STOCK ENHANCEMENT AND SEA RANCHING

DEVELOPMENTS, PITFALLS AND OPPORTUNITIES

Second Edition

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Chapter 2
Marine Stock Enhancement in the USA: Status, Trends and Needs

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Abstract

Americans have had a fascination with the idea of stocking to enhance marine fisheries dating back to the latter part of the nineteenth century. After the first salmon hatchery in America was established in Maine in the 1870s, the first marine finfish hatcheries were constructed in Woods Hole and Gloucester, Massachusetts. The marine hatcheries produced and released into the sea millions of fish fry – cod, flounder, haddock, pollock. But because only unmarked eggs and yolk-sac larvae could be released, no indication of success was evident and marine fisheries enhancement was curtailed in the United States for about 30 years. After the closure of commercial fisheries for red drum in Texas in the early 1980s, private, state and Federal funding became available to construct new marine fish hatcheries there for extensive culture and release of this highly prized sport fish. Over the past decade or so, new research-oriented marine stocking projects began in several states: California, Connecticut, Florida, Hawaii, Maryland, Mississippi, New Hampshire, North Carolina, South Carolina, Texas, Virginia and Washington. These new programs are placing much greater emphasis on evaluation than ever before. Marine fisheries enhancement in the US is strongly influenced by new aquaculture and marking technologies. Culture systems have progressed from extensive to semi-intensive and intensive rearing systems, and are now moving toward recirculating systems and sea cages. The research programs typically use chemical marks, coded wire tags, elastomer tags, and recently, sonic tags and genetic fingerprinting to identify hatchery animals.

Fisheries enhancement research in the USA is now characterized by field studies to determine genetic stock identification; comparison of natural levels of diseases and parasites between hatchery and wild fish; release–recapture studies to optimize release strategies and document contribution rate; behavioral studies; ecological studies; use of hydro-acoustics to track movements of hatchery fish and locate older released fish; increasing interest in evaluation of carrying capacity and its effects on success rate; and a move toward adaptive management, organization of research groups, and increased networking among scientists. There is a clear need for better development of a science of fisheries enhancement

in order to understand how to achieve a predictable, controlled enhancement effect. The priority research needs today are evaluation of density-dependent effects on hatchery-release effect and field evaluation of genetic effects on wild stocks.

Introduction

Advances in marine aquaculture and stocking techniques have made releases of hatchery-reared organisms into aquatic ecosystems seem an attractive option for managing coastal fisheries. But do we understand enough about the effects of stocking to use it effectively? Here I consider the status, trends, and needs of marine stock enhancement in the United States (US) in order to increase our understanding of this management option.

The year 1871 was a formative one for fisheries enhancement in the United States. The first US salmon hatchery was established in Maine, and soon after that the US Congress funded shore-based marine finfish hatcheries. In addition to Atlantic salmon, cod, haddock, pollock and flounder were produced, and eggs and yolk-sac fry were stocked in an effort to replenish diminished fish stocks. A trend had started that set the focus of US fisheries management for several decades (Richards & Edwards 1986, Blaxter 2000).

In 1938, the US Congress passed the Mitchell Act, amended in 1946, to mitigate in perpetuity for habitat and salmon runs lost to federal water projects within the Columbia River watershed (mainly hydro-electric dams) (US FWS 2000). The Mitchell Act supports 25 major salmon hatcheries, which produce over 70 million smolts annually.

Meanwhile, after 70 years of stocking marine finfish, the US closed its marine hatcheries, i.e. for organisms that spawn in seawater (Grimes 1995, Blaxter 2000). Emphasis had been on the magnitude of hatchery production, not on yield per stocked fish. After 70 years of stocking with no signs of success, the US Bureau of Commercial Fisheries was still stocking only newly hatched fry when the hatcheries at Woods Hole (1949) and Gloucester (1953) were closed.

While stocking to enhance marine fisheries was curtailed in the US, anadromous species stocking programs expanded, particularly for restoring and supplementing salmonids. The US Congress passed the Anadromous Fish Conservation Act in 1965 (US FWS 2000). This act mostly focused on increasing sportfishing opportunity by stocking hatchery-reared fish. Over time, support for anadromous enhancement grew with federal, state, industry and NGO support of US Pacific salmon fisheries, in support of the large sport and commercial fisheries, much of which were focused in the Pacific Northwest.

Current US public and private support for stocking Pacific salmon is substantial. Sources of funding for some of the largest programs are Alaska's private hatcheries (~US$25 million); the Mitchell Act (~$13 million); Bonneville Power Company (~$12 million); the Pacific Northwest Salmon Recovery Program (~$8 million); Salmon Hatchery Reform (~$5 million); Pacific NW Indian Tribes; US–Canada

Pacific Salmon treaty; Dingle Johnson/Wallop-Breaux sport fish restoration tax; US Fish and Wildlife Service; NGOs & Industry support (US FWS 2000).

