The Potential for Flounder and Red Drum Stock Enhancement in North Carolina

Summary of a workshop
held March 30-31, 1998,
at North Carolina State University,
Raleigh, N.C.

The Potential for Flounder and Red Drum Stock Enhancement in North Carolina

Summary of a Workshop Held March 30-31, 1998, at North Carolina State University, Raleigh, N.C.

Written by

B.J. Copeland
Department of Zoology
NC State University

John Miller
Department of Zoology
NC State University

Elizabeth B. Waters
Charlottesville, Va.

Edited and designed by
Daun Daemon
North Carolina Sea Grant

Acknowledgments

This report is based on a workshop organized and conducted by B.J. Copeland, North Carolina State University. Participating in the workshop were:

Harry Daniels, North Carolina State University, Raleigh;
Chris Duffy, Great Bay Aquaculture, Portsmouth, N.H.;
Churchill Grimes, National Marine Fisheries Service, Panama City, Fla.;
Wally Jenkins, S.C. Division of Natural Resources, Charleston;
Ken Leber, Mote Marine Laboratory, Sarasota, Fla.;
Larry McEachron, Texas Parks and Wildlife, Rockport;
John Miller, North Carolina State University, Raleigh;
Rick Monaghan, N.C. Division of Marine Fisheries, Morehead City;
William Neill, Texas A&M University, College Station;
Kilho Park, National Marine Fisheries Service;
Mike Ray, Texas Parks and Wildlife, Austin;
Steve Ross, University of North Carolina at Wilmington;
Steve Serfling, Mote Marine Laboratory, Sarasota, Fla.;
Theodore Smith, S.C. Division of Natural Resources, Charleston;
Michael Stoskopf, North Carolina State University, Raleigh;
Masaru Tanaka, Kyoto University, Japan.

Elizabeth B. Waters, Charlottesville, Va., served as the workshop facilitator and developed the first draft of the document from the workshop deliberations. The report was edited and produced by Daun Daemon, North Carolina Sea Grant, Raleigh, N.C.

Its publication was made possible by a grant from the National Coastal Resources Research Institute through NOAA grant #NA76RG0163 and through state appropriations to the N.C. Agricultural Research Service at the NC State University College of Agriculture and Life Sciences.

Introduction

A number of marine fisheries in North Carolina are under significant stress from overfishing and habitat degradation. Included are summer flounder, southern flounder and red drum. This situation has led to efforts to reduce commercial and recreational catches for some species and interest in other means to restore these stocks to past abundance.

Three approaches can rebuild declining fisheries:

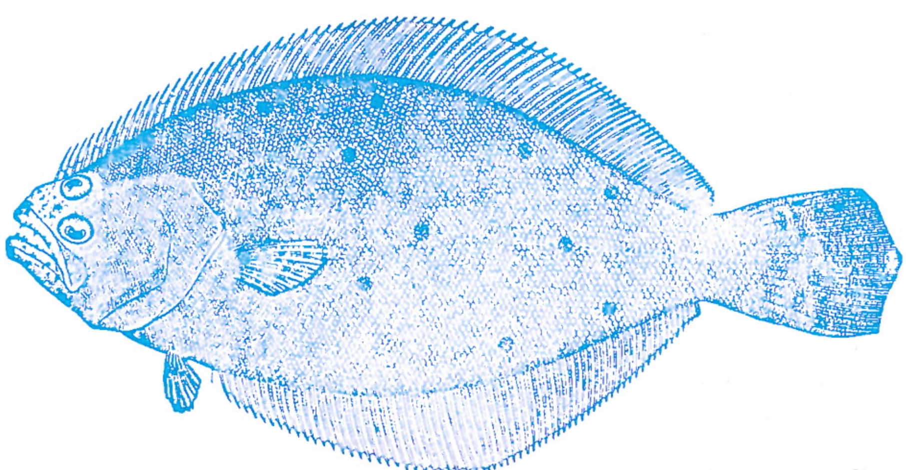
- ❖ restricting harvest
- ❖ restoring degraded fish nurseries
- ❖ enhancing stock.

To some degree, North Carolina regulates harvest and restores nurseries, but fishery managers believe much more can be done. To date, North Carolina has not initiated any stock enhancement programs for marine fish, although a number of other states and countries have.

Due to growing interest in using stock enhancement to restore marine fisheries, the Department of Zoology at North Carolina State University convened a workshop to examine the potential for marine stock enhancement in North Carolina. The organizers invited scientists and practitioners from around the country and Japan to come together for two days to respond to the following questions:

1. What is the state of the flounder and red drum stocks in North Carolina?
2. When does considering stock enhancement make sense, and would it replace traditional management techniques?
3. What are the concerns about stock enhancement in marine environments?
4. Are conditions favorable for stocking flounder and red drum in North Carolina?
5. Is there stock enhancement experience elsewhere to build on?
6. What are the major elements in designing a responsible stock enhancement program and building public support?
7. What are the issues to consider in designing and siting a hatchery?

This report summarizes the conclusions reached during the workshop and suggests steps the state should take when considering a stock enhancement initiative in North Carolina.



Summer flounder

Questions

1.

What is the status of the flounder and red drum fisheries in North Carolina?

Summer flounder, southern flounder and red drum catches in North Carolina have declined in recent years. Scientists believe this situation results from increased pollution in the species' habitat and overfishing. Management efforts for summer flounder and red drum appear to be rebuilding these fisheries, although at slower rates than anticipated and desired. No management plan is in place for southern flounder. All of these stocks are far below historical levels.

For a number of years, state and federal agencies have tagged fish and collected data to assess the status of these fisheries. Still, a host of unanswered questions — including where some of the fish spawned in North Carolina estuaries end up as adults — make fully assessing the status of these fisheries difficult. The following is a summary of what is known.

