Advances in Marine Stock Enhancement: Shifting Emphasis to Theory and Accountability

6

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Abstract

After over a century of use in the United States, marine stock enhancement is still at an early stage of development as a fisheries management tool in coastal environments. The principal constraint to rapid development of enhancement's potential is clear – the rush to use stock enhancement, and use it now, has nearly always led to emphasis on hatchery production at the expense of developing the science of stock enhancement. Until we develop, test and demonstrate a clear predictive capability about the outcome of hatchery release effect, premature conclusions will prevail and continue to hamper the development of stock enhancement as a fishery management tool. Multidisciplinary teams are needed, coupled with an experimental approach and adaptive management to resolve critical uncertainties. Two of the most important uncertainties are 'does stock enhancement increase production' and, if so, 'is this at the expense of wild individuals?' The theoretical background needed to stimulate hypothesis testing has yet to be transferred from related fields, such as aquatic ecology and fisheries economics. Since 1989, development of stock enhancement theory has accelerated, based on several basic hypotheses, which are beginning to appear in scientific papers and symposia discussions. The basic hypotheses are now being tested by several research groups around the world, and the need for a responsible approach to enhancement has been recognized. Within the past decade, several new examples of effective stock enhancement have emerged, along with a cautious optimism about the potential to manage enhancement effectively. However, there remains a compelling need to identify research priorities to help focus global research on the key issues that will resolve critical uncertainties about stock enhancement potential.

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Introduction

The State of World Fisheries and Aquaculture (FAO, 2000) confirms that 47% of the 441 major fish stocks in the world are fully exploited and are producing catches at or near their maximum limit. About 28% are overexploited and have no room for expansion, and only 4% are underexploited (FAO, 2000). A similar situation exists in the United States, where many of our traditionally harvested species are at record low levels. Production from aquaculture is clearly needed to maintain per capita consumption of seafood (New, 1997). Declining growth in capture fishery landings has precipitated a new interest in marine stock enhancement worldwide. We must ask two important questions, because of the desire to use new aquaculture technologies that are available for producing marine organisms suitable for stocking: 'What is the potential of marine stock enhancement as a fishery management tool?' and 'Is there a scientific basis for implementing large-scale stock enhancement programmes to supplement or enhance seafood catch?'

As knowledge about the gloomy status of our fishery stocks has increased in the past decade, so too has awareness of the pitfalls of inadequate development of fisheries management strategies, including those related to hatchery-based stock enhancement. This awareness, coupled with lack of development of a science of stock enhancement, has fuelled growing controversy about effects and effectiveness of hatchery releases. The controversy has had a healthy effect in fostering new research to evaluate the issues, along with a divisive effect on fisheries scientists and resource managers.

The Harvest from Production-oriented Stocking: Polarized Fisheries Management

After over a century of use in America, stock enhancement is still at an early stage of development as a fisheries management tool in coastal environments (Blankenship and Leber, 1995; Grimes, 1995; Munro and Bell, 1997; Hilborn, 1999; Leber, 1999). In the United States, hatcheries have been stocking to enhance populations of marine fishes since the 1880s (Grimes, 1995). The emphasis though, for over a century, has been on the magnitude of hatchery production. Salmonids, Spanish mackerel, cod, haddock, pollock and flounder were all stocked and biologists working with marine fishes were still stocking only newly hatched fry when the federal hatcheries were shut down at Woods Hole in 1948 and in Gloucester, Massachusetts, in 1953 (Richards and Edwards, 1986).