Current status of marine fisheries enhancement in the US

There is currently much renewed interest in marine stock enhancement in the US, following advances in marine aquaculture. Marine aquaculture systems in the US have progressed from extensive to semi-intensive and intensive rearing systems, and are now moving toward recirculating systems and sea cages (Stickney & McVey 2002). Several states in the US are researching marine stock enhancement potential. The research programs typically use chemical marks, coded wire tags, visible implant elastomer tags and, recently, sonic tags and genetic fingerprinting to identify hatchery animals (e.g. Leber *et al.* 1995, 1996, Willis *et al.* 1995, Smith *et al.* 1997, Blaylock *et al.* 2000, Garbor 2001, Fairchild 2002, Bert *et al.* 2003, Friedlander & Ziemann 2003). Among these programs, only California, Florida, South Carolina and Texas have state mandates to carry out marine fisheries enhancement, but there are also well-funded research programs at various state, federal, and private laboratories, which are designed to develop and test stock-enhancement technology. The states with the greatest-funded programs among these include:

California Hubbs-Sea World Research Institute, in cooperation with California Department of Fish and Game, is conducting research on stock enhancement of white sea bass, California halibut, and rockfish (leader is Don Kent; see Kent *et al.* 1995).

Connecticut The National Marine Fisheries Service, Northeast Fisheries Science Center's Milford Laboratory, is researching bay scallop and tautog stock enhancement (leader is Anthony Calabrese; see Goldberg *et al.* 2000).

Florida The Florida Fish and Wildlife Conservation Commission, in partnership with Mote Marine Laboratory, is researching enhancement potential of red drum, common snook, Gulf of Mexico sturgeon, bay scallops and (MML) red snapper (leaders: Bill Halstead, Ken Leber, Alan Huff, Bill Arnold; see Willis *et al.* 1995, Bert *et al.* 2003).

Hawaii The Oceanic Institute is researching striped mullet, Pacific threadfin, and red snapper stock enhancement (leader is David Ziemann; see Friedlander & Ziemann 2003).

Maryland The University of Maryland Biotechnology Institute's Center of Marine Biotechnology is evaluating stock enhancement potential of blue crab (leaders are Yonathan Zohar, Anson Hines; see Zohar & Mylonas 2001).

Mississippi The University of Southern Mississippi College of Marine Sciences, Gulf Coast Research Laboratory is researching red snapper and blue crab stock enhancement (leader is Bill Hawkins; see Pruder *et al.* 1999, Blaylock *et al.* 2000).

New Hampshire The University of New Hampshire Coastal Marine Laboratory is researching winter flounder stock enhancement (leader is Hunt Howell; see Fairchild & Howell 2000).

North Carolina North Carolina State University is researching blue crab and summer flounder stock enhancement (leader is Dave Eggleston; see Kellison *et al.* 2002).

South Carolina The South Carolina Department of Natural Resources, Marine Resources, is researching stock enhancement of red drum, cobia, and black sea bass (leader is Ted Smith; see Smith *et al.* 1997).

Texas The Texas Parks and Wildlife agency stocks red drum and spotted seatrout, and is working to develop culture technology for tarpon. Texas was the first state to re-establish stocking programs with marine fishes, and pioneered extensive pond rearing technology for marine fishes in the US (leader is Robert Vega; see McEachron *et al.* 1998).

Virginia The Virginia Institute of Marine Science of the College of William and Mary is evaluating blue crab stock enhancement (leader is Rom Lipscius; see Seitz *et al.* 2003).

Washington The National Marine Fisheries Service, Northwest Fisheries Science Center's Manchester Laboratory, and the Washington Department of Fish and Wildlife are researching lingcod, Pacific cod, rockfish and salmon stock enhancement (leader is Conrad Mahnken; see Berejikian *et al.* 2000).

Marine fisheries enhancement is at an intermediate stage of development in the US (see discussions in Blankenship & Leber 1995, Hilborn 1998, Leber 1999, 2002, Blaxter 2000). It is clear by now that many cultured marine fishes will survive and grow in the wild. The principal question in marine stock enhancement research today is about identifying whether stocking truly increases fish production and the precautions that are needed to ensure that cultured fish do not simply displace wild fish without any net increase in total production (Hilborn 1999). Many other critical uncertainties about stocking also remain unevaluated, e.g. the effectiveness and efficiency of release strategies, cost-effectiveness, unregulated fishing-effort dynamics, effects on wild stocks, effects on the ecosystem, sustainable replenishment versus dependency on stocking, and whether yields achieved from stocking are greater than yields from the alternatives – sound regulations and habitat management. Clearly, much research is needed to develop the full potential of stock enhancement in the US.

