Summary of case studies on the effectiveness of stocking aquacultured fishes and invertebrates to replenish and enhance coastal fisheries

Kenneth M. Leber
Director, Center for Fisheries Enhancement,
Mote Marine Laboratory, Sarasota, FL 34236, United States of America

INTRODUCTION

With coastal fisheries in decline around the world, there is mounting concern about how long current sources of seafood can supply world needs. Governments, resource managers and those who make their livelihood on fishing are seeking better ways to improve fishing yields. Many seek greater emphasis on restocking and aquaculture-based stock enhancement as a way rapidly to replenish depleted fish stocks and increase fishery landings. How to focus fishery-management resources so that priorities can be placed on successful management strategies is a crucial issue for the nations of the world that rely on seafood.

A look at any current textbook on fisheries science will show that there is little, if any, insight about how to make stocking an effective fishery-management tool in open-water coastal ecosystems (oceans, seas and estuaries). Currently, there is great debate among fishery scientists about whether stocking cultured fishes and invertebrates is an economically sound way to improve coastal fisheries (e.g. Blankenship and Leber, 1995; Hilborn, 1998, 1999; Blaxter, 2000). Yet many new sea ranching programmes are being planned, even as more and more people realize that there are very few successful examples of cost-effective stock enhancement of coastal stocks anywhere in the world.

Why, then, do coastal stocking programmes continue after more than a century of stocking aquacultured marine organisms in Asia, Europe and North America with little clear evidence of success? Stocking persists for two basic reasons: it is an attractive approach to fishermen and the public for increasing fishery landings; and until recently there was little if any evidence that could be used to evaluate the effectiveness, or lack thereof, of stocking coastal waters to improve fishery landings. Without much evidence to the contrary about stocking effectiveness, hatchery advocates have consistently been able to gain political support for funding large stocking programmes.

THE CASE STUDIES

In this volume, detailed overviews are presented on case studies that represent a range of marine ranching situations. These contributions represent what scientists and resource managers from several nations have found about stocking effectiveness, upon close examination of the efficacy of some of their regions' best examples of sea ranching (release of hatchery-reared animals into the sea to increase fishery landings). This volume presents, for the first time, a compilation of the goals, rationale, approach, assessment and needs of sea ranching from several different geographical areas of the world. What these papers show us is that stocking can clearly work in some cases to increase fishery landings, but that economic success will depend on many factors such as the management system, survival, culture costs and how the resource is valued. Sea-ranching technologies and strategies need far more scientific development before stocking can be generally accepted as an economically effective fishery-management tool in coastal regions.

The diversity of organisms and ecosystems covered by the case studies in this volume provide good insight about the current state-of-the-art in the field of stock enhancement and sea ranching. Among the most successful sea ranching programmes in the world are the scallop and marine fish programmes in Japan. The case study included here, which is on Japanese flounder, is one of the best examples anywhere that shows the potential for sea ranching to be an economically effective fishery management tool.

The major scientific effort to develop successful sea ranching of cod in the fiords of Norway shows the importance of carrying-capacity limitations on recruitment processes, which in this case were a barrier to success. However, the Norwegian studies of the effectiveness of stocking European lobster show good potential for successful sea ranching of crustaceans.

Assessment of the contribution of hatchery-released sturgeon by Iran in the landlocked Caspian Sea reveals how important stocking may be for preserving endangered species and for generating income from an extremely valuable fishery product, caviar. Yet the difficulties in managing sturgeon fisheries in the Caspian, especially since the collapse of the former Soviet Union, which helped to regulate the caviar fishery, reinforce our understanding of the clear need to blend sea ranching with other effective fishery-management strategies (good enforcement of fishing regulations and habitat preservation).

Sea Ranching work with barramundi in Australia shows how post-release survival can be maximized using a series of pilot release experiments to define optimal release strategies. The barramundi experience also points to the need to have good control over enhancement protocols already in place when expanding sea ranching from test sites and involving private growers and local communities in sea ranching efforts.