The principal constraint to rapid development of enhancement's potential is clear – the rush to use stock enhancement, and use it now, has nearly always led to emphasis on hatchery production at the expense of developing a scientific basis for how or whether to use stock enhancement. In fact, with marine fishes (i.e. those that spawn in seawater), little or no attention was given even

to evaluating hatchery-release impact on fisheries or wild stocks during the first 90 years of stocking programmes. No one knew if it worked – the biologists actually did not know if stocking marine fish had any effect on fisheries! There is little wonder why, in the late 1940s and 1950s, the US Bureau of Commercial Fisheries (now the National Marine Fisheries Service, NMFS) rightly took a definitive stance against the use of marine hatcheries as a fisheries management tool and has never looked back. Today, NMFS scientists are among the strongest opponents of marine stock enhancement in the United States, and dismiss the notion that enhancement might be effective with the attitude, 'we tried it and it didn't work'. This is understandable in light of the huge resources that were poured into hatchery boondoggles during the formative days of US fishery management. However, now, in the absence of NMFS stewardship, marine stock enhancement programmes are coming back into use in several states in the United States and some of these are well funded. This is because the public response to stocking has generally been very favourable, which encourages political support for stocking, regardless of whether any assessment of impact is conducted. The cycle of production hatcheries leading to denial is repeating itself and there are few data available to evaluate the claims of either the opponents or the supporters of hatchery-based enhancement. Given the public support for stocking and lack of information to evaluate enhancement impact and cost effectiveness, perpetual demand for stocking should be expected.

The lack of effectiveness of early stocking programmes in the United States curtailed much of the funding for assessment of stock enhancement effect on marine organisms until the advent and relatively recent proliferation of modern tagging technology, which provided a way to track released juveniles, albeit with varying degrees of success (e.g. the binary coded-wire tag, genetic 'tags', otolith marking, chemical marks, and various external tags; see Parker *et al.*, 1990; Bergman *et al.*, 1992). Because of the slow pace of research on marine enhancement following the closure of marine hatcheries in the northeastern USA, advances in marine stock enhancement effect have not kept pace with advances in marine aquaculture technology. Thus, we now have the capability to produce many species of marine fish but we lack basic knowledge about how or even whether to use hatchery-reared fish as a resource management tool in marine environments (Leber, 1999).

The Pros and Cons of Stock Enhancement

There is an allure to stocking that has captured our interest. The proponents of stock enhancement view it as a management tool with enormous potential to rapidly replenish depleted fisheries and supplement weak year classes; as a means for recovering endangered species; as a quick fix that can provide disaster relief from a host of environmental calamities, such as fish kills from red tide, hard winter freezes and various toxins introduced into aquatic

environments; and by targeting hatchery fish, as a way to transfer fishing pressure away from wild stocks. As an experimental tool, stocking can clearly increase knowledge about wild stocks.

On the other hand, there is very little development of the scientific background that is needed to make sound decisions about stocking and, thus, there are many critical uncertainties. There are very few good examples of marine enhancement to build upon and the track record is poor. Once started, stocking programmes are usually difficult to stop. Stocking can cause overfishing in mixed-stock fisheries, where abundant hatchery fish can result in elevated fishing rates on the wild stock. Some view stock enhancement as expensive, even arrogant use of technology. Stocking is potentially harmful to wild stocks, which could be adversely affected by transfer of disease, reduction in genetic diversity and fitness, and competitive displacement by hatchery fish. Also, public reaction to expected benefits from stocking can postpone or, even worse, subvert inevitable use of tough restrictions on fishing effort.

Assessing Stocking Impact and its Potential as a Fishery Management Strategy

Finally, after a century of neglect, researchers have begun to quantify survival of hatchery-reared fishes in the wild and gauge the effects of stocking programmes (e.g. Hager and Noble, 1976; Bilton *et al.*, 1982; Olla and Davis, 1988; Tsukamoto *et al.*, 1989; Svasand and Kristiansen, 1990a,b; Svasand *et al.*, 1990; Peterman, 1991; Kitada *et al.*, 1992, 1994; Nordeide *et al.*, 1994; Olla *et al.*, 1994; Ray *et al.*, 1994; Yamashita *et al.*, 1994; Secor *et al.*, 1995; Munro and Bell, 1997; Hilborn, 1998; Okouchi *et al.*, 1998). The authors cited were among the first to highlight key scientific and economic issues about salmonid and marine fisheries enhancement in peer-reviewed scientific journals.

