

American Fisheries Society Symposium 15:167-175, 1995
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A Responsible Approach to Marine Stock Enhancement

H. LEE BLANKENSHIP

*Washington Department of Fish and Wildlife
600 Capitol Way North, Mail Stop 43149
Olympia, Washington 98501, USA*

KENNETH M. LEBER

*The Oceanic Institute, Makapuu Point
Waimanalo, Hawaii 96795, USA*

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Abstract.—Declining marine fish populations worldwide have rekindled an interest in marine fish enhancement. Recent technological advances in fish tagging and marine fish culture provide a basis for successful hatchery-based marine enhancement. To ensure success and avoid repeating mistakes, we must take a responsible approach to developing, evaluating, and managing marine stock enhancement programs. A responsible-approach concept with several key components is described. Each component is considered essential to control and optimize enhancement. The components include the need to (1) prioritize and select target species for enhancement; (2) develop a species management plan that identifies harvest opportunity, stock rebuilding goals, and genetic objectives; (3) define quantitative measures of success; (4) use genetic resource management to avoid deleterious genetic effects; (5) use disease and health management; (6) consider ecological, biological, and life-history patterns when forming enhancement objectives and tactics; (7) identify released hatchery fish and assess stocking effects; (8) use an empirical process for defining optimum release strategies; (9) identify economic and policy guidelines; and (10) use adaptive management. Developing case studies with Atlantic cod *Gadus morhua*, red drum *Sciaenops ocellatus*, striped mullet *Mugil cephalus*, and white seabass *Atractoscion nobilis* are used to verify that the responsible approach to marine stock enhancement is practical and can work.

Marine fish populations are declining worldwide. In the United States, current abundance trends are known for only 15 of the most important marine stocks; about half of them are declining (NOAA 1991, 1992). Current harvest rates on most declining stocks are far in excess of exploitation levels needed to maintain the high long-term average yields that could be achieved through contemporary fishery management practices. Projected increases in human population size worldwide suggest this trend will continue into the future (FAO 1991).

Three principal tactics are available to fishery managers to replenish depleted stocks and manage fishery yields: regulating fishing effort; restoring degraded nursery and spawning habitats; and increasing recruitment through propagation and release (stock enhancement). The first two methods form the basis for the current federal approach to managing marine fisheries in the United States. The potential of the third method has not been convincingly documented with marine fishes.

Marine stock enhancement is not a new concept. In fact, hatchery-based stock enhancement was the principal technique used in an attempt to restore marine fisheries during the last part of the nineteenth century and early decades of the twentieth century. However, stock enhancement fell out of favor among fishery

biologists after a half century of hatchery releases produced no evidence of an increased yield. Atlantic cod *Gadus morhua*, haddock *Melanogrammus aeglefinus*, pollock *Pollachius virens*, winter flounder *Pleuronectes americanus*, and Atlantic mackerel *Scomber scombrus* were stocked. Regrettably, when the last of the early marine hatcheries in the United States closed in 1948, after 50 years of stocking marine fishes, the technology had progressed no further than the stocking of unmarked, newly hatched fry. This was partly a result of the early approach to assessment, in which the success of hatchery programs was judged by numbers of fry stocked rather than by numbers of adults surviving to enter the fishery (Richards and Edwards 1986).

A New and Responsible Approach

Two general problems have restricted development of marine stock enhancement technology this century. Lack of an evaluation capability to determine whether hatchery releases were successful has been a major obstacle. Before the development of modern marking methods, fish-tagging systems were not applicable to the small, early life history stages released by hatcheries. The other impediment to development of marine enhancement has been the inability to culture marine fishes beyond

early larval stages to the juvenile stage (fingerlings and larger sizes).

A new approach to marine stock enhancement is long overdue. Faced with declining stocks and an expanding world population, managers around the globe are looking at marine enhancement with renewed interest. To develop and evaluate stock enhancement's full potential, a process is needed for designing and refining stock enhancement tactics based on the combined effects of managing the resource (i.e., the interactive effects of hatchery practices, release strategies, harvest regulations, and habitat restoration on the condition of the managed stock).