Trends in fisheries enhancement in the US

Fishery management is undergoing dramatic evolution, as fish population dynamics become better understood (Walters & Martell 2004). However, owing largely to the lack of scientific information about interactions of hatchery fish with wild fish, there is much public and scientific debate in the US over stock enhancement. We have debated for decades the ethical use of fish culture in fisheries management; now the discussion has moved to the broader societal forum – the environmental community. Fishery management objectives in the US are mainly determined by public demand. For decades, the public has supported stocking initiatives. But now the criteria for the use of cultured species are changing in response to evolving public fishery policy – i.e. the precautionary principle (FAO 1995). Modern fishery management would ensure maintenance of natural systems with native biota and optimal biodiversity. The political climate among policy makers has shifted toward the greener side, following an increase in new environmental groups in the US. The end result needs to be a sound public policy that captures both the social and the economic benefits of renewable common property fishery resources (Hilborn 1999, Walters & Martell 2004).

In part because of environmental concerns about fish stocking programs (e.g. Hilborn 1999, Walters & Martell 2004), beginning about the early1990s researchers in the US joined a worldwide trend toward much greater emphasis on the quantitative research needed to develop and test stock enhancement theory before launching new large-scale enhancement projects. New technologies such as coded wire tags, elastomer tags, chemical, temperature and genetic stock identification, hydro-acoustics, and aquaculture advances have greatly facilitated research. Much of the emphasis in stock enhancement programs is now focused on applying a responsible approach to enhancement (as in Cowx 1994, Blankenship & Leber 1995, Munro & Bell 1997).

Today in the US, as in many countries, various research groups are testing marine stock enhancement impact and effectiveness in quantitative field studies. These include experimental releases to evaluate survival, optimize release strategies, and determine the contribution of hatchery fish to fisheries (e.g. Drawbridge *et al.* 1995, Leber *et al.* 1995, 1996, 1997, 1998, Roberts *et al.* 1995, Willis *et al.* 1995, Glazer *et al.* 1997, Smith *et al.* 1997, McEachron *et al.* 1998, Stoner & Glazer 1998, Blaylock *et al.* 2000, Fairchild & Howell 2000, Goldberg *et al.* 2000, 2001, Kellison *et al.* 2000, 2002, Masuda & Ziemann 2000, Arnold 2001, Brennan & Leber 2002, Collins *et al.* 2002, Denson *et al.* 2002, Hawkins *et al.* 2002, Bert *et al.* 2003, Friedlander & Ziemann 2003, Brennan *et al.* in press, Ziemann & Friedlander in press). Many of the new studies also involve research needed to develop genetic conservation protocols for stocking (e.g. Campton *et al.* 1992, Bartley *et al.* 1995, Tringali & Leber 1999, Garber 2001, Bert *et al.* 2003) and comparison of natural levels of diseases and parasites of hatchery and wild fish (Blaylock *et al.* 2000, Bert *et al.* 2003). And studies have begun to examine density-dependent processes and carrying capacity effects on stocking success and recruitment of hatchery and wild fish (e.g., Leber *et al.* 1995, Kellison *et al.* 2000, 2002).

A clear sign of a more quantitative approach to stock enhancement in the US is the increase in publications and symposia in this field within the past decade. A computer-generated Web of Science search of peer-reviewed scientific journals using the keywords *stock enhancement* or *stocking* found 49 references to US studies after 1993, compared to only 2 US references for all years on record prior to 1993 (dating back to 1949). US symposiums on stock enhancement reveal increasing emphasis on field studies designed to test stocking effects – e.g. the American Fisheries Society Symposium 15 (Schramm & Piper 1995); the Mote Symposium on Fisheries Ecology (Coleman *et al.* 1998); and the US–Japan Cooperative Program in Natural Resources (UJNR) Aquaculture Panel's symposia on stock enhancement (Howell *et al.* 1998, Nakamura *et al.* 2003).

Another sign of the expanding information base is that both Federal and state US fisheries management agencies are incorporating active adaptive management (Walters & Hilborn 1978, Hilborn & Walters 1992) as an integral part of the management process. There is increasing focus in the US on advancing the scientific background needed for developing effective enhancement programs prior to conducting large-scale stocking.

Fisheries enhancement needs in the US

First and foremost – predictable stocking effects

The gains would be great from developing a truly effective and reliable stocking technology that could rapidly replenish depleted stocks, augment fisheries, and save stocks that are on the brink of extinction. To achieve this capability, we must address and solve the many questions that remain about how to ensure stocking objectives are actually achieved. We must keep the more rapid development of a science of fisheries enhancement as a top priority. A formidable amount of work is needed to develop predictable, controlled results from stocking.

For stocking to become a practical fishery-management tool, cost-effective stocking strategies must be clearly determined. To do this, stocking plans are needed with protocols for critical stocking variables (size-at-release, release site, timing of releases, release magnitude; e.g. Leber *et al.* 1996, Leber 1999, Blaxter 2000). And these factors must be coupled with the tactics deemed necessary to control hatchery stock's interactions with wild stocks. Thus, the focus of marine enhancement studies needs to move beyond evaluating post-release survival, and effects of release strategies on survival, to new studies of interactions between hatchery and wild stocks.