Summer flounder

Summer flounder (*Paralichthys dentatus*) are found from the border of Canada to Florida. From a historical perspective, the summer flounder fishery in North Carolina is moderately abundant, but it is heavily exploited by commercial and recreational fishers. The life expectancy for summer flounder is 12 to 15 years. While the age distribution of the stock is improving due to recent management efforts, it is still skewed toward younger fish. This keeps the health of the fishery dependent on the size of each year's crop, which varies considerably from year to year. While evidence suggests that the size of the spawning stock is increasing, the productivity of this younger spawning population is unknown.

A significant portion of young recruited summer flounder use North Carolina estuaries as nursery areas in their first year. In the fall of their second year, young flounder leave the Pamlico Sound nurseries and move offshore. At this point, their life histories appear to vary according to whether they go north or south. Those that migrate north appear to live longer, and many of these return to North Carolina waters in future years. Those that migrate south do not appear to live as long and seldom return to North Carolina.

The summer flounder population is managed by the Mid-Atlantic Fishery Management Council and the Atlantic States Marine Fisheries Commission. As a result of management efforts, summer flounder are harvested at a reduced level, but still at a rate almost double the level recommended in the fishery management plan. In recent years, the fishery has shown some signs of recovery.

Southern flounder

Southern flounder (*Paralichthys lethostigma*) range from the mouth of the Chesapeake Bay to southern Florida's east and Gulf coasts and throughout the Gulf of Mexico. They remain more tied to nursery areas throughout their lives than summer flounder. Southern flounder are shorter lived and more easily caught by commercial fishing operations than summer flounder. Mature southern flounder are frequently caught in shallow water.

According to the North Carolina Division of Marine Fisheries, landings of southern flounder increased dramatically during the 1990s due to the decline of the summer flounder fishery and to catch limits placed on that species. Today, southern flounder has replaced summer flounder as the number one flatfish landed in North Carolina, placing considerable stress on this fishery. While the federal government has no management plan for southern flounder, the North Carolina Division of Marine Fisheries is developing one. Because the fishery has not been managed, it is more vulnerable and less information is available on the condition of the southern flounder population.

Red drum

Red drum (*Sciaenops ocellatus*) are found from Virginia to the Gulf of Mexico. They mature at age 4 or 5 and are long lived. The size of the red drum year class varies significantly from year to year.

Factors affecting this are not well understood. Scientists know that few juvenile red drum escape from North Carolina estuaries to the ocean, probably as a result of net fishing in the sounds. For the most part, large red drum caught off the coast of North Carolina have been spawned elsewhere and migrated there.

Red drum are managed by the South Atlantic Fishery Management Council and the southeastern states. Managers have determined that this fishery is overfished and experiencing significant reductions in spawning stock and recruitment of young fish. Red drum are showing some signs of recovery in North Carolina, but the low escape rate of subadults from estuaries to the ocean is of concern.

Unknowns

❖ What is the true status of the flounder and red drum stocks in North Carolina?

❖ What should be considered normal fluctuations in the flounder and red drum populations?

❖ What are the relative contributions of growth, recruitment, fishing and mortality to the size of these stocks from year to year?

2.

When does stock enhancement make sense, and would it replace traditional management techniques?

Five conditions should exist before considering a stock enhancement program in any location: a declining fishery, a growing demand for the species, excess carrying capacity in receiving waters, inability of traditional methods to manage the fishery and built-in environmental safeguards.

Declining stock

Stock enhancement should be considered only when an important fishery is steadily declining despite previous management efforts. While annual variability in production and catch are expected, sustained decline usually suggests chronic long-term problems requiring greater management intervention.

This red drum was netted in an estuary along with several other species. But this sight is becoming less frequent as the catch of red drum has declined in recent years.

Growing demand

Only when a fishery is declining and demand for that fish remains strong from commercial and recreational fishers is stock enhancement likely to be considered. Generally, growing demand from the fishing community means that the fish is in strong demand in the marketplace, that it is a particularly popular sport fish or that both are true. Because stock enhancement can be a costly way of rebuilding a fishery, it is likely to succeed only with a strong market for the product.

Excess carrying capacity

Excess carrying capacity in waters that will receive stocked fish is crucial to success and to minimize adverse effects on wild fish stocks and receiving waters. Releasing fish in ways that would compete with or further jeopardize wild stocks is counterproductive.

Ineffective management strategies

Stock enhancement should never be viewed as a replacement for traditional management strategies. It should always be used in conjunction with regulating harvest and restoring degraded habitat. Some scientists argue that these traditional management strategies, if strictly adhered to, are sufficient to restore fisheries without the risk and expense of stock enhancement. Others argue that stock enhancement is needed as a tool when the limits of what can be accomplished through regulations have been reached or political resistance to management regulations make further actions of this kind impossible. Some stock enhancement programs report that stocking has led to stronger not weaker support for management regulations and has helped attract a higher level of funding for overall management efforts.

Built-in environmental safeguards

Because of concern about negative impacts on wild stocks and receiving waters, stocking programs should include as many safeguards as possible to minimize potential harms. This requires revising regulations to govern this new management approach.

Unknowns

❖ Do the state's nursery areas have excess capacity, or would stocked fish displace wild fish?

❖ Are sufficient harvest regulations instituted and enforced?

❖ Would habitat restoration aid the fishery?

❖ What kinds of environmental safeguards should be in place before undertaking a stock enhancement program?

3.

What are the concerns about stock enhancement in marine environments?

Before undertaking any initiatives, policymakers should recognize that many scientists and fishers have serious concerns about the potential environmental impacts of stock enhancement programs.

Diluting genetic diversity of wild stock

One of the major concerns scientists have about stock enhancement is the potential for stocked fish to dilute the genetic diversity of wild stock, weakening it over time. Scientists believe that stocking programs should give particular care to selecting broodstock and periodically replacing it with new wild stock. Broodstock should be selected from the areas that will be stocked and should include genetic variations similar to those found in the wild. Research suggests developing and maintaining adequate genetic diversity would be easier in summer flounder than in southern flounder because of the high genetic variation within southern flounder stock. Because of potential negative impacts on wild stocks, some scientists suggest that enhancement be used only for endangered species like sturgeon, where the fishery is in danger of disappearing entirely. Further, overfishing reduces genetic diversity, usually by selectively removing the fastest growing genotypes. Careful genetic manipulation through stock enhancement programs could be — and is being — used to restore genetic diversity.