The new scientific discoveries made in the past two decades about enhancement are just the tip of the iceberg of what must be understood to evaluate enhancement's potential as a fisheries management tool (Hilborn, 1999; Leber, 1999). There has been little or no development of the theoretical basis for stock enhancement. Without this – without a paradigm – many of the obvious issues seem equally important. Thus we need to develop and test stock enhancement theory and prioritize the key questions, if we are to cope as scientists or fishery managers with the rash of unanswered questions about how to control enhancement impact. Systematic tests of sequential hypotheses are needed to resolve the critical uncertainties (Table 6.1). Until we develop, test and demonstrate a clear predictive capability about hatchery release effect, premature conclusions will prevail and continue to hamper the development of stock enhancement as a fishery management tool (Leber, 1999).

Clearly, a responsible and scientific approach is needed to evaluate stock enhancement potential (Cowx, 1994; Blankenship and Leber, 1995; Hilborn,

Table 6.1. Critical uncertainties in stock enhancement.

Does it work?
Effects of release strategies on growth and survival
• Fish size at release
• Release habitat
• Release timing
• Release magnitude
Actual impact on production
• Is there surplus productive capacity (carrying capacity) to support additional organisms?
• Are there positive effects on fishery yields and reproductive output?
Conservation issues
Effects on wild stocks
• Displacement
• Cannibalism
• Genetic diversity and fitness
• Health
Effects on ecological interactions
• Community dynamics
• Predator–prey interactions
Accounting issues
Cost effectiveness
• Yield per stocked recruit
• Optimal size at release
• Cost–benefit ratio
Sustainability versus dependency on constant stocking
Are yields achieved beyond yields from alternatives?
• Regulations
• Habitat protection and restoration

1999). Marine stock enhancement is now at an intermediate stage of development. Although survival, growth, and entry of stocked fish into fisheries are now well documented for several species (see Munro and Bell, 1997), multidisciplinary teams are needed, coupled with an experimental approach to resolve the key critical uncertainties (Leber, 1999). Two of the most important uncertainties are: 'Does stock enhancement increase production?' and, if so, 'Is this at the expense of wild individuals?' (Hilborn, 1999). Why have so few studies focused on these basic issues? There are several reasons. One is that basic and applied research on stock enhancement is underfunded. Another reason is the lack of theoretical development in the field.

To resolve the paradox of enhancement research (we have not developed much theory), we must: (i) seek to develop a more theoretical approach to stimulate hypothesis testing and a predictive capability in this field; (ii) identify and focus on species that are most suitable for resolving critical uncertainties

about stocking; (iii) seek multidisciplinary collaborations, because the range of issues is complex and crosses many fields of study; (iv) focus research on the question(s) of the day; and (v) publish more of our research findings in the peer-reviewed scientific literature.

Since 1989, evaluation of marine stock enhancement has accelerated, based on several basic hypotheses, which are beginning to appear in scientific papers and symposia discussions. These hypotheses are now being tested by several research groups around the world, and the need for a responsible approach to enhancement has been recognized. Within the past decade, some examples of effective stock enhancement have emerged, along with a cautious appeal to fisheries scientists and managers about the need to understand how to manage enhancement wisely and effectively (e.g. Blankenship and Leber, 1995; Grimes, 1995; Munro and Bell, 1997; Hilborn, 1998; Masuda and Tsukamoto, 1998). However, there remains a compelling need to identify research priorities to help focus global research on the key issues that will resolve critical uncertainties about stock enhancement potential. Many of these issues have surfaced in review papers and in the proceedings of stock enhancement symposia published over the past decade by Lockwood (1991), Danielssen *et al.* (1994), Schramm and Piper (1995), Munro and Bell (1997), Coleman *et al.* (1998) and Howell *et al.* (1999).