To understand and control interactions between hatchery and wild stocks, such as competitive exclusion, predation and cannibalism, genetic and health impacts, literally years of experimental field studies are needed. As we fill in the gaps in knowledge, the results need to be included in multispecies models focused on stocking effect. The ecosystem models that must be developed for predicting enhancement impact need to incorporate many ecological factors related to stocking that fishery scientists and ecologists have not yet addressed.

Field evaluations of genetic effects of stocking must also be done to quantify genetic impact and consequences. For example, are there threshold levels of outbreeding depression below which stocks can quickly recover? What degree of genetic change is detrimental?

Carrying capacity – how many fish should be stocked?

The current *question of the day* in fisheries enhancement is whether displacement of wild fish by hatchery fish can be avoided (Hilborn 1998, 1999, Chapter 17, Blaxter 2000). We clearly need more studies to develop stocking strategies that minimize competition for food and space between hatchery and wild stocks.

Carl Walters and colleagues' foraging arena theory provides a theoretical framework for evaluating density-dependent effects of stocking (Walters & Juanes 1993, Walters & Korman 1999, Walters & Kitchell 2001, Walters & Martell 2004). This theory holds that fish habitat availability is not what it seems – that refugia from predators are the principal microhabitats occupied by young-of-the-year recruits and that fish abundance is strongly mediated by food availability within and near refugia, with higher mortality of fish that move out of refugia. Density-dependent mortality rates result primarily from increased activity with increased density leading to higher predation rates, which are greater on prey that leave refugia in search of food (Walters & Juanes 1993).

A key corollary to these hypotheses is Walters' contention that unless spawning stocks are severely overfished, juvenile abundance is generally habitat-limited, not spawner or egg/fry abundance-limited (Walters & Martell 2004). Under this scenario, growth and foraging-time responses imply predation risk is proportional to density; competition for food is important even at low densities of juveniles; juvenile survival is density-dependent at low densities; and increasing juvenile density by stocking has high likelihood of increasing mortality – as juveniles leave their refugia in search of food. Thus, at low densities recruitment success is strongly proportional to density, resulting in a Beverton-Holt recruitment pattern. The problem for managers of stocking programs is to understand the relationship between juvenile density and survival at least well enough to know how much can juvenile abundance be increased before recruitment success starts to drop.

Considering fishing effort

In the US, sportfishing is a major form of recreation (Recreational Fishing Alliance 2000). In 2001, nearly 9 051 000 anglers made over 90 million marine fishing trips to the Atlantic, Gulf, and Pacific US coasts. Saltwater sport fishers spent $11 318 249 621, had an economic output of $31 085 904 333, and created 296 898 jobs with wages and salaries amounting to $8 138 400 181 (ASA 2002).

Florida's Fish and Wildlife Conservation Commission is currently investigating the potential of marine stock enhancement as a fishery management tool. The state of Florida accounts for over half of the estimated 4 million marine recreational anglers in the southeast US (Milon 2000). In Florida, saltwater recreational fishing has recently been estimated to contribute US$5.4 billion to the economy (ASA 2002). This was the greatest economic output from marine sportfishing in the US. Thus it is crucial that Floridians understand the effects and effectiveness of its stocking programs on these valuable fisheries.

A key need for stakeholders who support stock enhancement is to understand the expected fishing-effort response to stocking and how this will affect the ability to achieve stocking goals, particularly increasing catch-per-unit-effort (CPUE). Fishing groups in Florida are hopeful that stock enhancement can help increase the catch, and for that reason are supportive of expanding the state's marine stock enhancement program. But for sport fisheries, stocking does not necessarily put more fish in the boat. CPUE is proportional to fish abundance divided by fishing effort. Increases in fish abundance generally result in greater numbers of recreational anglers launching their boats (i.e. increased fishing effort). Hence, if fish abundance increases from stocking, fishers should understand that the greater fishing effort that results will likely negate the expected increase in CPUE. The exception to this is re-establishing a completely depleted fishery, where CPUE is close to zero prior to initiating the stocking program.

In the US, we are just learning that we can not increase CPUE as a goal of enhancement without managing fishing effort. But limits on the number of recreational anglers have been very difficult to establish in public waters in the US. Rather, most coastal states have harvest-size regulations, harvest limits, and seasonal closures but have not introduced effort limits. Thus, for the US, the target of stock enhancement is to increase fishing opportunity and total catch, not CPUE in recreational fisheries. This needs to be better communicated to the angling public, whose demands for greater CPUE are often the major motivation of new stocking programs.

Coupling stock enhancement with habitat restoration

One factor that fisheries managers have little control over is habitat degradation. Stocking effectiveness is critically dependent upon habitat availability and quality. Some of the most important uncertainties about stocking impact can be addressed by research that combines habitat manipulations with density manipulations. Artificial reef researchers have long debated whether reef-associated fish populations are recruitment- or habitat-limited (Lindberg 1997). If juvenile recruitment limitations are a primary mechanism in establishing fish abundance on reefs, then hatchery releases should increase abundance. Conversely, if habitat is a primary factor limiting the abundance of certain reef-associated fish populations, then hatchery releases afford a valuable research tool for measuring this constraint. Researchers in the US are now attempting to evaluate and quantify such density-dependent processes by simultaneously manipulating artificial reef surface area and stocking densities (e.g. Blaylock *et al.* 2000). Such studies should provide useful information to help resolve the artificial reef attraction–production issue and help guide habitat restoration efforts.