Exceeding carrying capacity of receiving waters

Another concern about stocking is that it could overpopulate estuaries already at their capacity to support the native fish population, displacing some of the wild fish with stocked fish. Variation in annual recruitment for one species may not be sufficient evidence that excess carrying capacity exists, since this "excess" habitat may be used in off years by other species as well. Because the colonization of estuarine nursery areas in North Carolina may be influenced by ocean/sound interactions, predicting demands on specific habitats in any given year is difficult. To support the high productivity found in North Carolina estuaries, a large number of seemingly underutilized nursery areas may be required. Most of the concerns about stocking tend to revolve around the long-term effects it may have on the ecology of the receiving waters and whether undesired interactions and displacements may occur.

Introducing disease

Many concerns about stock enhancement programs are related to disease, including the kinds of diseases stocked fish might encounter after their release, the diseases they might transmit to wild fish and the threats either of these might pose to human health. While there are no definitive answers for any of these concerns, the following are recommended approaches.

Environmental conditions that may affect the survival of stocked fish include pollutants in the receiving waters, predators and quality of bottom sediments. Exposing young fish to the natural pathogens in the receiving waters prior to release allows them to develop immunities and thus increase their chances of survival. Stock enhancement programs might also look for genetic markers of physiological traits that affect survival, such as rate of growth and disease resistance, as a way to produce fish as hardy as possible.

Very little is known about infectious diseases that may affect flounder or red drum and whether any of these diseases might be transmitted to humans. Initial efforts should concentrate on identifying diseases of greatest concern in related and cohabiting species. Once identified, these diseases could form the basis of a prescreening process to eliminate fish carrying disease.

The public will have concerns about the potential for stocking programs to create human health problems. While scientists do not anticipate major disease problems to result from stock enhancement, any program needs to address disease concerns so that human health as well as the health of wild and stocked fish are protected to the greatest extent possible. Programs should make the public aware that bacteria and viruses, which are present everywhere in the environment, become a problem only when they result in actual disease.

Undermining responsible management practices

Another concern is that stocking programs create a false sense of abundance, which leads to demands to reduce catch limits and places the fishery under even greater stress. Some are concerned that costly stock enhancement programs may divert resources from more traditional, and many believe more cost-effective, management strategies. However, stocking programs in Texas, Hawaii and Japan have contributed to a greater sense of resource ownership, thereby facilitating management.

Introducing exotic pathogens

Another important concern is introducing exotic pathogens. So little information exists on the natural levels of pathogens that this risk is difficult to assess. Therefore, we need to make those assessments.

Unknowns

❖ What does the genetic stock structure of flounder look like, and what should be the genetic profile(s) of released fish to sustain diversity?

❖ What will be the impact of releases on wild stocks and receiving waters, and how can we evaluate this?

❖ How can we screen for potential disease and diagnose and treat disease outbreaks when they occur?

❖ How can we prevent stocking from increasing demand and further degrading the fisheries we aim to restore?

❖ How can we assess the risk of introducing exotic pathogens?

4.

Are conditions favorable for stocking flounder and red drum in North Carolina?

Status of the stocks and demand

The summer flounder, southern flounder and red drum stocks in North Carolina are depressed, although the summer flounder and red drum stocks seem to be recovering somewhat in response to management efforts. Demand for southern and summer flounder remains very strong. Fewer data exist on the demand for red drum in North Carolina. The high variation in recruitment levels in these three species suggests that North Carolina's nursery areas have excess carrying capacity. Since no state management plan has been in place for southern flounder and management targets for summer flounder have not been met, potential benefits from traditional management strategies cannot be fully assessed.

While basic conditions should guide any stocking program, some factors are specific to stocking flounder and red drum in North Carolina.

Favorable conditions

For numerous reasons, North Carolina is well positioned to try stock enhancement as a way to rebuild its fisheries:

North Carolina's dynamic economy creates a positive climate for considering this new management option.

Because of its extensive coastline and system of sounds, North Carolina enjoys an abundance of good habitat for young fish.

The fishing industry's importance to the state has created an initial receptivity among key legislators and the fishing community to stock enhancement as a way to help rebuild selected fisheries.

The size of the fishing industry in the state and the existence of large amounts of gear in the water create the opportunity for careful evaluation and documentation of any stocking effort.

The state's excellent public and private universities with faculty actively pursuing aquaculture and stock enhancement research provide a strong foundation for a stock enhancement program.

Pound nets like these are used to harvest flounder.

Partnerships have already been formed between North Carolina researchers and scientists in other countries and states with programs in place.

The state has not only high interannual variation in abundance, but also high interannual variation in distribution of recruits. Both suggest that stocking in years of poor recruitment or in undercolonized nurseries would be successful.

The state can build on experience elsewhere (see appendices). According to one estimate, North Carolina could reduce the 20 years of research required in Texas to five years because of the information already gained by Texas researchers.

Challenges

A few challenges specific to North Carolina counterbalance some of the factors favorable to exploring stock enhancement in the state:

North Carolina is on the northern edge of the ecological zones for red drum and southern flounder. The design of stocking programs will need to account for environmental limits for the species.

The state's large system of sounds, its sound/ocean interactions and its location at the break point in migration patterns will make tracking fish and evaluating program success particularly difficult.

Extensive net fishing in the sounds poses a serious threat to any stock enhancement program's success.

Unknowns

❖ Would stocking facilitate or impede traditional management?

❖ What are the migration patterns of flounder and red drum, and will stocked fish leave North Carolina waters permanently before they mature?

❖ Does the level of demand for red drum justify the cost of exploring stock enhancement?

❖ How could conflicts between stock enhancement program needs and net fishing in the sounds be addressed?

❖ Would fall-stocked red drum successfully survive North Carolina's winters, or would spring stocking of larger fish be necessary?