Recent advances in both tagging technology and marine fish culture provide basic tools for a new approach to marine enhancement. We now have the technology for benign tagging of fish from juvenile through adult life stages (Bergman et al. 1992). Such tagging provides the basis for a quantitative assessment of stock enhancement success. Several marine fishes can be cultured to provide a wide range of life stages for release (e.g., McVey 1991; Honma 1993). Together, these tools allow an empirical evaluation of survival of cultured fish in the wild, and feedback on hatchery-release effects can be used to refine enhancement strategies. Release effects on wild stocks, and the fisheries based on them, can be quantified and evaluated. Survival can be examined over a range of hatchery practices and release variables (such as culture practices, fish size at release, release magnitude, release site, and season) to identify optimum combinations of hatchery and release strategies.

These new tools provide the basis for significantly increasing wild stock abundances. To ensure their successful use and avoid repeating past mistakes experienced in both marine and freshwater enhancement, we must use a careful approach in developing marine stock enhancement programs. The expression "a responsible approach to marine stock enhancement" embraces a logical and conscientious strategy for applying aquaculture technology to help conserve and expand natural resources. This approach prescribes several key components as integral parts in developing, evaluating, and managing marine stock enhancement programs. Each component is considered essential to control and to optimize the results of enhancement. The components include the need to (1) prioritize and select target species for enhancement; (2) develop a species management plan that identifies harvest opportunity, stock rebuilding goals, and genetic objectives; (3) define quantitative measures of success; (4) use

genetic resource management to avoid deleterious genetic effects; (5) use disease and health management; (6) consider ecological, biological, and life-history patterns when forming enhancement objectives and tactics; (7) identify released hatchery fish and assess stocking effects; (8) use an empirical process for defining optimum release strategies; (9) identify economic and policy guidelines; and (10) use adaptive management. Combining new marine fish culture and tagging technologies with these ten principles is gaining support as a responsible approach to marine stock enhancement.

Empirical data suitable for accurately assessing the effect of hatchery releases on wild populations are often lacking. Partly because of this uncertainty, there is an increasing division of conservationists into two camps—one adamantly favoring increased fishing regulations and habitat protection and restoration in preference to hatchery releases, the other supporting propagation and release as an additional tool to manage fisheries and restore declining stocks. This split must be reconciled. Is stock enhancement of marine fishes a powerful, yet undeveloped technology for rebuilding depleted wild stocks and increasing fishery yields? Or are emerging marine enhancement programs merely futile attempts at recovering precious resources, thus diverting money and attention away from habitat restoration and the regulations needed to control overfishing? To realize the full potential of marine enhancement for the conservation and rapid replenishment of declining marine stocks, we must develop the technology to supplement and replenish marine stocks responsibly and quickly.

We must act now to assess the potential of marine stock enhancement through carefully planned research programs. Using strong inference (Platt 1964), which is essentially the scientific method, and addressing all of the components of the responsible approach concept, research programs will either document the value of marine enhancement or reveal that enhancement is not a useful concept. Without determined and careful attention to the 10 points listed above, marine hatchery releases in the 1990s may serve only to fuel divisiveness between the two conservationist camps, with little or no positive effect on natural resources.

Applying the responsible approach concept to new stock enhancement initiatives is straightforward. Existing enhancement programs may find it useful to review the 10 components discussed here. Incorporating those components expanded upon below, that are not already part of ongoing enhancement programs should provide a measurable

increase in the realized effectiveness of replenishment efforts.

Prioritize and Select Target Species for Enhancement

In the absence of a candid and straightforward method, targeting species for stock enhancement can become a difficult and biased process. Unless attention is focused on the full spectrum of criteria that can be used to prioritize species, consideration of an immediate need by an advocacy group or simply the availability of aquaculture technology can become the driving factors in species selection. Commercial and recreational demand are obviously important criteria, but should they take precedence over other factors?

To reduce the bias inherent in selecting species, a semiquantitative approach was developed in Hawaii to identify selection criteria and prioritize species for stock enhancement research (Leber 1994). This approach involved four phases: (1) an initial workshop, where selection criteria were defined and ranked in order of importance; (2) a community survey, which was used to solicit opinions on the selection criteria and generate a list of possible species for stock enhancement research; (3) interviews with local experts to rank each candidate species with regard to each selection criterion; and (4) a second workshop, in which the results of the quantitative species selection process were discussed and a consensus was sought. This decision-making process focused discussions, stimulated questions, and quantified participants' responses. Panelists' strong endorsement of the ranking results and selection process used in Hawaii demonstrate the potential for applying formal decision making to species selection in other regions.