Considerations for a marine stocking code of ethics

A consensus plan for how to use stock enhancement effectively is seriously needed. The worldwide decline in fisheries landings (FAO 2000) has resulted in rapidly expanding interest in stock enhancement in the US. The new programs are mostly focused on marine species, and these programs have the opportunity to incorporate a responsible-approach framework (Cowx 1994, Blankenship & Leber 1995, Coates 1998). Because of the potential impact on wild stocks that could result from stocking, and because there is a paucity of scientific information needed to implement hatchery releases well enough to ensure stocking objectives are met, stock enhancement programs require a precautionary approach, adaptive management, and much monitoring to determine the effectiveness of stocking.

Walters & Martell (2004) suggest a model for the precautionary approach that is needed. Marine enhancement should not be used as a substitute for effective fishery regulation. Walters and Martell caution that marine stock enhancement could be used, temporarily, to accelerate rebuilding wild stocks suffering from overfishing or habitat damage, provided these problems are effectively addressed at the same time; marine enhancement could also be used to create fisheries where habitat constraints prevent wild recruitment – if there is no harm to wild stocks; monitoring of effectiveness should include (1) assessment of survival of enhanced fish – i.e. the net contribution to fishery harvests, (2) assessment of impact on survival and net fishery contribution of any wild stock impacted – i.e. by competition or predation due to stocked fish, and (3) assessment of changes in fishing mortality rates, on both wild and stocked fish – caused by unregulated responses of fishing effort to the presence of enhanced fish (Walters & Martell 2004).

Walters and Martell recommend that every marine enhancement program should be treated as an adaptive-management experiment, where monitoring of effectiveness is done in the context of planned comparisons of alternative stocking policies (stocking rates and sizes at release). Adaptive-management monitoring should be treated as a long-term cost component of enhancement investment – to be capable of detecting responses, wild-stock impacts, and performance of enhanced fish populations over multiple fish generations (Walters & Martell 2004, Carl Walters, pers. comm.).

Balancing society's priorities

In the US, as in other democratic nations, society ultimately sets fishery management policy. Managing food production in the sea is the polar extreme to managing marine biodiversity. Managing sportfishing opportunity lies somewhere in the middle of the (paradoxical) objectives of managing wild food resources and managing biodiversity. Because recreational anglers are satisfied with catching far fewer fish than are commercial fishermen, society in the US is beginning to move toward greater allocation of fish stocks to recreational anglers. Florida has a striking example, where in 1995 Florida voters banned, by referendum, gillnet fishing in inshore waters.

Currently, there is great debate in the US over how to balance fishing and biodiversity. We haven't yet decided even the goal of managing biodiversity, for in a variable ecosystem what is the target? Stopping or reversing succession? Or maintaining the status quo? Wanting for a better solution to overfishing, marine protected areas (MPAs) have emerged as the latest fashionable trend for managing biodiversity and fish production in the US. But the science for effective MPAs is no farther along toward a recipe for success than the science for marine enhancement. Nor have US scientists given society a palatable choice for managing its production fisheries by stock-assessment-based regulations, as indicated by so many declining commercial fisheries.

The clear need before us is to show society convincing evidence of the effectiveness, or lack thereof, of our fishery management strategies. While the US awaits a more effective fisheries management policy, we must avidly pursue better information for policy makers. The US needs its fishery scientists to evaluate the effectiveness of tools like MPAs and stock enhancement (Hilborn 1999). With forecasts for increasing population growth and fishery declines (FAO 2000), there has never been a greater need for balancing fishing regulations, habitat protection, and stocking strategies with the science needed to make them effective.

Conclusion

To harness the potential that exists for stock enhancement to be a truly effective and economically viable fishery management tool, we must develop better understanding and control of the effects and effectiveness of stocking. The principal needs are (1) to adopt a responsible approach to the development, planning, and use of stocking (e.g. Cowx 1994, Blankenship & Leber 1995, Walters & Martell 2004), (2) to develop a better scientific foundation for the subject of stocking cultured organisms, (3) to develop a system that achieves predictable, controlled stocking effects, (4) to assess the contribution of stocking to fishery production and landings, (5) to understand density-dependent effects on hatchery-release effect, (6) to evaluate genetic effects of hatchery stocks on wild stocks, and (7) to develop greater networking among scientists, fishery managers, marine policy makers, and stakeholders to increase awareness of what stocking can and cannot achieve as a fishery management tool.