5.
Is there stock enhancement experience elsewhere to build on?

The Japanese, who have stocked Japanese flounder for many years, have the most substantial body of experience with flounder stock enhancement. Though a different species, Japanese flounder shares many common characteristics with summer flounder.

In the United States, only limited experience with marine stock enhancement is available, but several states do have experience that North Carolina can draw on when considering this management option. They include a well-established program for stocking red drum in Texas and a red drum pilot program in South Carolina. Additionally, Florida has a pilot program for releasing hatchery-raised snook.

The following are brief descriptions of lessons learned from existing programs in Japan and the United States.

Japan

In Japan, both commercial aquaculture and natural fisheries each produce about 50 percent of the country's total flounder population. The number of juvenile flounder produced in hatcheries is about 50 million annually, of which 23 million are released along Japan's coast.

When the Japanese began a flounder stocking program, their goal was to mass produce and release juveniles. They gave little attention to understanding the genetic stock structure of wild fish, the ecology of receiving waters or the functioning of nursery areas. They did not establish monitoring programs at the outset, although they are now adding them. These narrow initial goals limit what the Japanese experience can contribute to questions about long-term ecological effects, but their experience has led to understanding some important factors for raising and releasing healthy juveniles.

Japanese flounder seem to thrive in many different habitats and migrate both north and south. Because of their habits and natural environment, factors deemed important in successful stocking include:

✓ timing of release
✓ size of released fish
✓ food availability
✓ cooperation from fishers.

Based on experience, the Japanese have started releasing fish earlier in the season, when food is more abundant and fewer predators are about. Because predators are among the greatest threats to successful stocking, the Japanese have increased the size of released fish from 5 to 10 centimeters. In a unique partnership arrangement, fishers buy fingerlings of 3 to 4 centimeters from public or private hatcheries and grow them out to about 10 centimeters. Their involvement in the stocking program has led them to release undersized fish when they catch them, contributing to more effective overall management of the fishery. The abnormal pigmentation of hatchery-raised flounder allows fishers and fishery managers to track what happens to wild and stocked fish.

The Japanese experience suggests that flounder stock enhancement can be successful. The Japanese believe pilot releases can be used to identify suitable areas, but only large releases will have any real effect on the fishery. They believe carefully monitored large releases are necessary to evaluate the effects of stocking on the carrying capacity and biodiversity of receiving waters. The Japanese are broadening their criteria of stock enhancement success to include increasing fisheries production, increasing reproductive capacity, educating fishers and conserving the coastal system.

Texas

Texas cultures large numbers of fish for research, commercial aquaculture and stocking. One of its best established stocking programs is for Gulf red drum, a different genetic strain from the Atlantic red drum found in North Carolina, but one that shares many similarities. In the early 1980s, the red drum fishery in Texas was in peril. Public outcry and strong demand for the fish from recreational fishers led to the stock enhancement program.

Texas began by establishing a genetic protocol for red drum: to create and maintain a genetically diverse broodstock. They conducted pilot releases and found that the red drum thrives in a variety of habitats. They established an ongoing monitoring program using gill nets and determined that an average of 20 percent of the stocked fish survive to maturity, with variation among stocking locations. Initial results suggest that stocked fish do not replace wild fish, but more analysis is needed to evaluate this fully.

Texas enacted a number of regulations to accompany its stocking program. The state banned nets in coastal waters, eliminating commercial harvest and bycatch. Texas also enacted and enforced highly conservative recreational harvest regulations. Overall enforcement increased threefold, and bonuses were offered to fishers who report catching tagged fish, to strengthen monitoring efforts. The state also launched an education and outreach program and strengthened its habitat protection program. As a result of these efforts, subadult red drum in Texas bays are now twice as abundant as in 1980 and recreational catch rates have increased 18 percent.

Satisfied with the success of the program, Texas is moving from a goal of restoring the fishery to a goal of maintaining and enhancing it. The state will continue to refine its techniques for rearing and release. While Texas spent almost 20 years in research and development to establish this mature stocking program, the state believes that by building on the experience of others development time can be shortened to five to seven years. However, it stresses that new stocking programs must be approached cautiously, given variations in species and habitats and the large number of unknowns about the effects of stocking in general.

South Carolina

For the past several years, South Carolina has conducted research into the feasibility of enhancing its Atlantic red drum fishery through stocking. The state has developed basic culture, marking and stocking techniques, and conducted a number of pilot releases. It has tracked released fish for two years and has not been able to determine any effect on the wild fish, although no data on possible displacement are available.

In addition to developing various rearing and release protocols related to fish size, tagging, and timing and location of release, South Carolina has developed criteria to evaluate success. These include factors such as status of the fishery, ratio of recruitment to spawning and cost effectiveness.

The next phase of work in South Carolina is a full-scale demonstration project. The state considers establishing a state hatchery premature until the demonstration phase is complete and the cost efficiencies of purchasing hatchery fish from the private sector are explored. Because of the many similarities between the two states, techniques and protocols developed in South Carolina should be transferable to North Carolina. And the similarities indicate a potential for joint programs.

Florida

In 1996, Mote Marine Laboratory, a private nonprofit marine laboratory, began a program to breed and raise local species of marine and estuarine fish in closed cycle recirculating tanks. It achieved early success with rearing more than 10,000 snook fingerlings in the first year. In the spring of 1997, Mote collaborated with the Florida Department of Environmental Protection's Stock Enhancement Research Facility to release more than 5,000 snook into the waters around Sarasota, Fla. The juvenile snook, nine months old and ranging from 4 to 10 inches, were fitted with tags to allow the study team to monitor their patterns, survival and destinations. Additional releases have followed. Because of questions about the possible presence of disease in some of the released fish, a coordinating group of disease specialists has been established to study the potential problem and make recommendations.

Unknowns

❖ To what extent is experience in other states and countries transferable to North Carolina?

❖ What can be done to maximize information transfer between stock enhancement programs and research efforts and to form partnerships with other countries and states?

6.

What are the major elements in designing a responsible stock enhancement program and building public support?