A critical step in removing bias from the species selection process lies in the type of numerical analysis used. The relative importance of the various criteria can be used in the analysis by factoring the degree to which each fish meets each criterion by the criterion weight. This produces a score for each species. This same concept is used to determine dominance in ecological studies of species assemblages (i.e., relative abundance times frequency of occurrence in samples). Using a trained facilitator to conduct the workshops also reduces bias by focusing activities on achieving results and by encouraging participation by all present.

Formal decision-making tools have been used effectively to prepare comprehensive plans for fisheries research (Bain 1987). Mackett et al. (1983)

discuss the interactive management system for the Southwest Fisheries Center of the National Marine Fisheries Service. Similar processes have been used for research on North Pacific pelagic fisheries, in strategic planning for Hawaii's commercial fishery for skipjack tuna *Katsuwonus pelamis* (Boggs and Pooley 1987), and for a 5-year scientific investigation of marine resources of the main Hawaiian Islands (Pooley 1988).

Develop a Species Management Plan

A management plan identifies the context into which enhancement fits into the total strategy for managing stocks. The goals and objectives of stock enhancement programs should be clearly defined and understood prior to implementation. The genetic structure of wild stocks targeted for enhancement should be identified and managed according to objectives of the enhancement program. What is the population being enhanced? Can it be geographically defined? Clearly, in the interest of both production aquaculture and conservation, effort must be made to maintain genetic diversity (Kapusinski and Jacobson 1987; Shaklee et al. 1993a, 1993b).

Assumptions and expectations about the performance and operation of the enhancement program necessary to make it successful should be identified (such as postrelease survival, interactions with wild stocks, long-term fitness, and disease). Critical uncertainties about basic assumptions that would affect the choice of production and management strategies should likewise be identified and prioritized. Evaluation of these uncertainties should be an integral part of the species management plan, and a feedback loop to evaluate and change production and management objectives should be included.

Define Quantitative Measures of Success

Without a definition of success, how do you know if or when you have it? Explicit indicators of success are clearly needed to evaluate stock enhancement programs. The objectives of enhancement programs need to be stated in terms of testable hypotheses. To be testable, a hypothesis must be falsifiable (Popper 1965). Depending on enhancement objectives, multiple indicators of success may be needed. These could include statements such as

Hatchery releases will provide at least a 20% increase in annual landings of *Polydactylus sexfilis* in the Kahana Bay recreational fishery by the third year of the project.

Monitoring will show less than 3% change in the frequency of rare alleles (frequency less than 0.05) after 5 years of hatchery releases (this assumes that a control for the effects of environmentally induced change in allele frequencies is possible).

Numerous indicators should be identified to track progress over time. Although simplistic, indicators like the two examples above could be linked to success and would provide a basis for evaluating enhancement efforts during the initial period of full-scale releases. Clearly, to examine such indicators requires a reliable, quantitative marking and assessment system for tracking hatchery fish.

Use Genetic Resource Management

The need for genetic resource management in stock enhancement programs is currently the subject of intense public debate, and its importance cannot be over-rated. Responsible guidelines are now becoming available to aid resource managers in revitalizing stocks without loss of genetic fitness that could follow from inbreeding in the hatchery and subsequent outbreeding depression in the wild (Kapuscinski and Jacobson 1987; Shaklee et al. 1993a, 1993b). Once the genetic status of the target stock and the genetic goals of the enhancement program are identified, the approach for managing genetic resources is similar to the approach for managing other enhancement objectives (e.g., controlling the level of impact of stocked fish on abundances of the target population). This approach includes (1) identifying the genetic risks and consequences of enhancement; (2) defining an enhancement strategy; (3) implementing genetic controls in the hatchery and a monitoring and evaluation program for wild stocks; (4) outlining research needs and objectives; and (5) developing a feedback mechanism. These points are discussed in detail by Kapuscinski and Jacobson (1987) and Shaklee et al. (1993a, 1993b).

A genetic resource management plan should encompass genetic monitoring prior to, during, and after enhancement, as well as proper use of a sufficiently large and representative broodstock population and spawning protocols, to maintain adequate effective broodstock population size. Prior to enhancement, a comprehensive genetic baseline evaluation of the wild population should be developed to describe the level and distribution of genetic diversity. This baseline evaluation should at least include the geographical range of the particular stock targeted for enhancement. The monitoring should take place over a long enough period to

observe possible short-term fluctuation or long-term change. The baseline can be used as a basis to determine an effective population or broodstock size to minimize the undesirable genetic effects of inbreeding, changes in allele frequencies, and loss of alleles. Genetic monitoring of the broodstock and its released progeny should be undertaken to measure success. Long-term genetic monitoring of the wild stock after enhancement should also occur to measure possible loss of genetic diversity, which might be attributed to enhancement efforts.