Work to develop a sea cucumber sea ranching technology for small-island developing states in the Pacific is a good example of how many issues one is faced with, and the planning that needs to be conducted, prior to starting new stocking programmes. Through such planning, studies to resolve several limitations that need to be overcome are now under way and many uncertainties will be resolved before much stocking is done.

These case studies are all good examples of how much focus there is today on using a scientific and responsible approach to develop and test sea ranching technologies. They all exemplify the need to use a scientific and adaptive approach to planning and implementing stocking programmes.

REVIEW OF THE FISHERY

It is clear from all of the case studies that fishery harvests over the past 30 years have declined. In some cases, however, the declines are so drastic (beluga sturgeon in the Caspian Sea, sea cucumbers in Chuuk) that there is little hope these stocks will recover on their own.

In many of the case studies, overfishing is clearly a principal problem with the fishery. The case study of sturgeon in the Caspian Sea shows how stocks plummeted, beginning in 1991. Following the collapse of the Soviet Union, it has been difficult to enforce fishery management strategies in the northern Caspian Sea, where strong centralized control over the fishery by a single government was replaced with weak to little control in some of the new nations that were formed, and sturgeon poaching has increased dramatically as a result.

Sea cucumbers in the Pacific and European lobster in Norway are also good examples of how absence of strong regulations and enforcement can result in serious depletion of the fishery. Overharvesting has severely reduced some stocks of sea cucumbers. The boom-and-bust pattern, with three to four decades before stocks could recover to levels where profitable harvests were possible again, made them especially vulnerable to fishing. Management of stocks at high harvest levels is particularly difficult in small-island developing states, which often do not have the financial and human resources needed to enforce management regulations. In the Pacific, emphasis now is on greater awareness and community-based fishery management. In Norway, strict regulations were not developed. Thus, lobster stocks were declining in Norway at the same time that other European nations that enforced tougher catch restrictions were able to maintain relatively stable yields in their lobster fisheries.

By contrast, there are relatively strong fishery management practices for barramundi in Australia, where fishing effort is strongly regulated (except for some recreational fisheries). Consequently, barramundi sea ranching is more likely to be used to enhance stocks only during poor recruitment years and there is less need to replenish depleted stocks.

Troubles for sturgeon fisheries in the Caspian Sea (and barramundi fisheries in Australia) are compounded by development, particularly of dams. Dams have been constructed on all of the great rivers that flow into the Caspian Sea, except for the Ural River. As a consequence, most of the spawning habitat for sturgeon is now inaccessible to fish migrating to spawning grounds. Oil pollution is another major concern in the Caspian Sea.

RATIONALE FOR SEA RANCHING PROGRAMMES

A principal factor that has sparked the use of sea ranching is the long time required for recovery of depleted (recruitment overfished) fisheries if only traditional management measures are used. It can take decades to recover some stocks by decreasing harvest rates and increasing minimum size for harvest. The hope for sea ranching is to be able to increase numerical abundance rapidly by bypassing juvenile recruitment bottlenecks. A prime example of this is sturgeon. Sea ranching was chosen for sturgeon more or less out of necessity, to try to sustain stocks that were fast disappearing, because there was little chance that natural recruitment could reverse declines in fishery landings. Similarly, sea ranching was planned with sea cucumber because of severe recruitment limitations in their coral reef habitats.

Other sea ranching programmes were initiated to enhance fishing opportunities. Barramundi stocking is focused mainly on recreational fisheries and was started to establish impoundment fisheries in waters that otherwise would have had only limited fishing potential. Only in Queensland are barramundi stocked in the sea, in an effort there to develop stocking techniques that can increase abundance of a relatively well-managed stock. Japanese flounder sea ranching was started as part of a large, multispecies, national effort to enhance commercial fisheries. Both depleted and declining stocks were targeted. Likewise, the Norwegian sea ranching programme (PUSH) was started as a national initiative to coordinate development efforts to enhance fishery landings of four species. The intent of the PUSH programme was to assess from a biological point of view the potential for sea ranching in Norway.

