STOCK ENHANCEMENT AND SEA RANCHING

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Chapter 5
Rationale for an Experimental Approach to Stock Enhancement

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Abstract

A critical evaluation is needed of the potential for marine stock enhancement to replenish depleted fisheries and increase fishery production. Historical emphasis on aquaculture production and release magnitude has overshadowed key questions about stocking effects on fisheries landings and fish populations. Advances in 'enhancement effect' have not kept pace with advances in marine aquaculture technology. Examples are presented of results achieved in Hawaii using 'strong inference' to investigate some of the basic assumptions and major uncertainties of the stock-enhancement hypothesis. Strong inference is, essentially, *systematic application* of the scientific method of inductive inference. A series of pilot release experiments was initiated to eliminate alternative release strategies that proved ineffective. Subsequently, the effect of hatchery releases of juvenile striped mullet, *Mugil cephalus*, on abundance, recovery rate and fishery contributions was increased considerably (by as much as a 600% improvement in recruitment of hatchery-reared fish in juvenile habitats). After developing optimal release protocols, pilot-scale releases (30000 to 90000 fish per year) made a 15 to 20% contribution to catch in subsistence and recreational fisheries in Hawaii. Wider use of an experimental approach, based on the principles of strong inference and 'active-adaptive management' would move the field forward considerably faster.

Introduction

Advances in marine aquaculture, coupled with the global plateau in capture-fisheries landings (New 1997), have prompted a rapidly expanding, worldwide interest in marine stock enhancement (releasing cultured animals that spawn in seawater to increase fish or invertebrate population size in coastal environments). Although there is much scientific debate about the efficacy of using stock enhancement to replenish fisheries, clear potential has been shown with salmonids (Coronado & Hilborn 1998), scallops (Honma 1993), and Hirame flounder (Kitada *et al.* 1992, Okouchi *et al.* 1999). If the current trend continues, new marine aquaculture capabilities will likely spawn many new stocking programmes, and the debate over

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stock enhancement will intensify. Until there is a concerted scientific effort to make major progress in developing and testing stock enhancement theory, I believe these new programmes will fail to meet their expectations.

Whereas this chapter is focused on stock enhancement of organisms that spawn in seawater, much of the discussion can be extended to freshwater and anadromous species. The focus on marine stock enhancement here is deliberate, because recent advances in marine aquaculture have established a new interest worldwide in stock enhancement potential. It is this interest that I want to address, because marine stocking programmes have a unique history; they disappeared for decades in the USA and are now rapidly resurfacing. Attention to the phases of this reversal back and forth in interest in marine stock enhancement provides insight that may benefit stock enhancement in freshwater and anadromous fisheries, which has been conducted continuously during this century.

Technical constraints to stock enhancement

Why, after a century of stocking marine fishes into the wild, is there still so little understanding of the effects of marine stock enhancement? Historically, little emphasis has been placed on understanding the impacts of stocking on fisheries landings. The approach to marine stock enhancement during most of the twentieth century can be characterized as the *production phase*, the period when all of the emphasis and accountability in stocking programmes was focused on aquaculture production and release magnitude. This emphasis on production is pervasive, even today, and has overshadowed critical questions about stocking effects on fisheries landings and fish populations. Absence of the technology needed to tag eggs, larvae and fry also contributed to the paucity of information available to assess stocking impact during the production phase of marine stock enhancement.

After decades of stocking without clear indications of impact, the objective of marine fisheries management in the USA shifted around the middle of this century from emphasis on stocking to controlling catch rates (Richards & Edwards 1986, Grimes 1995). Subsequently, a whole generation of fisheries biologists learned to reject marine stock enhancement, which had been exposed (by lack of evidence of any impact) as a waste of public resources. This period can be characterized as the *denial phase* of marine stock enhancement. The denial phase fractured fisheries biologists into two camps, one advocating stocking, the other adamantly favouring increased fishing regulations and habitat protection and restoration over stock enhancement. For several decades, funding for marine stock enhancement all but disappeared in the USA. The denial phase 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;

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Parker *et al.* 1990, Bergman *et al.* 1992). Because of the slow pace of research during the denial phase, 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.