Maintenance and proper use of a sufficient broodstock population may be one of the toughest and most expensive components of marine stock enhancement. It is also one of the most important. The typically high fecundity rate of marine fish provides the opportunity for a greatly reduced effective population size in a hatchery environment because relatively few adults could potentially contribute a large number of eggs. Fortunately however, marine fish are genetically more homogeneous than freshwater and anadromous species on a relative scale, and genetic studies show relatively little stock separation due to geographic, clinal, or temporal factors (Gyllensten 1985; Waples 1987; Bartley and Kent 1990; King et al. 1995, this volume). In vagile marine species gene flow is often sufficient to homogenize the genetic structures over broad areas. Regardless, sufficient numbers of broodstock must be used so that the genetic diversity (including rare alleles) of the fish being released is the same over time as their wild counterparts.

Hubbs-Sea World Research Institute (Hubbs) has been an early promoter of a responsible genetic management plan. Hubbs leads a consortium of California researchers who are evaluating the feasibility of enhancement of white seabass *Atractoscion nobilis*. Although the genetic profile of progeny from an individual spawn may differ from wild spawns, use of multiple hatchery spawns can approximate the genetic variability observed in the wild. Bartley and Kent (1990) successfully used this concept with white seabass and showed that over 98% of the genetic variability observed in the wild could be maintained with an effective population of 100 broodfish.

Texas Parks and Wildlife Department's (Texas) enhancement program for red drum *Sciaenops ocellatus* provides a good example of maintaining a large broodstock with yearly replenishment (McEachron et al. 1995, this volume). Texas has 140-170 adult broodstock for its program, with an annual replacement of at least 25%. In Norway, studies of allele frequencies are being used to com-

pare broodstock and their progeny with wild populations of Atlantic cod (Svasand et al. 1990).

Use Disease and Health Management

Disease and health guidelines are important to both the survival of the fish being released and the wild populations of the same species or other species with which they interact. Florida Department of Environmental Protection (Florida) has developed an aggressive and responsible approach in this area in association with their red drum enhancement project (Landsberg et al. 1991). Florida's policy requires that all groups of fish pass a certified inspection for bacterial and viral infections and parasites prior to release. Maximum acceptable levels of infection and parasites in the hatchery populations are established based on the results of screening healthy wild populations.

Form Enhancement Objectives and Tactics

During the design phase of enhancement programs ecological factors that can contribute to the success or failure of hatchery releases should be considered. Predators, food availability, accessibility of critical habitat, competition over food and space, environmental carrying capacity, and abiotic factors, such as temperature and salinity, are all key variables that can affect survival, growth, dispersal, and reproduction of cultured fish in the wild. Predatory losses and food availability have long been thought to be among the principal variables that mediate recruitment success in wild populations (Lasker 1987; Houde 1987).

Habitat degradation in marine environments can also affect recruitment success. For example, seagrass meadows are important nursery habitats for fishes and crustaceans (see Kikuchi 1974). In vegetated aquatic environments, habitat availability and habitat quality (e.g., structural complexity) have been shown to mediate survival from predators (Crowder and Cooper 1982; Stoner 1982; Main 1987). In some cases, habitat degradation in marine environments may be so complete that certain habitats are unsuitable for stock enhancement (Stoner 1994). To enhance fisheries in some locales, restoration of coastal habitat may be the first priority.

The authors feel strongly that marine stock enhancement should never be used as mitigation to justify loss of habitat. However, we also feel that enhancement efforts with cultured fishes can fill a void where critically important habitats such as coastal wetlands and estuaries, which provide nurs-

eries for early life stages, are irretrievably lost or degraded.

In addition to ecological factors, there may be physiological and behavioral deficits in hatchery-reared fish that strongly reduce survival in the wild (e.g., swimming ability, feeding behavior, predator avoidance, agonism, schooling, and habitat selection). In Japan, Tsukamoto (1993) has evaluated the effect of behavior on survival of cultured madai *Pagrus major* (called red sea bream by Tsukamoto) released into the sea. Tsukamoto's results indicate that a predator-avoidance behavior (tilting), in which wild fish lay flat against the substratum, may be reduced or absent in cultured fish during the first few days after release into the sea. Abnormal tilting behavior was directly correlated with mortality rate. For certain learned behaviors, exposure to behavioral cues and responses by wild fish in hatchery microcosms may be needed to overcome behavioral deficits (Olla and Davis 1988).