Accountability in Stock Enhancement Programmes

Cowx (1994) and Blankenship and Leber (1995) summarized several issues that should be considered to conduct stock enhancement initiatives responsibly. Munro and Bell (1997) expanded on the development of some of these issues. Hilborn (1999) highlighted the greatest bottleneck to resolving the issue of whether stock enhancement can be effective: 'The responsible scientific fisheries community needs to step in and realistically evaluate fish stocking versus other management tools'.

The search for information to evaluate stock enhancement has motivated new research to determine stocking effects on coastal fisheries and wild stocks. Within the past decade or so, marine stock enhancement began to move beyond the early fact-finding stage that Kuhn (1970) observed to characterize new fields of science. To resolve the unanswered questions about stock enhancement, fishery scientists must now work closer with the fishery managers who implement stocking. This is a key issue, highlighted below from Leber (1999).

> Now, we must deal with the lack of theoretical development in the field and the clear need to reduce uncertainty about the effects of hatchery releases in coastal environments. Wider use of the scientific method and 'strong inference' (Platt, 1964) would advance knowledge in this branch of fisheries science considerably faster than its current pace. Much of the new research is focused on evaluating

post-release survival. We have entered a passive–adaptive assessment phase of marine stock enhancement (Leber, 1999), which is best described by Walters and Hilborn (1978) and Hilborn and Walters (1992).

However, given the poor track record in developing the scientific basis for stock enhancement, we can ill afford the time it takes to make progress with a passive approach. We need to increase the rigour of scientific studies of stock enhancement potential. Platt (1964) argued that, for exploring the unknown, there is no faster method than 'strong inference' – the systematic application of the age-old scientific method of inductive inference that dates back to Francis Bacon. What makes strong inference so effective is, according to Platt (1964), systematically '. . . recycling the procedure, making subhypotheses or sequential hypotheses to refine the possibilities that remain; and so on'. A key component of strong inference is acknowledging the competing alternative hypotheses (major uncertainties) that could explain an observation, and then rigorously weeding out the false alternatives through experimentation.

Walters and Hilborn (1978) added a caveat for fishery management. 'We learn most rapidly by introducing large disturbances and much monitoring, but we incur high risks and costs by doing so . . . the dual control problem'. Because of uncertainty about genetic, health, and ecological risks to wild stocks, large-scale experimental stocking can pose risks to the very stocks we are trying to replenish. And to advance this field we must experiment, yet funding for marine stock enhancement research lies largely within the management agencies that are implementing hatchery releases. By mandate, the agencies must manage resources (i.e. implement enhancement, not study it). The solution to both issues (risks and costs imposed by large-scale experiments) is active–adaptive management (Walters and Hilborn, 1978; Hilborn and Walters, 1992), where risks of failure are restricted to substocks of the stocks being managed.

With a modest research budget, active–adaptive management in pilot release–recapture experiments should be applied as part of every release in stocking programmes (Leber, 1999). When there is a logical flow of scientific queries about the effectiveness of stock enhancement, which should always be made when resource agencies are engaged in stocking, this form of active–adaptive management is essentially strong inference adapted to fishery science. A quick scan of Platt's (1964) paper reminds us also that it is the systematic application of a logical tree of hypothesis tests and exclusions that produces much more rapid progress than in fields of science that use other approaches. Coupling strong inference and active–adaptive management principles to marine stock enhancement research is the logical next phase in this field (Leber, 1999).

Research in Hawaii to evaluate the potential of marine stock enhancement is one example of the utility of the adaptive management approach. The focus of that research from the outset was mainly on testing critical assumptions about stock enhancement effects in pilot release experiments. The pilot experiments were designed to gain information needed to design release strategies for a test of the marine stock enhancement hypothesis with striped mullet, *Mugil cephalus* (Leber, 1995; Leber *et al.*, 1996, 1997; Leber and Arce, 1996), and with a highly valued, inshore marine fish – Pacific threadfin,

Polydactylus sexfilis (Leber *et al.*, 1998; Ziemann *et al.*, 2002). Leber *et al.* (1996) showed how hatchery contribution to juvenile recruitment was increased 600% over 3 years using an active–adaptive management approach. Results from field experiments indicated that there was a realized increase in production in nursery habitats, rather than replacement of wild recruits (Leber *et al.*, 1995, summarized by Leber and Lee, 1997).

