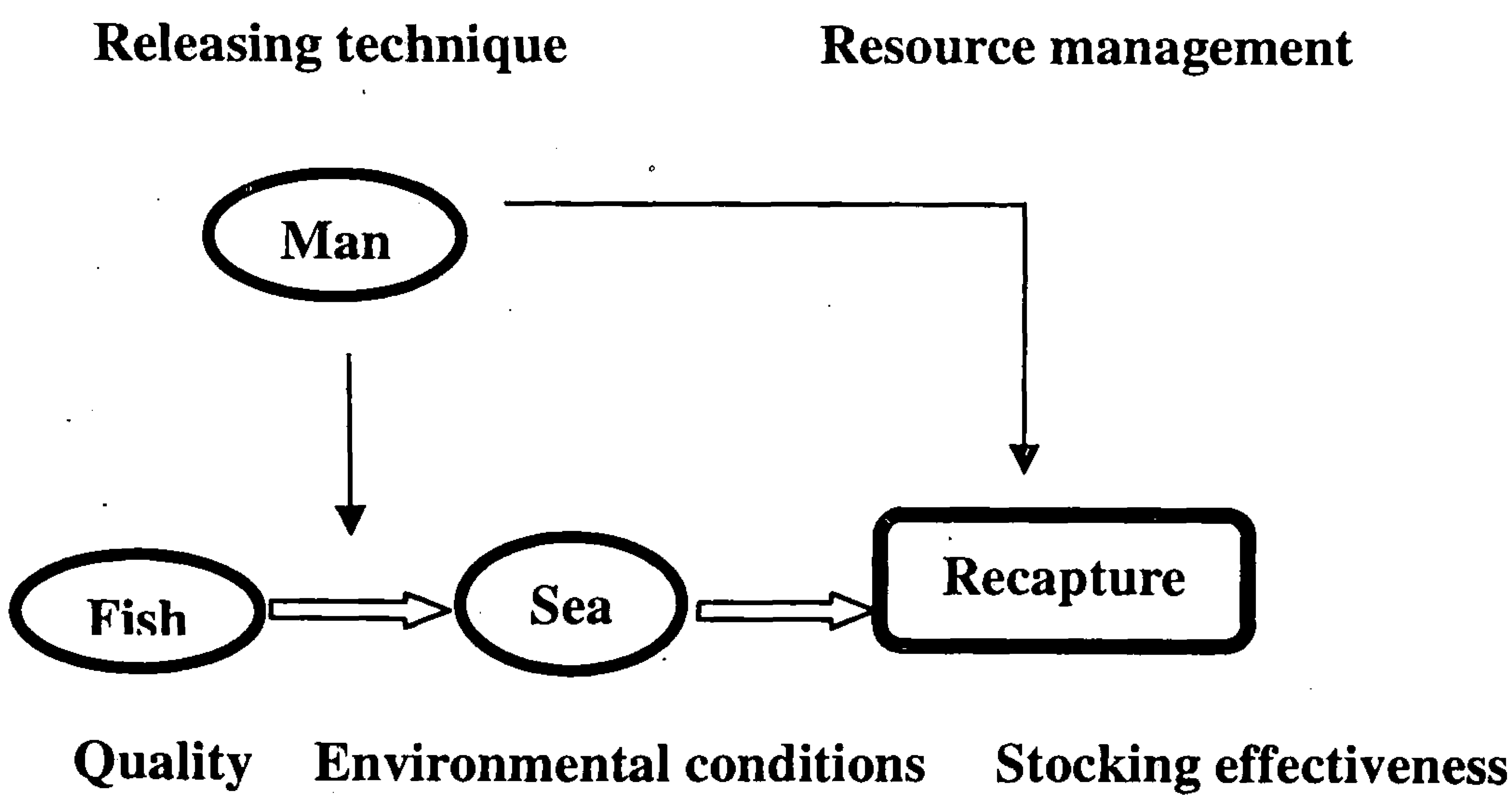

Fig. 2. Three factors that determine the stocking effectiveness of released fish

Additional factors such as morphology, physiology and behavior of each fish species is to be carefully studied before selecting a species. The special behavior of fish species such as the trilling behavior of Red Sea bream, off-bottom behavior of Japanese flounder and jumping and spacing behavior of *ayu* (sweet fish, *Pleceglossus altivelis*) were considered when dealing with a stock enhancement program.