Despite the general lack of impact assessment and theoretical development in this field, there has been a recent increase in interest in marine stock enhancement as marine aquaculture capabilities have expanded. Because of the importance of restoring declining fisheries resources, many governments are allocating substantial resources for marine stock enhancement, irrespective of the fact that the field is only at an intermediate stage of development. Given the century-long history of questionable results of marine stock enhancement, is this wise? Is it time to turn resources away from stocking marine species and, instead, focus those resources on improving other fisheries management strategies?

The answer is clearly no; turning resources away from stock-enhancement research would be jumping to unfounded conclusions. We should keep a strong emphasis on developing and testing marine stock enhancement because this field is a *new science*.

Scientific inquiry of marine stock enhancement

Marine stock enhancement shows many of the symptoms of a new science:

(1) Absence, until recently, of articles in peer-reviewed scientific journals

This is the most important symptom. The earliest empirical evaluation of marine stock enhancement effect that I can find in the peer-reviewed scientific literature is Tsukamoto *et al.*'s (1989) study of size-at-release effect on recapture rates of red sea bream in Japan. There certainly could be earlier quantitative studies on the impact of releases of animals that spawn in seawater (my apologies to authors who have published in other languages), but I haven't seen them or references to them in my search of the scientific literature. Apparently, the 'science' of marine stock enhancement began only 10 years ago. This observation is disturbing, given that marine stocking began over a century ago. It reveals a fundamental lack of scientific research in this field. The lack of scientific development makes the rationale for the denial phase of marine stock enhancement completely understandable, but it does not justify the longevity or continuation of this phase.

Opportunity Given the new wave of interest in marine stocking, resources are becoming available to support scientific research in this field. We should strive, then, to use those resources to develop and test stock enhancement theory, at the same

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time that we stock hatchery-reared organisms, and assess their contribution to the fishery. Because marine stock enhancement programmes are rapidly resurfacing, the omnipresent denial in the USA and elsewhere of their usefulness as a management strategy clearly has been ineffective in resolving the central issue – whether hatchery-reared organisms can help 'enhance' wild stocks. For the benefit of society and fisheries science, we must use the new resources available for stocking marine organisms to critically evaluate stock enhancement potential once and for all. As in any new science, there are numerous key questions to answer.

(2) Unclear terminology

Another symptom that marine stock enhancement is a new science is the lack of agreement on terminology in the field. A simple example of this is the confusion about what is meant by 'stock enhancement' and 'sea ranching', and how these terms differ from 'sea farming'. Are these synonyms, or does the former term imply 'replenishment of wild stocks' and the latter two terms 'open-range agriculture in the sea'? Does 'stock enhancement' imply only hatchery releases, or should it have a broader meaning including all management strategies intended to 'enhance' stocks (i.e. artificial reefs, habitat replenjshment, fishery closures, etc.)?

Opportunity To facilitate the development and testing of stock-enhancement theory, a minimal amount of agreed-upon, standard terminology is needed to increase clarity of meaning and to reduce development of jargon. This can be a slow process, driven by the frequency of literature citations of accepted terminology. Alternatively, the scientific community could become more proactive on clarifying terminology by striving to rid the field of jargon terms and seeking consensus on emerging terminology.

(3) Absence of textbooks on the field of stock enhancement

With the exception of Honma (1993), which was written to provide an overview as well as a textbook on 'sea farming' in Japan, few, if any, other textbooks include extensive coverage of marine stock enhancement. This is another symptom of the early stage of development of this field.