A solid understanding of the ecological and biological mechanisms mediating target species abundances can require exhaustive field studies for each species considered for enhancement. Whole careers have been dedicated to understanding mechanisms behind animal distributions and abundance; it does not seem practical to hold off on stock enhancement research until the ecological mechanisms are completely understood. However, failure to consider such factors can result in poor performance of released fish at best and at worst have negative impacts on natural stocks (Murphy and Kelso 1986).

Our viewpoint is that preliminary, pilot-scale experimental releases with subsequent monitoring of cultured fish afford a direct method for evaluating assumptions about the effects of uncontrolled environmental factors. For example, assumptions about carrying capacity in particular release habitats can and should be evaluated through pilot releases conducted prior to full-scale enhancement at those sites (Leber et al. 1995, this volume). This approach is elaborated below.

Identify Released Hatchery Fish and Assess Stocking Effects

One of the most critical components of any enhancement effort is the ability to quantify success or failure. Without some form of assessment, one has no idea to what degree the enhancement was effective or, more critically, which approaches were totally successful, partially successful, or a downright failure. Natural fluctuations in marine stock abundance can mask successes and failures. Maximiza-

tion of benefits cannot be realized without the proper monitoring and evaluation system.

Tagging or marking systems that are benign and satisfy the basic assumption that identified fish are representative of untagged counterparts are essential, but weren't available until relatively recently. The detrimental effects of external tags are well documented (Isaksson and Bergman 1978; Hansen 1988; McFarlane and Beamish 1990), and few fishery managers or researchers defend their use today, especially with juvenile fish. Useful information retrieved from external tags is usually restricted to migration and growth rates of relatively large fish (Scott et al. 1990; Trumble et al. 1990).

In recent years, a few identification systems (e.g., coded wire tags, passive integrated transponder tags, genetic markers, and otolith marks) have been developed that meet the requirements that identified fish are representative of the species with regard to behavior, biological functions, and mortality factors, and thus provide unbiased data (Buckley and Blankenship 1990). The story of the development and now widespread use of the coded wire tag (Jefferts et al. 1963) is well known, and it is fair to say that it has revolutionized the approach to stock enhancement (Soloman 1990).

With an unbiased tag or mark, quantitative assessment of the effects of release is possible. In developing enhancement programs, evaluation of hatchery contributions can be partitioned into at least four distinct stages: initial survival, survival through the nursery stage, survival to adulthood (entry into the fishery), and successful contribution to the breeding pool. In Hawaii, the percent of hatchery fish in field samples taken after pilot releases of striped mullet *Mugil cephalus* has been as high as 80% in initial collections, 50% in some nursery habitats through the tenth month after release, and (in a recreational fishery in Hilo, Hawaii) as high as 20% of the catch (Leber, in press; Leber et al. 1995; Leber et al., in press). In Norway, genetic markers are beginning to show that released Atlantic cod produce viable offspring in the wild (Jorstad 1994).

Assessment of the effects of release should go further than evaluation of survival and contribution rates of hatchery fish. Evaluation of hatchery fish interactions with wild stocks is also critical. Clearly, evaluation of genetic impact is important. It is equally important to understand whether hatchery releases increase abundances in the wild or simply displace the wild stocks targeted for enhancement. At least one experimental study in Hawaii has documented that released hatchery fish can indeed in-

crease abundances in a principal nursery habitat, without displacing wild individuals (Leber et al. 1995).

Use an Empirical Process to Define Optimum Release Strategies

Just as preliminary releases can be used to evaluate ecological assumptions, pilot release experiments afford a means of quantifying and controlling the effects of release variables and their influence on the performance of cultured fish in coastal environments (Tsukamoto et al. 1989; Svasand and Kristiansen 1990; Leber, in press; Willis et al. 1995, this volume).