Marine stock enhancement is a new and underdeveloped science with many unanswered questions. It presents significant challenges in program design and public acceptance. To ensure scientific and technical responsibility, any stock enhancement program must have a strong research component, with new information constantly integrated into pilot efforts. A multiyear commitment to the effort is necessary to answer the most important questions about effectiveness, costs and benefits. Because stock enhancement is still such a young science, it will arouse a high level of public interest and concern. To be effective, the state must design a wide-reaching public education effort and forge as many partnerships as possible.

Designing a responsible program

Experience suggests the following framework as the most responsible approach to stock enhancement:

❖ prioritize species

❖ identify genetic and harvest objectives

❖ define quantitative measures of success

❖ incorporate genetic, disease and health management

❖ identify or develop a reliable hatchery source

❖ use pilot releases to identify optimum release protocols

❖ mark hatchery fish to assess stocking impact

❖ consider ecological and biological impacts

❖ identify economic and policy guidelines

❖ use adaptive management to integrate new information

❖ make a minimum five-year commitment to the program.

Marine stock enhancement research has shown that hatchery fish can survive in the wild and contribute to fishery landings and that the level of impact of stock enhancement on a fishery depends on factors such as size of the fish at release, conditions in receiving waters, and the timing and magnitude of releases. Much less is known about the most effective release strategies and the environmental effects of stocking.

Because of the many unknowns, building a strong research component into an enhancement program is critical. Initial stocking efforts must be closely monitored so lessons learned can be integrated into the next round of activity. Addressing the unanswered questions will require collaborative research by multiple disciplines: marine aquaculture, genetics, marine ecology, environmental risk assessment, fisheries economics and others. While combining intervention with research will require more resources, it is the essence of an adaptive management approach and is the only responsible way to proceed.

Building public acceptance

For the public to consider the costs and risks associated with stock enhancement, it must perceive a serious problem with a valued fishery and believe the fishery can recover in the foreseeable future. Often, an initial public education effort is needed to get a stock enhancement program underway. State resource managers are central to helping the public understand the current status of a fishery and whether it makes sense to explore a stock enhancement program as part of the state's management approach.

If the state decides to proceed, the following are key elements in gaining and keeping public support for stocking programs:

✓ develop a goal and vision for the program

✓ gain support of legislators and state resource agency staff

✓ form a broadly representative task force to guide the effort

✓ recruit partners and sign agreements detailing specific responsibilities

✓ conduct scoping meetings with public stakeholder groups

✓ initiate an aggressive media/outreach campaign

✓ adopt a logo and display it on stationery, trucks and uniforms

✓ produce videos and brochures for all partners to use

✓ keep the program and its successes visible to the public.

Once the public becomes aware of and involved in a stock enhancement effort, it will be eager to see tangible results from its investments, such as a new hatchery, release of fingerlings and increased landings. The public will also be interested in tracking long-term ecological effects. Access to visitors centers at hatcheries is one way to build understanding and keep the public informed. Since long-term financial support is required for stock enhancement programs, public support must be developed at the outset and sustained throughout.

Unknowns

❖ Which species should North Carolina consider stocking?

❖ What are the best release strategies?

❖ Will enhancement restore the fishery or create dependence on stocking?

❖ How will results in both costs and benefits of stocking compare to those achieved through traditional management efforts?

❖ Is the public prepared to support such an effort in North Carolina?

7.

What are the issues to consider in designing and siting a hatchery?

For North Carolina to move forward with a stock enhancement program for flounder or red drum, it would need to develop a reliable source of young fish. Other states currently take several approaches: developing a state hatchery, contracting with private hatcheries or forming a public-private partnership of some kind. South Carolina currently contracts with a private hatchery to produce red drum fingerlings. Texas operates nine state hatcheries for red drum and other species. Florida's Department of Environmental Protection's Stock Enhancement Research Facility collaborates with the private Mote Marine Laboratory to produce fingerlings for state aquaculture, stocking and research programs.

If the state decides to develop its own hatch-

For stock enhancement to be successful, state-of-the-art facilities are needed for fingerling production.

ery to produce juvenile fish for stocking, it must first make four strategic decisions.

Facility purpose and design

The first major decision involves determining the purpose of the hatchery and its size. A single hatchery can be designed to produce many different species of fingerlings and to produce fingerlings for both aquaculture and stock enhancement, although different broodstocks are required and special attention must be given to health and disease management. In addition to the hatchery production facility, the site may include a research facility and a separate visitors center to build and maintain public support for the project and direct visitors away from the more sensitive research and production facilities.

Control over the hatchery environment is critical to success. Recirculating systems are more easily controlled than flow-through systems. Ponds should be lined and covered to maximize control. The facility must have the capability to produce algae and rotifers needed to feed marine fish. Hatcheries must have dedicated personnel and mechanical backups for all systems.

Site selection

Hatcheries for marine fish should be sited near, but not on, the ocean. Oceanfront property is too expensive, and environmental permits for those locations are too difficult to obtain. Ideally the site should be about 15 feet above sea level to enable ponds to drain. Wells must be available for high-quality sea water and fresh water. The soil must be suitable for buildings and ponds. The site should have space for an adequate number of recirculating tanks and ponds, with some room to expand. The site must be able to be secured. Previous uses of a site should be investigated, as well as the receptivity of neighbors to constructing a hatchery. Sites should be accessible to population centers to recruit quality staff and have access to necessary support services. Proximity to major transportation routes is essential if tourism development is a goal.

Ownership

Hatchery ownership can take a variety of forms. The advantages of a state-owned hatchery include a dedicated focus on the public interest, with maximum attention to broodstock diversity and disease control, and better access to state resources. The disadvantages include large start-up costs, a facility that may lie fallow for a long time each year if used for a single species and the concentration of risk that comes with a single hatchery.

Advantages of using privately owned hatcheries include cost effectiveness through competitive bidding, economies of scale and year-round efficiencies that come with a diverse established operation, and insulation of the state from major financial risks if the program is discontinued. Disadvantages include the requirement of a much more diverse broodstock for stock enhancement than for aquaculture that private hatcheries may be less willing or unable to provide. Also, the public may not trust a private hatchery to produce fingerlings for stock enhancement given the potential environmental risks. Finally, the state takes the risk that these hatcheries will fail, bringing the stocking program to a halt.