Despite these success stories in Japanese stock enhancement programs, there are some genetically associated problems with cultured fish when compared to the wild fish larvae. Some genotypic differences between hatchery and wild fish have been reported for the following marine species: black sea bream (Taniguchi *et al.*, 1983), Japanese flounder (Sekino *et al.*, 2002), and Red Sea bream (Tabata *et al.*, 1997). A general awareness of the danger of losing genetic variation in using hatchery-produced juveniles has thus increased.

Stock enhancement practices in Sri Lanka

In Sri Lanka, records of methodological and sustainable stock enhancement practices for coastal or marine finfish species are scarce. The National Aquaculture Development Authority of Sri Lanka (NAQDA) was engaged in releasing post larva of *Penaeus monodon* (a Penaeid shrimp) with the objective of stock enhancement in the Nandikadal Lagoon located in the Northern Province in Sri Lanka. The purpose of this project was to increase the shrimp production in the lagoon and to benefit the fishermen. Under this project 1.5 million larvae of *P. monodon* have been stocked in the lagoon. In order to ensure a higher survival rate, post larvae of shrimps were released to a pen enclosure installed within the lagoon and after rearing them in the pen for about 21 days, they were released into the lagoon (NAQDA, 2011). The impacts of these releases, however, are not being monitored in a consistent manner; estimates of survival rates, environmental conditions and recapture rates are not measured correctly. A successful stock enhancement of lagoon prawn fishery has, however, been reported by Davenport *et al.*, (1999) in Sri Lanka using cultured post larvae of *P. monodon*. This activity was carried out in the Rekawa Lagoon (250 hectares) where artisanal fishery was dominated by *P. indicus* (93.6% of total catch) and small amount of *P. monodon* (0.8%). Post-larvae of *P. monodon* were released at the rate of 55,000 in 1996 and 70,000 in 1997 and the annual catch was enhanced by 1,400%. Despite this demonstration of an ecologically and economically sustainable Penaeid stock enhancement, no attempts have been made to introduce this methodology to other lagoons in Sri Lanka. Since Sri Lanka is a country with many coastal lagoons such enhancement activities could be performed to popularize such stock enhancement programs. The main reasons for not carrying out stock enhancement in these lagoons are the lack of technology and guidance, difficulties in getting post larvae and the lack of financial support. As the present level of exploitation of many coastal fishery resources in Sri Lanka is not sustainable (Haputhantri *et al*, 2008), it is vital to pay urgent attention on commencement of basic and initial research for long term responsible stock enhancement programs in the sea.

Conclusions

Since Sri Lanka, similar to many other nations is facing a problem of the depletion of fishery resources a concerted effort is needed to develop fish stocks. Stock enhancement would be a long lasting and an environmentally friendly method to deal with depleting stocks. Even though, Sri Lanka has made some attempts in stock enhancements by releasing larvae to water bodies in the past, it is clear that there is still a lack of responsible stock enhancement programs being carried out. Such programs should encompass all aspects of the process from stocking to harvesting. The success rate of the stocked fish larvae should be always calculated after the harvest to determine the contribution of stocked larvae to the yield. Mark and recapture methods (tagging) need to be developed to differentiate the stocked fish from the natural population. In carrying out such exercises, lessons could be learnt from the experience could be in Japan and similar steps followed in developing responsible stock enhancement approaches in Sri Lanka.

Acknowledgements

This work was carried out while the first author was attending a group training program on "Stock Management and Enhancement in the Sea" at Usa Marine Biological Station, Kochi University, Japan with the support of Japan International Cooperation Agency (JICA) under the International Cooperation Programme of the Government of Japan. The support given by Professor Izumi Kinoshita and JICA staff (Colombo and Shikoku) are greatly acknowledged.

References

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

Blackenship, H.L. and Leber, K.M. (1995). A responsible approach to marine stock enhancement. *American Fisheries Society symposium* **15**: pp 165-175.

Cooney, R.T. and Brodeur, R.D. (1998). Carrying capacity and North Pacific salmon production: Stock enhancement implications. *Bulletin of Marine Science* **62**: pp 443-464.

Coronado, C. and Hilborn, R. (1998). Spatial and temporal factors effecting survival of hatchery reared Salmonids in the Pacific Northwest. *Bulletin of Marine Science* **62**: pp 409- 425.

Davenport, J., Ekaratne, S.U.K., Walgama, S.A., Lee D. and Hills, J.M. (1999). Successful stock enhancement of lagoon prawn fishery at Rekawa, Sri Lanka using cultured post-larvae of penaeid shrimp. *Aquaculture* **180**: pp 65- 78.