Experiments to evaluate fish size at release, release season, release habitat, and release magnitude should always be conducted prior to launching full-scale enhancement programs. These experiments are a critical step in identifying enhancement capabilities and limitations and in determining release strategy. They also provide the empirical data needed to plan enhancement objectives, test assumptions about survival and cost effectiveness, and model enhancement potential. The lack of monitoring to assess survival of the fish released by marine enhancement programs early in this century (through the 1940s) was the single greatest reason for the failure of those programs to increase stock abundances and fishery yields (Richards and Edwards 1986).

Based on the results of pilot experiments by The Oceanic Institute in Hawaii, hatchery-release variables were steadily refined to maximize striped mullet enhancement potential. This resulted in an increase in recapture rates by at least 400% over a 3-year period (Leber et al. 1995; Leber et al., in press.) During the third year of pilot studies in Kaneohe Bay, hatchery fish provided at least 50% of the striped mullet in net samples during the entire 10-month collection period after releases. An understanding of how fish size at release and release habitat affected survival were the primary factors needed to increase recapture rates. However, understanding the interaction of release season with size at release and release habitat also had significant effect on refinement of release strategies. The apparent doubling effect on abundances in the third year was achieved with a release of only 80,000 juveniles into the principal striped mullet nursery habitat in Kaneohe Bay, the largest estuary in Hawaii. A subsequent study documented that mullet releases did not displace wild juveniles from that nursery habitat (Leber et al. 1995). Thus, hatchery

releases in Kaneohe Bay appear to be increasing population size in the primary nursery habitat. Clearly, these pilot experiments are crucial for managing enhancement impact.

Identify Economic and Policy Objectives

Initially, costs and benefits can be estimated and economic models developed to predict the value of enhancement. This information can be used to generate funding support through reprioritization, legislation, or user fees. The information can contribute to an explicit understanding with policy makers and the general public on the time frame that is needed for components such as adaptation of culture technology and pilot-release experiments before full-scale releases can begin. The education of the public and policy makers on the need and benefits of a responsible approach is also important. In Florida, pressure is mounting to drop the responsible approach concept involving pilot-scale releases and instead plant millions of red drum fry as a neighboring state has done (Wickstrom 1993). Advocates of the latter approach simply assume that the bigger the numbers planted, the better.

Use Adaptive Management

Adaptive management is a continuing assessment process that allows improvement over time. The key to this improvement lies in having a process for changing both production and management objectives (and strategies) to control the effects of enhancement. Essentially, adaptive management is the continued use of the nine key components above to ensure an efficient and wise use of a natural resource. The use of adaptive management is central to the successful application of the approach outlined above. Some minimum level of ongoing assessment is needed, superimposed over a moderate research framework that provides a constant source of new information. New ideas for refining enhancement are thus constantly considered and integrated into the management process.

Summary

The need for marine stock enhancement has been identified, and we must learn from mistakes made in the past. The necessity and benefit of following a responsible approach in implementing enhancement cannot be overemphasized. Several organizations have started to subscribe to this new approach to marine stock enhancement. The juveniles from their pilot releases are just starting to enter the fisheries, so the results are not known.

The exception is the striped mullet enhancement program in Hawaii at The Oceanic Institute. This program has shown the benefits that can be gained from closely following the approach outlined in this paper. In addition to The Oceanic Institute's decision to develop a proper genetic management plan and to make quantitative assessments of the effects of hatchery releases on wild populations, it performed numerous pilot studies to optimize release strategies.

Without these pilot experiments, Hawaii researchers would not have increased survival rate by over 400% in Kaneohe Bay nor provided a 20% contribution to the catch in the recreational fishery in Hilo Bay. We predict that identifiable fish from each of the other programs referenced will also have a substantial effect on the catch and validate our suggested approach. What is needed now is a concerted effort by the managers of new and existing enhancement programs to use, evaluate, and refine the approach described here.

Given the worldwide decline in fisheries catch rates, bold new initiatives are needed to revitalize fisheries. We need to take care, though, to preserve existing stocks as we work to restore and increase the harvest levels of those stocks using cultured fishes.

Acknowledgments

We wish to thank Devin Bartley, Don Kent, Rich Lincoln, Stan Moberly, and Scott Willis, who have greatly contributed to the development of the ideas expressed herein. We also thank Maala Allen, Paul Bienfang, Churchill Grimes, Gary Sakagawa, Kimberly Lowe, and Dave Sterritt for insightful comments on the manuscript. Order of authorship was determined by the flip of a coin.

This paper is funded in part by a grant from the National Oceanic and Atmospheric Administration (NOAA). The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its subagencies.

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