One attractive ownership option is for public and private sectors to divide responsibilities. A model public-private partnership is currently used in clam bed restoration in New England. The public sector develops and maintains the broodstock and produces the eggs. The private sector does the hatching and grow-out according to husbandry protocols developed by the state. The state monitors the entire operation and pays only for the young fish it receives for release.

Cost

Building a hatchery is expensive and requires a sustained source of operations and maintenance funding. Initial costs to build a full-scale hatchery generally range from $5 million to $10 million, depending on the size and type of facility. Operating expenses can range from $1 million to $2 million annually. Constructing large facilities to produce multiple species presents economies of scale, but these require more money up front and concentrate risks. A pilot hatchery can be built and operated less expensively, but expanding a pilot hatchery can add costs and require the owner to endure the entire permitting process again. If private hatcheries are used, long-term contracts enable hatchery owners to borrow funds and expand to meet the state's needs. One consideration in selecting a site may be local communities' contributions to land, site improvements or other incentives. In some cases, states have recruited private partners to help with land acquisition or other hatchery development costs.

Need for a pilot facility

An experimental hatchery could improve North Carolina's capability for traditional wild stock management as well as stock enhancement by helping to provide answers to the basic questions on which effective management is based. Current wild stock management is based on many untested fundamental ecological assumptions. For example, we do not know the true carrying capacity of our sounds for any species or stage. The most efficient way to determine this is to "load" the system and follow the growth of released fish. Also, stocking, and subsequently recovering, tagged fish (a technique analogous to mark/recapture used in freshwater lakes) is the most efficient way to determine the true stock size as well as stock structure and migration patterns. Assessing fish performance and thus habitat quality could be greatly facilitated with the ability to place fish in particular habitats, either in stocked enclosures or by releasing free-ranging tagged fish. Certain population genetics questions are central to both management and stock enhancement. To efficiently answer them, hatchery fish can be produced with genetic "tags." Other questions cannot be answered with conventional studies. For example, it is difficult to determine the nursery capacity of Albemarle Sound because juvenile fish cannot colonize it due to unfavorable currents.

Unknowns

❖ How many fingerlings would the state need each year to launch a stock enhancement program?

❖ Should fingerlings for aquaculture and stock enhancement be produced in the same facility?

❖ Should the state build its own hatchery, contract with the private sector or undertake a joint venture?

❖ If the state decides to develop a hatchery on its own or in partnership with others, where should that facility be located?

Recommendations

1. Conduct research to determine the true status of the population and sustainable yield for summer flounder, southern flounder and red drum. Establish the range in annual variability, its normal fluctuations and the relative contributions of growth, recruitment and mortality (including harvesting, bycatch and natural rates) to the characteristics of the three fisheries.

2. Determine the distribution and movement of natural and introduced stocks through a sophisticated tagging program (e.g., acoustic, electronic).

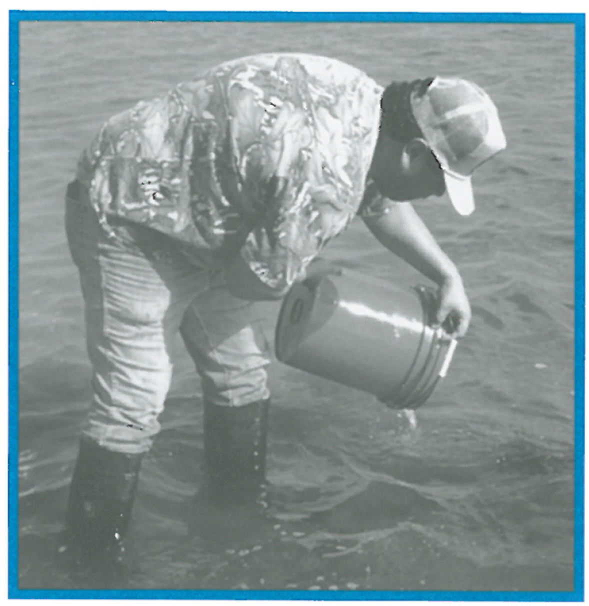
3. Characterize the genetic profiles for summer flounder, southern flounder and red drum to determine genetic diversity within North Carolina stocks.

4. Establish mechanisms to assure that adequate fisheries management continues to build up natural stocks, to prevent the substitution of stocking at the expense of natural populations and to prevent stocking from increasing demand that could further degrade the fisheries.

5. Conduct a study to determine the current and future demand for flounder and red drum at various user group levels. Determine whether demands justify the costs of exploring and initiating stock enhancement.

6. Establish a board of directors to develop state policy recommendations for stock enhancement. As a starting point, the board should address several major issues, including characterizing the need for stock enhancement, developing the most effective release strategies, pushing for more comprehensive fisheries management, developing mechanisms for gaining public support and identifying sources of financial support. Board members should represent all major interests, beneficiaries and affected parties. This board should have vested authority to make recommendations at the legislative and governor's levels.

7. Complete detailed analyses of hatchery needs (including costs) to support decisions for proceeding. Develop a partnership to ensure continuing public/private hatchery operation. A modern marine finfish hatchery can serve multiple purposes, but only with careful planning and adequate support. Establish a hatchery advisory committee to guide hatchery development. The advisory committee should balance aquaculture and stock enhancement interests and include some out-of-state, experienced practitioners.



Once fingerlings are produced, they are loaded into carrying tanks and transported from the hatchery to the estuarine release site and released there.

Appendix I

For several years, Japanese fisheries managers have engaged in stock enhancement with the Japanese flounder and red sea bream. They have successfully produced large crops of these species. We believe that the Japanese flounder is comparable to summer flounder and that the bream is similar to red drum. Masaru Tanaka, a fisheries scientist from Kyoto University, has researched stock enhancement since the beginning of the Japanese program. Below, he comments on some of our questions.