In none of the case studies were other fishery management options ignored. For example, in Australia control of fishing effort is the principal management technique. The extreme situation evident in recent attempts to manage sturgeon stocks clearly reflects how important sound regulations, good enforcement and habitat protection all are to maintaining fished stocks. Stocking alone would be no substitute for other management methods and may have little or no effect without them.

METHODOLOGY OF SEA RANCHING

The case studies reveal that clear efforts are now being made to use a responsible approach in developing and applying sea ranching technology, albeit to different degrees. It is notable that a strong scientific approach to developing, testing and evaluating sea ranching potential is now being used in most of the case studies presented here . This follows decades of little or no science available to plan such programmes effectively worldwide. Stocking strategies for sturgeon in the Caspian Sea have been developed since 1955 and now support an active commercial fishery.

To conserve the genetic diversity of wild stocks, broodstock selection and management is a key consideration in sea ranching. Whereas strict protocols are followed in some of the case studies to prevent translocation of exogenous genes and changes in allele frequencies of wild stocks, this is still not a universal practice.

To prevent transferring diseases and parasites to wild stocks, or enhancing disease in the wild, strict controls are needed to ensure that only healthy hatchery-reared organisms are released. There is clear variation among the case studies in the degree of emphasis on evaluating and certifying the health of hatchery organisms prior to release.

Methods for selecting release strategies also varied widely among the case studies. Some regions used controlled experiments to compare effects of release strategies on recapture rates; others have not. There appear to be opportunities to increase post-release survival rates, especially in cases where optimal release strategies have not been identified or followed. For example, “spot stocking”, the introduction of stocked fish into receiving waters at the same time, is often used with sturgeon because it is easier than the more desired practices of “scatter stocking”, in which fish are introduced into several sites within a region, or “trickle stocking”, in which fish are introduced into a given region over a period of time, even though the latter afford better results.

In the sea cucumber studies in the Pacific islands, there has been a concerted effort to understand ecology and life history prior to launching a stocking programme. This programme, based firmly on a responsible approach, exemplifies the trend seen in most of the case studies to use pilot release experiments to optimize release strategies.

MONITORING AND EVALUATION PROGRAMMES

Measures of success

There is much variation among the case studies in the ability to gauge success, largely because of differences in marking and assessment capabilities for identifying stocking contributions to fisheries. Some programmes use high-information content tags to optimize release strategies, others use simply a benign indicator mark that identifies stocked organisms as such but has no additional information. Unfortunately, so far the search for a marking system for sea cucumbers has proved entirely futile. Some of the case studies conduct quantitative assessment, whereas others rely on more casual observations of hatchery contributions to the catch.

The contribution of hatchery fish to fishery landings varied widely in the case studies. However, all of the case studies presented impressive results. Although the actual contribution of stocked sturgeon is slightly unclear, it was evident from the European lobster studies in Norway, and with all of the species tested in the other case studies, that hatchery organisms can make substantial contributions to recruitment in coastal environments (i.e. clearly greater than 10 percent in most cases and often substantially higher).

Although a large hatchery contribution to fishery landings is impressive – it indicates that hatchery fish have survived and entered the fished stock – the more important estimate of success of coastal stocking programmes is the amount of increase in total catch afforded by stocking. But this is much harder to evaluate. Nevertheless, it is essential to determine the effect of stocking on total catch. High fishery contribution rates from stocked fish, coupled with evidence that total catch has not increased from stocking, is an indication that hatchery fish are merely replacing wild individuals. A good example of stocking success, in which total catch has clearly increased from released hatchery organisms, is the scallop fisheries of Hokkaido, Japan, (Honma, 1993). Catch increases to levels well above historic catches were initially based almost entirely on stocked *Patinopectin yessoensis* (Honma, 1993).

The importance of adapting a quantitative assessment procedure to sea ranching programmes

Benign marks that can distinguish hatchery from wild organisms, such as the pigmentation on cultured Japanese flounder and the absence of an olfactory septum in cultured sturgeon, are a valuable assessment tool. Such benign marks provide a simple and inexpensive way to distinguish hatchery from wild stocks and quantify the contribution of stocked fish to fishery yields. However, to understand and achieve their potential, sea ranching programmes need more than a simple benign mark; because there are so many unanswered questions that remain critical uncertainties about how to manage stocking effectiveness, more answers are needed to make sea ranching effective (Leber, 2002).