(4) Poor development of theoretical background

Only recently (during the past two decades) have critical questions about stock enhancement begun to emerge as testable hypotheses. Yet there are many very important assumptions about stock enhancement that have not been evaluated. Greater attention to development of stock enhancement theory would focus more research on fundamental unresolved issues in the field. At this juncture, only the most basic hypotheses about survival, growth and genetic impact of cultured organ-

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isms in the wild are being examined. To evaluate whether and how we can manage the effects of cultured organisms in the wild, a much more advanced understanding is needed of the ecological, behavioural, physiological and physical-chemical processes that mediate interactions among cultured organisms, wild organisms and the environment. The study of stock enhancement involves scientific inquiry in many sub-disciplines. There is a clear need to integrate at least ten principal sub-disciplines to move forward responsibly in this branch of fisheries science:

- Marine aquaculture
- Genetics
- Aquatic health
- Marine ecology
- Fisheries biology
- Environmental risk assessment
- Experimental design
- Mathematical modelling
- Fisheries and aquaculture economics
- Statistical decision analysis.

(5) Infrequent use of the 'scientific method'

A less obvious symptom that marine stock enhancement is an undeveloped science is the scarcity of experimental field studies designed to test hypotheses, among the publications about enhancement that do exist in scientific journals. If science is indeed advanced by establishing and testing theory and advancing theory through successive paradigms (Kuhn 1970), then a look at the scientific literature reveals that marine stock enhancement is plainly in its infancy as a science.

Advancing the 'science' of marine stock enhancement

In the 1990s, marine stock enhancement began to move beyond the early fact finding stage that Kuhn (1970) observes characterizes new fields of science. In the 1990s, after a century of preoccupation with fish culture, researchers in this field began to publish tests of the hypothesis that cultured marine fish could survive in the wild and contribute to fishery landings. A rapid expansion of scientific studies and philosophical debate on marine hatchery releases has begun, following initial publications by researchers in Japan and Norway (Tsukamoto *et al.* 1989, Kristiansen & Svåsand 1990, Svåsand & Kristiansen 1990a,b, Svåsand *et al.* 1990), and earlier work with salmonids in the USA and Canada (for example Hager & Nobel 1976, Bilton *et al.* 1982) (see also studies and additional citations in symposia proceedings edited by Lockwood 1991, Danielssen *et al.* 1994, Schramm & Piper 1995 and Coleman *et al.* 1998). Marine stock enhancement has begun to be treated scientifically.

Now, we must deal with the lack of theoretical development in marine stock

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enhancement 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. We can characterize much of the experimental work now emerging in this field as a period of trial-and-error evaluation of the hatchery-release hypothesis (releasing cultured fish can increase fishery production). We have entered a *passive-adaptive assessment phase* of marine stock enhancement, which is best described by Walters and Hilborn's (1978) (and see Hilborn & Walters 1992) *passive-adaptive management* approach. Platt (1964) argues 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 systematically '... recycling the procedure, making sub-hypotheses or sequential hypotheses to refine the possibilities that remain; and so on' (Platt 1964). 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. Platt reminds us that for a hypothesis to be testable we must be able to state what conditions would show the hypothesis is false (Popper 1959, 1965).

Walters and Hilborn (1978) reiterate Platt's argument about exploring the unknown, but add 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'. The paradox is that 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 this paradox is *active-adaptive management* (Walters & Hilborn 1978, Hilborn & Walters 1992), where risks of failure are restricted to substocks of the stocks being managed. 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.

Experimental approach to marine stock enhancement in Hawaii

Research in Hawaii to evaluate the potential of marine stock enhancement began in 1988. This work is summarized in Leber and Lee (1997) and the references below. The focus of research from the outset in Hawaii was mainly on testing critical assumptions about stock enhancement effect in pilot release experiments. The pilot

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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 & Arce 1996) and with a highly-valued, inshore marine fish – Pacific threadfin, *Polydactylus sexfilis* (Polynemidae) (Leber *et al.* 1998).