We cannot afford to miss the opportunity that this moment of time affords us. We are at a turning point in the history of fisheries management – we must decide either to walk away from spending more on ambiguous results, or to make the shift to a more scientific approach in planning stocking programs, and integration of *active adaptive management* (Walters & Hilborn 1978, Hilborn & Walters 1992) in the implementation stage. That shift will give us the science and information we need to use stock enhancement wisely. Our fisheries community must rise to the challenge before us – to develop a reliable, effective, environmentally responsible stock enhancement and sea ranching technology.

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References

Arnold, W.S. (2001) Bivalve enhancement and restoration strategies in Florida, USA. *Hydrobiologia*, **465**, 7–19.

ASA (2002) *Sportfishing in America: Values of our Traditional Pastime*. American Sportfishing Association, Alexandria (Virginia). http://www.asafishing.org/content/statistics.

Bartley, D.M., Kent, D.B. & Drawbridge, M.A. (1995) Conservation of genetic diversity in a white seabass hatchery enhancement program in Southern California. *Am. Fish. Soc. Symp.*, **15**, 249–258.

Berejikian, B.A., Tezek, E.P., LaRae, A., Flagg, T.A., Kummerow, E. & Mahnken, C.V.W. (2000) Social dominance, growth and habitat use of age-0 steelhead (*Onchorhynchus mykiss*) grown in enriched and conventional hatchery-rearing environments. *Can. J. Fish. Aquat. Sci.*, **57**, 628–636.

Bert, T.M., McMichael, R.H. Jr, Cody, R.P., Forstchen, A.B., Halstead, W.G., O'Hop, J., Ransier, J.M., Tringali, M.D., Winner, B.L., Kennedy, F.S., Leber, K.M. & Neidig, C.L. (2003) A multi-disciplinary approach to evaluate red drum (*Sciaenops ocellatus*) stock enhancement strategies in a Florida estuarine system. In: *Ecology of Aquaculture Species and Enhancement of Stocks* (eds Y. Nakamura, J.P. McVey, K. Leber, C. Neidig, S. Fox & K. Churchill), pp. 105–126. Proceedings of the Thirtieth US–Japan meeting on aquaculture. Sarasota, Florida, 3–4 December, 2001. *UJNR Technical Report No. 30*. Sarasota, FL: Mote Marine Laboratory. 194pp.

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

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

Blaylock, R.B., Leber, K.M., Lotz, J.M., Stuck, K.C. & Ziemann, D.A. (2000) The US Gulf of Mexico marine stock enhancement program (USGMSEP): the use of aquaculture technology in 'responsible' stock enhancement. *Bull. Aquacult. Assoc. Can.*, **100**(3), 16–22.

Brennan, N.P. & Leber, K.M. (2002) Effects of release micro-habitat on survival and growth of hatchery snook (*Centropomus undecimalis*), in a Florida estuary. *Second International Symposium on Stock Enhancement and Sea Ranching*, Book of Abstracts, Tokyo.

Brennan, N.P., Ransier, J.M., Blankenship, H.L., Debruler, R. Jr & Leber, K.M. Adapting tag technology for stock enhancement of the common snook, *Centropomus undecimalus*. *North Am. J. Fish. Manage.* (in press).

Campton, D.E., Berg, C.J. Jr, Robison, L.M. & Glazer, R.A. (1992) Genetic patchiness among populations of queen conch *Strombus gigas* in the Florida keys and Bimini. *U.S. Fish. Bull.*, **90**, 250–259.

Coates, D. (1998) Codes of practice for the stocking and introduction of fish. In: *Stocking and Introduction of Fish* (ed. I.G. Cowx), pp. 383–396. Fishing News Books, Oxford.

Coleman, F., Travis, J. & Thistle, A.B. (eds) (1998) Marine stock enhancement: a new perspective. *Bull. Mar. Sci.*, **62**(2), 303–714.

Collins, R.R., Smith, T.I.J., Jenkins, W.E. & Denson, M.R. (2002) Small marine reserves may increase escapement of red drum. *Fisheries*, **27**(2), 20–24. http://www.fisheries.org.

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

Denson, M.R., Jenkins, W.E., Woodward, A.G. & Smith, T.I.J. (2002) Tag-reporting levels for red drum (*Sciaenops ocellatus*) caught by anglers in South Carolina and Georgia estuaries. *U.S. Fish. Bull.*, **100**, 35–41.

Drawbridge, M.A., Kent, D.B., Shane, M.A. & Ford, R.F. (1995) The assessment of marine stock enhancement in Southern California: a case study involving the white seabass. *Am. Fish. Soc. Symp.*, **15**, 568–569.

Fairchild, E.A. (2002) *Winter Flounder Pseudopleuronectes americanus Stock Enhancement in New Hampshire: Developing Optimal Release Strategies.* Dissertation, University of New Hampshire, Durham.

Fairchild, E.A. & Howell, W.H. (2000) Predator–prey size relationship between *Pseudopleuronectes americanus* and *Carcinus maenas*. *J. Sea Res.*, **44**(1–2), 81–90.

FAO (1995) Precautionary approach to fisheries, Part 1: Guidelines on the precautionary approach to capture fisheries and species introductions. *FAO Fish. Tech. Pap.*, **350**, Part 1. Food and Agriculture Organization of the United Nations, Rome.