Many of the case studies require improvements in yield–cost ratio in order to be cost effective. To establish the potential impact of stocking, a mechanism should be deployed to determine if higher yields per stocked fish can be achieved. What is needed is high-information content, benign marks or tags, a critical requirement for adaptive management, to improve results based on experience when questions are posed with each release – an identifying tool that will allow any occasion for stocking to be used to address critical uncertainties about stocking strategies. High-information tags afford a way to perform scientific queries on a range of issues, simultaneously, identifying experimental variables, control conditions and replicates. A key improvement over the sea ranching practices used during most of the twentieth century (prior to the 1990s) is that assessment of stocking contribution was conducted in all of the case studies presented here.

ECONOMIC ANALYSIS (COST/BENEFIT)

Most of the case studies indicated that improvements in yield–cost ratio are needed in order to be cost effective. Release contributions to fishery landings spanned a wide range among the case studies. Except for Japanese flounder and beluga sturgeon, the economics of the other programmes showed that more research is needed before any of them would be economically viable. The case study with Japanese flounder, however, shows the greatest potential for successful sea ranching. There was a strong scientific approach used and clear economic benefits were documented for several Japanese flounder stocking locations. Given the potential for further improvements in post-release survival through adaptive management, after adopting a high-information content tag, the economic benefits already evident could substantially increase.

There were also very promising results with European lobster and barramundi, in part because of the strong scientific approach used by these programmes. Clear economic benefit has not been documented with these species, but it seems achievable if these studies continue to resolve critical uncertainties about stocking. Although carrying capacity constraints were documented with stocked cod, there is clearly some potential for profitability with Atlantic salmon, Arctic char and sea cucumbers given improved survival and growth rates, reduced rearing costs and improvement in market price.

In general, the case studies focusing on marine organisms indicate that sea ranching costs can probably be reduced in the future, as improvements in survival in the hatchery are made as a result of advances in aquaculture technology. There also appears to be latitude for improvement in post-release survival in many of the case studies.

PROBLEMS WITH PAST STOCK ENHANCEMENT PROGRAMMES

The principal problem in coastal stock enhancement programmes during most of the past century has been lack of attention on the results of stocking. Stocking coastal waters to enhance fisheries began in the last two decades of the nineteenth century in Norway, Japan and the United States. In the period that followed and until about the 1970s (for salmonids) and 1990s (for marine species), there had been so little attention given to what was achieved from stocking that even the most rudimentary stocking strategies had not been tested for effectiveness and efficiency.

The emphasis historically in stocking programmes has been on the number of fish stocked, when it should have been on fishery yield per stocked fish, ways to improve that yield and interactions with wild stocks. Why were these key success factors not considered? This was because fishery managers and scientists lacked the basic technologies needed to develop the scientific basis for stocking programmes: (1) a mark or tag to identify small hatchery fish, and (2) the marine aquaculture technology needed to grow advanced juveniles (Blankenship and Leber, 1995). As coastal fishery landings were falling, the pressure to fill stocking quotas only increased. This in turn led to fixation on stocking mostly tiny fish (postlarvae), as the unit cost to produce larger individuals is much greater. Many of the case studies, however, have shown that size-at-release is a critical variable, which can make or break stocking success (e.g. Svåsand *et al*., Russell and Rimmer, Okouchi and Kitada).

The early stocking programmes were method orientated, not problem orientated. Scientists were not seeking answers to critical uncertainties about post-stocking survival and interactions with wild stocks. In addition, only recently has there been greater acceptance of the process for optimizing stocking strategies – adaptive stocking, in which critical uncertainties about stocking effect are evaluated and ideas for improvement are tested and recycled through the process of strong inference (Baconian science) (Platt, 1964; Cowx, 1994; Blankenship and Leber, 1995; Leber, 1999).