Hypotheses and major uncertainties tested in Hawaii

The hypothesis that hatchery releases can help increase marine fish abundance has two fundamental corollaries that need to be tested. Corollary 1 is that cultured fish released into coastal waters actually survive, grow and contribute to recruitment to the spawning stock. Corollary 2 is that cultured fish do indeed increase abundance rather than displace wild stocks. Both of these alternative hypotheses were tested in Hawaii. For a rigorous test of both corollaries, data were needed from pilot releases to define effective release strategies. Fish size at release, release habitat and the timing of releases were important choices that needed to be made. If any of these variables affected survival of released fish, they would also affect the power of any test of corollaries 1 and 2.

Assumptions about size at release and release habitat were examined first (Leber 1995). A principal uncertainty was whether small postlarvae, which could be grown in greater numbers and at less expense than larger juveniles, would survive and recruit to the local population (for example see Hager & Nobel 1976, Tsukamoto *et al.* 1989, Liu 1990, Svåsand & Kristiansen 1990b, Ray *et al.* 1994). Another uncertainty was whether distribution and abundance of wild juveniles afforded a good prediction of appropriate release sites.

We reasoned that by comparing recapture rates from several different release habitats frequented by wild striped mullet, some general characteristics of good and bad release sites should emerge. The habitat comparisons were basically trial-and-error, guided by habitat preferences of wild individuals. The size-at-release comparisons were a direct test of the hypothesis that striped mullet no larger than advanced postlarvae (45–60 mm total length, TL) would survive and recruit to nursery habitats at densities that could be tracked in our net collections and fisher creel surveys.

Once effects of size at release and release habitat were revealed in initial experiments, we would need to evaluate effects of the timing of releases (Bilton *et al.* 1982, Leber *et al.* 1997). A major uncertainty was whether release season affected survival and recapture rates. Two other uncertainties were whether any size-at-release effects evident in initial experiments were reproducible, and if so, whether release timing could affect the outcome of size-at-release effects.

After conducting three pilot experiments to test the above uncertainties, results were used to modify release strategies. A follow-up experiment was conducted to test release effect using 'optimized' release strategies, and to examine whether release effect could be improved using knowledge gained about juvenile recapture

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rates from the earlier pilot experiments (Leber *et al.* 1996). Subsequently, another experiment was conducted to test the hypothesis that released juveniles increased abundance in nursery habitats, rather than displacing wild individuals (Leber *et al.* 1995).

To evaluate the full potential of marine stock enhancement, results of pilot releases need to be quantified at various stages of the life cycle. Following the pilot studies above that evaluated recruitment success and survival patterns during the juvenile stage, surveys of fishermen were initiated to examine growth and survival after cultured fish dispersed from their nursery habitats into habitats occupied by adults (Leber & Arce 1996). The objectives of the surveys were:

(1) to determine whether cultured striped mullet released as juveniles could survive and grow to mature adults and recruit to the local spawning stock;
(2) to identify the per cent contribution of cultured fish in the local fishery; and
(3) to determine whether survival patterns of released fish changed after the juvenile stage (e.g. Nordeide *et al.* 1994), by comparing survival patterns of adult cultured fish captured in the bay-wide fishery to results from previous studies of juveniles in nursery habitats in that bay.