FAO, (2010). World review of fisheries and aquaculture 2010. Part I. p 88 *Food and Agricultural Organization, Rome.*

Fukusho, K. (1986). Qualitative evaluation of artificially reared fry. In: Sea farming technology of Red Sea bream, ed.Takaka, M. and Matsumiya, Y. pp 26-36. Koseisya Koseikaku, Tokyo.

Fushimi, H. (2001). Production of juvenile marine fish for stock enhancement in Japan. *Aquaculture* **200**: pp 33-53.

Haputhantri, S.S.K., Villanueva, M.C.S. and Moreau, J. (2008). Trophic interactions in the coastal ecosystem of Sri Lanka: An ECOPATH preliminary approach. *Estuarine Coastal and Shelf Science* **76**: pp 304 –318.

Imamura, K. (1999). The organization and development of sea farming in Japan. In: *First International Symposium on stock enhancement and sea ranching*. Fishing News books, ed. Howell, B.R., Moksness, E. and Svasand, T. pp 557-572. Blackwell Scientific Publications, Oxford.

Johnson, B.O. and Jenson. A.J. (1986). Infections of Atlantic salmon, Salmo salar, by Gyrodactylus salaries in Norwegian rivers. *Journal of Fish Biology* **29**: pp 233- 241.

Kitada,. S., (1999). Effectiveness of Japan's stock enhancement programmes; current perspectives. In: *First International Symposium on stock enhancement and sea ranching*. Fishing News Books, ed. Howell, B.R., Moksness, E. and Svasand, T. pp103-131, Blackwell Scientific Publications, Oxford.

Kitada, S. and Kishino, H. (2006). Lessons learned from Japanese marine finfish stock enhancement programmes. *Fisheries Research* **80**: pp 101–112.

Kitada, S., Shishidou, H., Sugaya, T., Kitakado, T., Hamasaki, K. and Kishino, H. (2009). Genetic effects of long term stock-enhancement programmes. *Aquaculture* **290**: pp 69-79.

Kitada, S., Taga, Y. and Kishino, H. (1992). Effectiveness of a stock enhancement program evaluated by a two-stage sampling survey of commercial landings. *Canadian Journal of Fisheries and Aquatic Sciences* **49**: pp 1573- 1582.

Kitajima, C. (1991). The current status and programs for seedling production of Red Sea bream. *Suisanzosyoku* **43**: pp 112-113.

Leber, K.M., Brennan N.P. and Arce, S.M. (1996). Marine enhancement with striped mullet: Are hatchery releases replenishing or displacing wild stocks? *American Fisheries Society Symposium* **15**: pp 376- 387.

Molony, B., Lenanton, R.C.J., Jackson, G. and Norriss, J. (2003). Stock enhancement as a fisheries management tool. *Reviews in Fish Biology and Fisheries* **13**: pp 409-432.

Muir. J. and Young, J.A. (1998). Aquaculture and marine fisheries: Will capture fisheries remain competitive? *Journal of Northwest Atlantic Fisheries Science* **23**: pp 157-174.

NAQDA, (2011). Aquaculture News. The News letter of National Aquaculture Development Authority of Sri Lanka (NAQDA). **08**, (1and 2)

Sekino, M., Hara, M. and Taniguchi, N. (2002). Loss of microsatellite and mitochondrial DNA variation in hatchery strains of Japanese flounder. *Paralichthys olivaceus. Aquaculture* **213**: pp 101–122.

Stottrup, J.G. and Sparrevohn, C.R. (2007). Can stock enhancement enhance stocks? *Journal of Sea Research* **57**: pp 104-113.

Tabata, K., Kishioka, H., Takagi, M., Mizuta,A. and Taniguchi, N. (1997). Genetic diversity of five strains of red sea bream *Pagrus major* by RFLP analysis of the mtDNA D-loop region. *Fisheries Science* **63**: pp 344–348.

Takebe, T. (1999). Number of hatchery-raised seeds and its release in the period April 1997- March 1998. *Saibai* **90**: pp 8-18.

Taniguchi, N., Sumantadinata, K. and Iyama, S. (1983). Genetic change in the first and second generations of hatchery stock of black sea bream. *Aquaculture* **35**: pp 309- 320.

Taylor, M.D., Palmer, P.J., Fielder, D.S. and Suthers, I.M. (2005). Responsible estuarine finfish stock enhancement: an Australian Perspective. *Journal of Fish Biology* **67**: pp 299-311.

Tsukamoto, K., Masuda, R., Kuwada, H. and Uchida, K. (1997). Quality of fish release: behavioral approach. *Bulletin of National Research Institute of Aquaculture Supplement* **3**: pp 93-99.

Short Communications