Thus many stocking practices today are not built on a very scientific basis (Leber, 1999). As such, few of the critical uncertainties about stocking effects are actually understood. And there are few good examples of successful stock enhancement or sea ranching. Many stocking programmes still lack an adaptive approach and rely on a relentless interest in numbers stocked to sustain their funding base.

GENERAL CONCLUSIONS AND BROAD LESSONS FROM STOCK ENHANCEMENT AND SEA RANCHING PROGRAMMES

Except for a few specific examples, stock enhancement and sea ranching technology is generally lacking in sufficient information needed to ensure profitability. As the case studies clearly show, using cultured organisms to increase fishery landings is not straightforward and entails much more than merely releasing cultivated organisms. Limitations on stock abundance must be understood, and responsible protocols are needed to ensure success. For example, size of released organisms and when and where to release are critical considerations that affect survival of released fish. Acclimatization and behavioural conditioning may be needed to prevent severe mortality shortly after stocking.

Stock enhancement effectiveness depends on how well stocking is integrated with other management strategies. Stocking technology must be coupled with adequate regulations; it cannot effectively be used by itself as a strategy for managing fisheries targeting coastal stocks. In addition, lack of financial and human resources to enforce resource-management regulations remains one of the greatest problems in managing fisheries, with and without the use of stocking as an additional tool.

There is a need for fishing communities to work together to manage fished stocks. When hatchery releases are very effective at increasing fishery landings, stocking is also likely to increase fishing effort, which could result in overfishing of wild stocks unless there is a concerted effort to limit the take of wild individuals.

Although clear potential for success exists, the science of stock enhancement has not yet been developed enough to be widely implemented as a fishery management tool for catadromous and marine species. For example, after an extensive programme to evaluate stock enhancement and sea ranching potential in Norway, it is concluded that it is possible to increase the total population of some species (e.g. European lobster), but profitability has not yet been shown even for lobster, the most successful species tested.

To develop reliable stocking techniques, improvements in rearing technology and extensive testing through pilot release–recapture experiments are needed. There is a critical need for more science to advance the fields of aquaculture as well as the biology and ecology of stocked populations and interactions of hatchery and wild stocks.

Much will be learned about improving the efficiency of release strategies, as well as the life histories and management needs of wild stocks, if cultivated individuals are marked and released for experimental evaluation of stock enhancement potential. It is important to select a high-information content marking method. Better and smaller acoustic tags need to be developed, as well as smaller radio tags, to help managers and researchers gain a better understanding of fish movement patterns and harvest levels.

The economic aims for sea ranching activities must be evaluated over an extensive time frame needed to advance the technology. Only for Japanese flounder and beluga sturgeon has a clear economic advantage been shown from releasing cultivated juveniles. Improvements in survival during both the aquaculture and the release phases of the other case studies will be needed before conclusions can be drawn about the economic potential of those programmes.