STOCK ENHANCEMENT IN NORTH CAROLINA
Based on Japanese Experience with Flounder

Masaru Tanaka
Laboratory of Marine Stock Enhancement Biology
Division of Applied Biosciences
Graduate School of Agriculture
Kyoto University
Kyoto, Japan

Traditional management

Stock enhancement versus less expensive traditional management is of concern, especially from the standpoint of "giving up" on management and relying on stocking. Our recent understanding of this problem is that the same biological backgrounds exist behind both stock enhancement and traditional management. In other words, stock enhancement could accelerate more effective management. In northern Japan, fishers decided to stop catching small fish after they released juvenile flounder (limiting size increased year by year), and they learned that effective management increased income.

Carrying capacity

Carrying capacity (or environmental capacity) is the most basic and necessary information for stock enhancement. Though difficult and time consuming, estimating the capacity before stocking is best.

Accumulating interannual variation in ecological traits like growth and distribution area seems an orthodox approach, but it requires time. I believe stock enhancement is a kind of large scale, in situ ecological experiment. That is, we could manipulate density of juveniles in the nursery at any scale if we could provide a large number of high-quality fish. With an overpopulation of released fish, various signs of food and space limitation could appear. Stock enhancement projects could provide more detailed information on carrying capacity of nursery grounds.

Combination between prerelease and postrelease processes

In Japan, the initial approach was to mass produce and mass release fish without adequately understanding the ecology and physiology of fish in the nursery, ecophysiological diversity and genetic stock structure. The basic strategy was to produce a sufficient number of seedlings. However, seedling production was carried out separately from ecological research in the nursery where fish were released. These early approaches led to an understanding that a feedback system from the postrelease process to the prerelease process is definitely important in effectively promoting a stock enhancement project.

Defining success

Qualifying enhancements as successful or unsuccessful depends on many factors — locality, quality of fish, environmental characteristics, releasing tactics, etc. — even for a same species.

Japanese flounder present three typical examples:

1) Release timing is a critical component in successful stocking. Based on starvation-predation theory, fish were released in the southern part of the Sea of Japan earlier in the season, when prey is abundant and predators are less abundant, resulting in several times increase in percent recapture.

2) Size at release is also a critical component on the northern Pacific coast of Japan, where predation is a limiting factor in successful stocking. Unions buy 3- to 4-centimeter seedlings from public and/or private hatcheries and grow them to about 10 centimeters before releasing. Fishers can recognize successful stocking in the nursery and stop harvesting until the fish grow to a reasonable size. This significantly increased catchable minimum size. Thus, a stock enhancement program could contribute to more effective management.

3) Food availability is a dominant component in some extreme areas like Tokyo Bay, which is highly influenced and damaged by human impacts. Most of the shoreline is covered by artificial construction, and its bottom is covered with a muddy substratum. This does not appear a preferable environment for Japanese flounder. However, the Kanagawa Prefecture stocked flounder based on the extremely high abundance of gobies. Results clearly demonstrated a high percent survival and extraordinarily rapid growth: The most extreme example is larger than 60 centimeters at just 2 years (compared to wild fish at 40 centimeters, even in warmer areas).

Red sea bream in Kagoshima Bay, a highly enclosed bay, presents another example related to stocking strategies. Located near the southern distribution limit of red sea bream, Kagoshima Bay is considerably deep and lacks enough shallow nursery areas inhabitable by juveniles smaller than 10 centimeters. Juveniles larger than 10 centimeters were released there, and this strategy yielded a reasonable percent recapture.

Flounder as a candidate for enhancement

An important consideration in stock enhancement is that fishers are able to recognize stocked fish. In this respect, flounder are good candidates for stock enhancement because they have abnormal pigmentation on the blind side of the body. The blind-side pigmentation generally occurs when juveniles are reared in tanks without sand, and it does not disappear as fish grow. (Recent findings have demonstrated that major blind-side pigmentation is not caused by light.)

Successful stock enhancement

Evaluating successful stock enhancement depends on several criteria:

✓ increase in fisheries production

✓ increase in reproductive capacity

✓ educational effect on commercial and recreational fishers

✓ conservation or protection of the coastal system.

Negative effects of stock enhancement

Stock enhancement has some potential negative effects:

Genetic Disturbance. A limited broodstock could easily reduce genetic diversity of hatchery-produced fingerlings. Genetic variabilities that have occurred in hatchery-raised fish are directly related to the number of broodstock. Therefore, the genetic stock structure of wild fish should be surveyed before stocking, and broodstock should be replaced at reasonable intervals by sea-caught fish.

Disease. In addition to producing healthy fingerlings, preventing epidemic impacts on coastal ecosystems is vitally important.

Potential of flounder stock enhancement

The summer flounder population seems larger than that of Japanese flounder. At present, Japanese flounder production is about 8,000 metric tons per year, and aquaculture production is nearly the same. The total number of juveniles produced in hatcheries is about 50 million per year, 23 million of which are released into Japanese seas in all but the northernmost and southernmost areas. The east coast of the United States has a much larger area of nursery ground for summer flounder.

Releasing a limited number of fish does not work effectively. It is important to find suitable areas with reasonable biotic and abiotic conditions but that are not colonized because of lack of larval recruitment. In other words, releasing trials are good tools to evaluate nursery areas for stocking.

Appendix II

Over the past few years, several stock enhancement experiments have been conducted in the United States. Kenneth M. Leber, Mote Marine Laboratory, has been involved in that research, and his summary assessment appears below.

A SUMMARY OF STOCK ENHANCEMENT RESEARCH

Kenneth M. Leber
Mote Marine Laboratory
1600 Ken Thompson Parkway
Sarasota, FL 34236

To replenish depleted fisheries and increase fishery production, a critical evaluation of the actual potential for marine stock enhancement is needed. 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. Research to assess stocking impact has only emerged in the 1990s (e.g., Grimes 1995; Munro and Bell 1997; Leber In Press; references in those papers).