FAO (2000) *The State of World Fisheries and Aquaculture, 2000.* Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/DOCREP/003/X8002E/X8002E00.htm.

Friedlander, A.M. & Ziemann, D.A. (2003) Impact of hatchery releases on the recreational fishery for Pacific threadfin (*Polydactylus sexfilis*) in Hawaii. *U.S. Fish. Bull.*, **101**, 32–43.

Garber, A.F. (2001) Utilization of a hypervariable region as a molecular marker for red snapper, Lutjanus campechanus, stock enhancement. Thesis, University of Southern Mississippi, Hattiesburg.

Glazer, R.A., McCarthy, K.J., Jones, R.L. & Anderson, L.A. (1997) The use of underwater metal detectors to recover outplants of the mobile marine gastropod *Strombus gigas* L. *Proc. 49th Gulf and Caribbean Fish. Inst.*, **49**, 503–509.

Goldberg, R., Pereira, J. & Clark, P. (2000) Strategies for enhancement of natural bay scallop, *Argopecten irradians irradians*, populations: a case study in the Niantic River estuary, Connecticut, USA. *Aquacult. Int.*, **8**(2–3), 139–158.

Goldberg, R., Pereira, J. & Clark, P. (2001) Stock enhancement: moving from wishful thinking toward sound ecology. In: *Collected Abstracts of the Seventh NESFC Science Symposium*, NSFC Reference Document 01–17. NOAA/NMFS Northeast Fisheries Science Center Reference Document, Westbrook. p.4. http://www.nefsc.noaa.gov/nefsc/publications/crd/crd0117/0117.htm.

Grimes, C.B. (1995) Perspective of the AFS marine fish section on uses and effects of cultured fishes in aquatic ecosystems. *Am. Fish. Soc. Symp.*, **15**, 593–594.

Hawkins, W.E., Leber, K.M., Lotz, J.M., Pruder, G.D. & Ziemann, D.A. (2002) Using the red snapper, *Lutjanus campechanus*, in the Gulf of Mexico to conduct stock enhancement research. *Book of Abstracts, World Aquaculture 2002*, The Annual Meetings of the World Aquaculture Society & the China Society of Fisheries, Beijing.

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*, Chapman & Hall, New York and London. 570pp.

Howell, W.H., Kellere, B.J., Park, P.K., McVey, J.P., Takayanagi, K. & Uekita, Y. (eds) (1998) Nutrition and technical development of aquaculture. Proceedings of the Twenty-Sixth US–Japan Symposium, University of New Hampshire Sea Grant Program, Durham.

Kellison, G.T., Eggleston, D.B. & Burke, J.S. (2000) Comparative behaviour and survival of hatchery reared versus wild summer flounder (*Paralichthys dentatus*). *Can. J. Fish. Aquat. Sci.*, **57**(9), 1870–1877.

Kellison, G.T., Eggleston, D.B. & Tanaka, M. (2002) Density-dependent predation and implications for stock enhancement with Japanese flounder. *J. Fish Biol.*, **60**(4), 968–980.

Kent, D.B., Drawbridge, M.A. & Ford, R.F. (1995) Accomplishments and roadblocks of a marine stock enhancement program for white seabass in California. *Am. Fish. Soc. Symp.*, **15**, 492–498.

Leber, K.M. (1999) Rationale for an experimental approach to stock enhancement. In: *Stock Enhancement and Sea Ranching* (eds B.R. Howell, E. Moksness & T. Svåsand), pp. 63–75. Blackwell Scientific Publications, Oxford.

Leber, K.M. (2002) Advances in marine stock enhancement: shifting emphasis to theory and accountability. In: *Responsible Marine Aquaculture* (eds R.R. Stickney & J.P. McVey), pp. 79–90. CABI Publishing, New York.

Leber, K.M., Arce, S.M., Sterritt, D.A. & Brennan, N.P. (1996) Test of marine stock-enhancement potential with striped mullet in Hawaii: growth, survival and release impact in nursery habitats *U.S. Fish. Bull.*, **94**, 452–471.

Leber, K.M., Blankenship, H.L., Arce, S.M. & Brennan, N.P. (1997) Influence of release season on size-dependent survival of cultured striped mullet, *Mugil cephalus*, in a Hawaiian estuary. *U.S. Fish. Bull.*, **95**(2), 267–279.

Leber, K.M., Brennan, N.P. & Arce, S.M. (1995) Marine enhancement with striped mullet: are hatchery releases replenishing or displacing wild stocks? *Am. Fish. Soc. Symp.*, **15**, 376–387.

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.

Lindberg, W.J. (1997) Can science resolve the attraction–production issue? *Fisheries*, **22**, 10–13.

Masuda, R. & Ziemann, D.A. (2000) Ontogenetic changes of learning capability and stress recovery in Pacific threadfin juveniles. *J. Fish Biol.*, **56**, 1239–1247.