KNOWLEDGE GAPS AND RESEARCH PRIORITIES INDICATED BY THE CASE STUDIES

- Interactions of stocked animals with wild stocks are the greatest concerns in coastal stocking programmes. Genetic diversity issues notwithstanding, the primary concern today regarding stocking programmes in coastal environments is whether stocked fish displace wild stocks or increase production. Given the intensity of the debate (e.g. Hilborn, 1998, 1999; Wertheimer *et al*., 2001), this issue warrants serious scientific enquiry. Several of the case studies state that the stocked organisms had not displaced wild individuals but rather had added to production. However, the evidence is weak or not presented. Determining how many fish can be sustained in different habitats is a difficult research topic, but this is a critical issue for stocking programmes.
- Genetic interaction of stocked organisms with wild stocks is another hotly debated topic for which there is scant empirical evidence one way or the other (Campton, 1995). This topic has been emphasized in numerous symposia and publications. Yet there have been almost no attempts to evaluate empirically the effects of hatchery–wild genetic interactions on wild stocks. The Norwegian studies on this topic are some of the best available, as they have begun to examine actual effects of stocking on allele frequencies.
- There was no discussion of cannibalistic effects of stocked fish on wild fish. This issue is a clear topic for future evaluation by programmes releasing carnivorous organisms.
- Use of benign, high-information content tags is growing (e.g. Russell and Rimmer, this volume, with barramundi; Svåsand *et al*., this volume, with European lobster). Their benign effects, and the large number of codes that are available for release–recapture experiments, make the coded-wire tags used in these studies ideal for resolving critical uncertainties in sea ranching. Coded-wire tags greatly facilitate development of optimal release strategies and adaptive management, as all experimental treatment conditions, controls and replicates can be coded in quite small organisms using these tags with minimal effects on animal performance.
- Many countries are working to develop genetic markers to identify hatchery stocks. Recent improvements in microsatellite DNA technology have opened the door to using genetic fingerprinting to identify different batches of hatchery fish. Genetic marks will provide a way to mass-mark batches of siblings affordably. However, genetic markers also have limitations. Because so many different tag codes are needed, it would be difficult to use genetic codes to perform, for example, simultaneous studies of release strategies such as size-at-release, release habitat and release season, as in Leber, Brennan and Arce (1998), Rimmer and Russell (1998), Russell and Rimmer (this volume) and Svåsand *et al*. (this

volume). In some of those studies, up to 80 different tag codes were used to batch-mark fish in a single experiment.

- In spite of the strong scientific approach used in the case studies, all listed critical uncertainties that need to be resolved. This topic is considered in both Munro and Bell (1987) and Leber (1999, 2002). For example, an experimental control for stocking effect is needed in studies to examine whether stocking actually increases production, instead of replacing wild fish. Simply comparing catch per unit effort (CPUE) before and after stocking is not sufficient because stocking effect is confounded by annual variability in fish abundance. What is needed to test stocking effect on abundance is a comparison of catch statistics at multiple sites with and without stocking.

SUGGESTIONS FOR A RESPONSIBLE APPROACH TO FUTURE STOCK ENHANCEMENT PROGRAMMES

There are several good summaries available of what is generally regarded today as a responsible approach to stock enhancement and sea ranching (e.g. Cowx, 1994; Blankenship and Leber, 1995; Munro and Bell, 1997). Many of the key issues are listed below.

Clearly, numerous critical uncertainties remain about how to design with confidence effective stocking programmes (Hilborn, 1999; Leber, 1999, 2002). Thus, a critical design aspect of any new stocking programme is to include at the outset a research component to evaluate ecological and economic potential to enhance a stock. Stocking programmes will continue to require an initial research phase until such time that clear protocols exist for how to ensure success, based on the body of evidence that will be gained from the development of scientific principles about stock enhancement.

It is also clear from the case studies here, and from history, that active adaptive management (Hilborn and Walters, 1992) needs to be incorporated into every stocking programme. When new questions are posed within the plans for every stocking event, new answers will become available to help guide subsequent stocking efforts. Thus, incorporating a modest research framework into stocking programmes will ensure that refinements are made constantly to improve the efficiency and effectiveness of stocking and to resolve critical uncertainties about stocking impact. Because of great uncertainty about the performance of stocking programmes, it is both economically and ecologically irresponsible to conduct stock enhancement and sea ranching programmes without a solid research framework (Hilborn, 1999; Leber 2002). Active adaptive management is the single most important measure that can be taken to improve the potential for success in existing stocking programmes.

Measures of success in new sea ranching programmes should include evaluation of key milestones at various stages of the development process (Blankenship and Leber, 1995). The various stages of development were described in several of the case studies presented here. To summarize, responsible stock enhancement and sea ranching programmes should gauge success at the following stages of development:

- Identify the priority target species.
- Identify the problems: what are the limiting factors to current fishery yields?
- Develop a management plan showing how stocking would be used within the context of other fishery-management strategies.
- Identify life history patterns.
- Identify genetic structure of target stocks and develop genetic protocols.
- Identify diseases and parasites of target stocks and develop high-health protocols.