Experimental design

Pilot experiments followed the same basic design. To evaluate effects of size at release, release habitat and release season, pilot releases were conducted using a factorial experimental design, where at least two levels of each variable were compared simultaneously. In the evaluation of release-season impact on size-at-release effect, we released five size groups of fish at two different release sites in spring, then repeated this in summer. Replication of experimental conditions was achieved using a randomized block ANOVA design, where treatments were blocked within discrete time intervals (Sokal & Rohlf 1981). During each season, this entailed releasing the five size groups at both release sites weekly for 3 consecutive weeks in the spring, and repeating this design over 3 weeks in summer. This experiment required 60 different batch codes to identify treatment conditions and replicates – 5 size-at-release groups × 2 release habitats × 3 release lots (weeks) × 2 release seasons (Leber *et al.* 1997). Binary coded wire tags (Northwest Marine Technology, Inc) were used to identify treatment conditions and replicates. To evaluate whether cultured fish displaced wild fish, experimental design was modified after Main (1987) to include an initial evaluation of tagged and released wild fish at each of two release sites (three release lots at each site), followed by releases (three lots) 1 month later of cultured fish (treatment effect) at only one of the sites. Dispersal of wild fish was monitored before (pretreatment dispersal) and for 10 months after releases of cultured fish (post-treatment dispersal).

To evaluate treatment effects of the pilot experiments in Hawaii, we tracked recapture rates of released fish prior to and after their entry into the fishery. Each

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year, beginning about 2 weeks after the final releases in each season, monthly cast-net collections were made in six nursery habitats over about a 10-month period to monitor recapture rates, growth and dispersal of the juvenile cultured fish (e.g. Leber *et al.* 1997). Adult fish were recovered in ad hoc creel surveys (e.g. Leber & Arce 1996).

Experimental results

Data from the pilot releases of striped mullet revealed that survival of hatchery-released mullet during the juvenile phase of the life cycle was strongly affected by size at release, release site and the seasonal timing of releases (Leber 1995, Leber & Arce 1996, Leber *et al.* 1997). The pilot releases excluded the alternative of stocking advanced postlarvae during summer or autumn in the follow-up experimental test of the stock enhancement concept in Hawaii. Rather, fish stocked during summer and autumn would need to be >60 mm to detect an effect of hatchery releases on fishery landings. Greatest recovery of the smallest fish released (individuals <60 mm) occurred following spring releases, which coincided with peak recruitment of similar size wild *M. cephalus* juveniles. Release season also controlled the outcome of size-at-release effects following releases of Pacific threadfin, *Polydactylus sexfilis*, in Hawaii. The release season effect showed an interaction with release site in that study (Leber *et al.* 1998). We hypothesized that survival of cultured fish will be greater when releases are timed so that fish size at release coincides with modes in the size structure of wild stocks (Leber *et al.* 1997).

Release site effect was significant. Over 30 000 juveniles stocked in Kaneohe Bay, but not in a nursery habitat preferred by striped mullet, apparently suffered complete mortality (Leber & Arce 1996, see also Secor *et al.* 1995). There was clearly much better survival of hatchery-reared mullet when they were released into documented nursery habitats of wild mullet.

The Hawaii work clearly shows that to optimize effectiveness of stock enhancement as a fishery-management tool, pilot release-recapture experiments should be conducted to evaluate effects of release protocol on recovery of released animals. In Hawaii, hatchery production cost per hatchery fish caught in the fishery was less for releases of 70–85 mm TL fingerlings than for 45–60 mm fingerlings when releases were conducted in summer. By refining release protocol over a 3-year period, proportions of cultured fish in juvenile nursery habitats 10 months after release increased from 3% to 10% and finally to 50% of the total striped mullet (wild and cultured) collected in net samples. Recapture rate increased by ~600% as a direct result of modifying release strategies.

The experimental evaluation of striped mullet hatchery-release effects on wild individuals showed no displacement of wild striped mullet by hatchery fish (Leber *et al.* 1995). Results indicated that release habitats were below carrying capacity in that study, and that the release site could support additional striped mullet biomass. This issue needs to be examined in much greater depth. This kind of experimental

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evaluation affords one way of approaching the question of whether release sites can support additional production.

Following the pilot hatchery releases from 1990 to 1993, striped mullet fisheries in Kaneohe Bay, Hawaii, were sampled to recover cultured fish from the bay-wide catch. Direct sampling of 181 fishing trips resulted in recovery of 211 cultured striped mullet. By autumn 1994, cultured fish comprised 13.0% (+/–2.8%) of the commercial mullet catch in Kaneohe Bay, and the percentage was increasing logarithmically (Leber & Arce 1996).