In the meantime, while research is investigating enhancement potential, how do we conduct existing stock enhancement programmes knowing full well that the science needed to guide them is incomplete, or in many cases does not exist? History has shown us that without considerable effort to adopt a scientific approach, stock enhancement programmes will continue to suffer from overemphasis on a production approach where most, if not all, of the success and accountability of enhancement is judged simply on the basis of production efficiency and numbers of animals stocked. Resource agencies need to evaluate their approach to stocking, and if they are not already enhancement oriented in such programmes (Fig. 6.1), they need to take all measures needed to adopt active–adaptive management strategies (Walters and Hilborn, 1978; Hilborn and Walters, 1992) into their operating procedures. For only through posing questions can we gain answers, and active–adaptive management is the single most important measure that can be taken to improve the potential for success in existing stock enhancement programmes. Responsible enhancement programmes need to pose questions about critical uncertainties, by marking a subset of the animals released to evaluate enhancement effect

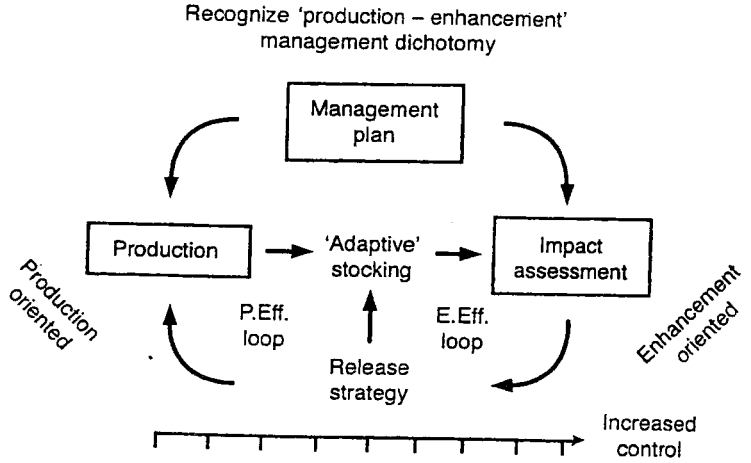

Fig. 6.1. To increase control over stock enhancement effect, stocking programmes need to seriously question whether they are 'enhancement oriented', which involves adaptive management as a key component of every stocking opportunity, or 'production oriented', which yields little if any control over enhancement success. P. Eff, production efficiency; E. Eff, enhancement efficiency.

and develop improved stocking strategies, such as examining effects of stocking density to evaluate carrying capacity; size at release to optimize this variable; effects of other release strategies, and so on (Blankenship and Leber, 1995). Major gains can be made in improving enhancement efficiency and effectiveness by embedding tests of critical assumptions within each release (e.g. Leber *et al.*, 1996; Leber, 1999). Without this approach, stocking programmes can maximize growth and survival in the hatchery, only to suffer great losses of hatchery organisms, and even wild ones, after releases. Why post-release mortality does not get the same attention in stocking programmes that mortality in the hatchery receives is inexplicable.

In summary, stocking's baggage is that lack of consensus on key research issues during 90 years of stocking, and failure to treat stock enhancement as a science, have constrained advances in this branch of the fisheries discipline. The result has been: (i) splintering of fishery scientists into camps for and against stock enhancement; (ii) little, if any, development of stock enhancement theory; and (iii) few data to evaluate either camp's position. Marine stock enhancement research over the past decade shows some potential for stocking to be an effective management tool, but we cannot understand the actual effectiveness of stocking in coastal environments until we develop and test stock enhancement theory. Multidisciplinary research partnerships and an active–adaptive management approach are needed to resolve the critical uncertainties, test key assumptions and evaluate stock enhancement potential as a fishery management tool.

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