McEachron, L.W., Colura, R.L., Bumguardner, B.W. & Ward, R. (1998) Survival of stocked red drum in Texas. *Bull. Mar. Sci.*, **62**(2), 359–368.

Milon, J.W. (2000). Current and future participation in marine recreational fishing in the southeast US region. NOAA technical memorandum. NMFS-F/SPO-44, 44pp.

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

Nakamura, Y., McVey, J.P., Leber, K., Neidig, C., Fox, S. & Churchill, K. (2003) Ecology of aquaculture species and enhancement of stocks. Proceedings of the Thirtieth US–Japan meeting on aquaculture. Sarasota, Florida, 3–4 December, 2001. *UJNR Technical Report No. 30*. Sarasota, FL: Mote Marine Laboratory. 194pp.

Pruder, G.D., Ziemann, D.A., Leber, K.M., Lotz, J.M., Hawkins, W.E. & Conquest, L.D. (1999) US Gulf of Mexico marine stock enhancement five-year program: 1999–2004: program management for planning, execution, review, and evaluation. *Bull. National Res. Inst. Aquacult.* (Japan) Suppl. **1**, 89–99.

Recreational Fishing Alliance (2000) *Testimony to pew ocean commission*. http://www.pewoceans.org/activities/2002/07/12/activities_27631.asp.

Richards, W.J. & Edwards, R.E. (1986). Stocking to restore or enhance marine fisheries. In: *Fish Culture in Fisheries Management* (ed. R.H. Stroud), pp. 75–80. American Fisheries Society, Bethesda.

Roberts, C.M., Quinn, N., Tucker, J.W. Jr & Woodward, P.N. (1995) Introduction of hatchery-reared Nassau grouper to a coral reef environment. *North Am. J. Fish. Manage.*, **15**(1), 159–164.

Schramm, H.L. Jr & Piper, R.G. (eds) (1995) Uses and effects of cultured fishes in aquatic ecosystems. *Am. Fish. Soc. Symp.*, **15**, 608pp.

Seitz, R.D., Lipcius, R.N., Stockhausen, W.T., Delano, K.A., Seebo, M.S. & Gerdes, P.D. (2003) Potential bottom-up control of blue crab (*Callinectes sapidus*) distribution at various spatial scales. *Bull. Mar. Sci.*, **72**, 471–490.

Smith, T.I.J., Jenkins, W.E. & Denson, M.R. (1997) Overview of an experimental stock enhancement program for red drum in South Carolina. *Bull. National Res. Inst. Aquacult.* (Japan), Suppl. **3**, 109–115.

Stickney, R.R. & McVey, J.P. (2002) *Responsible Marine Aquaculture*. CABI Publishing, New York.

Stoner, A.W. & Glazer, R.A. (1998) Variation in natural mortality: implications for queen conch stock enhancement. *Bull. Mar. Sci.*, **62**(2), 427–442.

Tringali, M.D. & Leber, K.M. (1999) Genetic considerations during the experimental and expanded phases of snook stock enhancement. *Bull. National Res. Inst. Aquacult.* (Japan), Suppl. **1**, 109–119.

US FWS (2000) *Digest of Federal Resource Laws of Interest to the U.S. Fish and Wildlife Service*. http://laws.fws.gov/lawsdigest/reslaws.html.

Walters, C.J. & Hilborn, R. (1978) Ecological optimization and adaptive management. *Annu. Rev. Ecol. Syst.*, **9**, 157–188.

Walters, C.J. & Juanes, F. (1993) Recruitment limitation as a consequence of natural selection for use of restricted feeding habitats and predation risk taking by juvenile fishes. *Can. J. Fish. Aquat. Sci.*, **50**, 2058–2070.

Walters, C.J. & Kitchell, J.F. (2001) Cultivation/depensation effects on juvenile survival and recruitment: implications for the theory of fishing. *Can. J. Fish. Aquat. Sci.*, **58**, 39–50.

Walters, C.J. & Korman, J. (1999) Linking recruitment to trophic factors: revisiting the Beverton-Holt recruitment model from a life history and multispecies perspective. *Rev. Fish Biol. Fish.*, **9**, 187–202.

Walters, C.J. & Martell, S. (2004) *Fisheries Ecology and Management*. Princeton University Press, Princeton.

Willis, S.A., Falls, W.W., Dennis, C.W., Roberts, D.E. & Whitchurch, P.G. (1995) Assessment of season of release and size at release on recapture rates of hatchery-reared red drum. *Am. Fish. Soc. Symp.*, **15**, 354–365.

Ziemann, D.A. & Friedlander, A.M. Carrying capacity for hatchery-reared Pacific threadfin (*Polydactylus sexfilix*) in native nursery habitats in Hawaii. *Trans. Am. Fish. Soc.* (in press).

Zohar, Y. & Mylonas, C.C. (2001) Endocrine manipulations of spawning in farmed fish: from hormones to genes. *Aquaculture*, **197**, 99–136.