The series of experiments to test the stock enhancement hypothesis in Hawaii shows a clear need for an experimental approach in order to understand how to use cultured fishes effectively to affect recruitment to juvenile and spawning stocks. The experiments tested simplistic, but important, hypotheses about the potential to enhance wild striped mullet in Hawaii. To understand the ecological mechanisms affecting survival, more experimental work is needed, for example, to gain a better understanding of why release season influenced size-at-release effect. However, in the absence of that information, releases resulted in predictable outcomes when treatment conditions were repeated in separate years. The series of experiments discussed above reveals the potential to greatly increase release impact using release strategies optimized in this manner.

Synthesis

In summary, lack of consensus on key research issues during 80 years of stocking marine fishes and failure, until this decade, to treat marine stock enhancement as a science have constrained advances in this branch of fisheries science. The result has been:

(1) splintering of fishery biologists into camps for and against stock enhancement,
(2) little, if any, development of stock enhancement theory, and
(3) few data to evaluate either of these camps' positions.

For the field to advance rapidly as a science, consensus is needed about what the central scientific problems are, and Platt's (1964) 'strong inference', coupled with Hilborn and Walters' (1992) *active-adaptive management* approach, need to receive greater emphasis in stock enhancement research programmes. The inattention for 80 years to applying rigorous scientific inquiry and evaluating the effects of *marine* hatchery releases on fishery landings and on the wild stocks 'enhanced' has fuelled strong opposition to repeating mistakes of the past. Today, hatchery releases without a quantitative basis for evaluating release impact (i.e. without a strong assessment component) must be recognized as imprudent and that approach put to rest.

In the absence of a paradigm in marine stock enhancement, many of the obvious issues seem equally important (Kuhn 1970). One way to advance this field is to prioritize the key questions and highlight the need to resolve them. Below are some of the key issues that keep surfacing at stock enhancement symposia. Most of these issues are familiar to workers in this field. Most are also considered in more detail

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in Cowx (1994), Blankenship and Leber (1995) and Munro and Bell (1997). A sample of some of the most basic questions about managing stock enhancement is included as an example of why we must begin to focus much more on developing stock enhancement theory.

Central questions in marine stock enhancement

Management issues

What are the goals of stock enhancement? What are explicit indicators of success? How are the indicators of success measured? What issues need to be resolved before beginning a hatchery-release programme? When should hatchery releases be used? What determines when to stop? What is a 'full-scale' programme? What other fishery management strategies need be coupled with stock enhancement? What protocols are needed to conserve genetics and health of wild stocks? What hatchery and stocking protocols would increase survival of released fish? What is a responsible approach to marine stock enhancement? What improvements need to be made to existfng approaches?

Major uncertainties

Do hatchery releases contribute to fishery production? Can the same level of 'enhancement' gained from hatchery releases be achieved through stronger fishing regulations and enforcement? Through habitat restoration? Is there sufficient environmental carrying capacity to support additional production at release sites? Are released cultured fish displacing wild stocks? Cannibalizing wild stocks? What measures of environmental carrying capacity can be used to plan release magnitude? What are the key measures of suitable habitat for releases? What are the genetic effects on wild stocks from releasing cultured fish. What are the health effects on wild stocks? What are the ecological effects of releases of cultured fish? What are the optimal release strategies? Do the costs of stock enhancement outweigh the gains? Are gains made with stock enhancement sustainable?

To address these and other key issues in stock enhancement, many sub-disciplines need to be considered. Clearly, research collaborations are needed to integrate the principal sub-disciplines into stock enhancement research programmes. Rapid advances can be made in understanding marine stock enhancement potential by focusing such collaborations on resolving major uncertainties, using strong inference and active-adaptive management.

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