- Identify risks and benefits of stocking.
- Identify critical uncertainties.
- Establish efficient aquaculture production technologies.
- Establish optimal release strategies (i.e. size at release, release habitat, release timing, release magnitude, conditioning and acclimatization, transport method, release distribution, marking method, adaptive management framework).
- Establish pilot-scale tests of enhancement potential.
- Identify release impact (hatchery contribution to fishery, recapture rate, whether there is a displacement effect, effect on genetic diversity of wild stock, net production effect, net effect on fishery yields, and contribution of spawning and recruitment to the next generation).
- Evaluate costs and values.
- Design and test a full-scale stocking programme.
- Use adaptive management to refine stocking strategies.

Fishery resources are rapidly declining in the face of an expanding human population. We must act now to resolve the critical uncertainties about stocking programmes. In the twenty-first century, the world will need increasingly effective new strategies for replenishing and sustaining world fisheries. We cannot afford to neglect the development of reliable stock enhancement and sea ranching technologies, if such techniques have the potential to help restore, augment and sustain viable fish populations. As the case studies here show, substantial potential exists if stock enhancement and sea ranching can be made more economical.

ACKNOWLEDGEMENTS

Many of the ideas expressed here are the product of discussions with Rich Lincoln, Conrad Mahnken, Ray Hilborn and members of the World Aquaculture Society Working Group on Marine Stock Enhancement. I thank FAO for their promotion of responsible stocking practices and for their work to expand current knowledge about recent developments in the field of stock enhancement.

References

Blankenship, H.L. & Leber, K.M. 1995. A responsible approach to marine stock enhancement. *Amer. Fish. Soc. Symp.*, 15: 167–175.

Blaxter, J.H.S. 2000. The enhancement of marine fish stocks. *Adv. Mar. Biol.*, 38: 1–54.

Campton, D.E. 1995. Genetic effects of hatchery fish on wild populations of Pacific salmon and steelhead: what do we really know? *Amer. Fish. Soc. Symp.*, 15: 337–353.

Cowx, I.G. 1994. Stocking strategies. *Fish. Manage. Ecol.*, 1: 15–30.

Hilborn, R. 1998. The economic performance of marine stock enhancement projects. *Bull. Mar. Sci.* 62(2): 661–674.

Hilborn, R. 1999. Confessions of a reformed hatchery basher. *Fisheries*, 24(5): 30–31.

Hilborn, R. & Walters, C.J. 1992. *Quantitative fisheries stock assessment*, New York and London, Chapman and Hall. 570 pp.

Honma, A. 1993. *Aquaculture in Japan*. Tokyo, Japan-FAO Association. 98 pp.

Leber, K.M. 2002. Advances in marine stock enhancement: shifting emphasis to theory and accountability. *In* R. Stickney & J. McVey, eds. *Responsible aquaculture*, pp. 79–90. Abingdon, UK, CABI.

Leber, K.M. 1999. Rationale for an experimental approach to stock enhancement. *In* B. R. Howell, E. Moksness & T. Svåsand, eds. *Stock enhancement and sea ranching*, pp. 63–75. Oxford, UK, Fishing News Books, Blackwell Science Ltd. 606 pp.

Leber, K.M., Brennan, N.P. & Arce, S.M. 1998. Recruitment patterns of cultured juvenile Pacific threadfin, *Polydactylus sexfilis* (Polynemidae), released along sandy marine shores in Hawaii. *Bull. Mar. Sci.*, 62(2): 389–408.

Munro, J.L. & Bell, J.D. 1997. Enhancement of marine fisheries resources. *Rev. Fish. Sci.*, 5(2): 185–222.

Platt, J.R. 1964. Strong inference. *Science*, 146: 347–353.

Rimmer, M.A. & Russell, D.J. 1998. Survival of stocked barramundi, *Lates calcarifer* (Block), in a coastal river system in far northern Queensland, Australia. *Bull. Mar. Sci.*, 62(2): 325–335.

Wertheimer, A.C., Smoker, W.W., Joyce, T.L. & Heard, W.R. 2001. Hatchery pink salmon in Prince William Sound: enhancement or replacement? *Trans. Amer. Fish. Soc.*, 13