The elements that distinguish successful stock enhancement programs from unsuccessful ones depend upon how success is defined. If success is measured in terms of a clear capability to increase production and an understanding of how to control the impact of hatchery releases on a fishery, then precious few examples of success exist. But shouldn't the ability to control release impact be implicit as a key factor in determining success?

I believe that control over release effect is the mechanism for achieving the ultimate goal of stock enhancement programs: increasing fishery production efficiently without harming wild stocks. In this vein, successful stock enhancement programs embrace four key issues that lead to understanding enhancement impact and how to control it:

1. systematically and quantitatively assessing the effect of hatchery releases on fishery landings and impact on wild stocks (see recent review by Munro and Bell 1997);

2. evaluating the effectiveness of the range of potential stocking strategies in pilot release-recapture experiments to identify optimal stocking protocols (e.g., Leber et al. 1996);

3. integrating adaptive management theory (Hilborn and Walters 1992) as an integral component of managing stock enhancement;

4. seriously attempting to use a responsible approach in planning and implementing stock enhancement (e.g., Cowx 1994; Blankenship and Leber 1995).

The rationale for the importance of these four basic issues is presented by Leber (In Press). Several programs around the world currently employ this strategy. The most current synthesis of information on those programs' results is provided by Munro and Bell (1997) and will soon be published in the peer-reviewed book *Stock Enhancement and Sea Ranching* (Howell et al. In Press). The research papers in Howell et al. (In Press) were all presented in 1997 at a stock enhancement symposium in Norway, and the authors and topics presented can be reviewed at http://158.37.91.10/sear/hav97.html.

Using strong inference (Platt 1964) to investigate some of the basic assumptions and major uncertainties of the stock enhancement hypothesis, true progress is being made in advancing stock enhancement as a science (Leber In Press; Howell et al. In Press). Strong inference is, essentially, *systematic application* of the scientific method of inductive inference. This approach has been adapted to fisheries management by Hilborn and

Walters (1992) in their active adaptive management concept. Research in Hawaii is one example of the strong inference approach now used in several countries to investigate marine stock enhancement potential. In Hawaii, a series of pilot releases of cultured marine finfish were 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 percent improvement in recruitment of hatchery-reared fish in juvenile habitats).

After developing optimal release protocols (a solid understanding of optimal habitat for releases, optimal size-at-release and the optimal timing of releases, including an understanding of which levels of each of these variables result in failure), pilot-scale releases (30,000 to 90,000 fish per year) made a 15 to 20 percent contribution to catch in subsistence and recreational mullet fisheries in Hawaii. Similar results were documented with Pacific threadfin (*Polydactylus sexfilis*) released along moderate wave-energy, sandy beaches in Hawaii. Wider use of an experimental approach, based on the principles of strong inference and active adaptive management, would move the field of stock enhancement forward considerably faster. Results from the pilot release experiments to test critical assumptions about stocking strategies in Hawaii are published in Leber (1995), Leber et al. (1995), Leber et al. (1996), Leber and Arce (1996), Leber et al. (1997) and Leber et al. (In Press).

Beginning in 1989 (Tsukamoto et al. 1989), quantitative study of the effect of different stocking strategies with marine species has revealed that hatchery releases clearly can affect recruitment patterns of juvenile fish in coastal ecosystems. Munro and Bell (1997) provide a good summary of the current status in this field. Okouchi et al. (In Press) provide the first quantitative evidence that hatchery releases can be a cost-effective mechanism for supplementing commercial fishery landings. In that study, landings of Japanese flounder in the marketplace provided as much as a 1.96x return on the costs of rearing and stocking hatchery-reared flounder into Miyako Bay in Japan.

The current understanding of marine stock enhancement research is that releases of hatchery fish can, under certain conditions, have a marked and substantial effect on juvenile recruitment and fishery landings. The science of marine enhancement has advanced to the point that we now know that hatchery fish clearly can survive and grow in the wild and contribute to fishery landings and that the magnitude of release impact on a fishery is a direct function of release strategies and environmental conditions (interactions among fish size-at-release, release habitat, and the timing and magnitude of releases).

However, many critical uncertainties need evaluation:

— Do hatchery releases increase 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 subdisciplines should be considered. To move forward responsibly in this branch of fisheries science, at least ten principal subdisciplines should be integrated:

- ❖ marine aquaculture
- ❖ genetics
- ❖ aquatic health
- ❖ marine ecology
- ❖ fisheries biology

- environmental risk assessment
- experimental design
- mathematical modeling
- fisheries and aquaculture economics
- statistical decision analysis.

Clearly, research collaborations are needed to integrate the principal subdisciplines into stock enhancement research programs. Rapid advances can be made in understanding marine stock enhancement potential and advancing the science of stock enhancement by focusing such collaborations on resolving major uncertainties, using strong inference and active-adaptive management.

Key References Related to Marine Stock Enhancement

Bergman, P.K., F. Haw, H.L. Blankenship and R.M. Buckley. 1992. Perspectives on design, use, and misuse of fish tags. *Fisheries* (Bethesda, USA). 17(4):20-24.

Bilton, H.T., D.F. Alderdice and J.T. Schnute. 1982. Influence of time and size at release of juvenile coho salmon (*Oncorhynchus kisutch*) on returns at maturity. *Canadian Journal of Fisheries and Aquatic Science*. 39:426-447.

Blankenship, H.L. and K.M. Leber. 1995. A responsible approach to marine stock enhancement. *American Fisheries Society Symposium*. 15:167-175.

Coronodo, C. and R. Hilborn. In Press. Spatial and temporal factors affecting survival of hatchery-reared salmonids in the Pacific Northwest. *Bulletin of Marine Science*.

Cowx, I.G. 1994. Stocking strategies. *Fisheries Management and Ecology*. 1:15-30.

Danielssen, D.S., B.R. Howell and E. Moksness (Eds). 1994. *Aquaculture and Fisheries Management*. 24 (Suppl. 1), 264 pp.

Grimes, C.B. 1995. Perspective of the AFS marine fish section on uses and effects of cultured fishes in aquatic ecosystems. *American Fisheries Society Symposium*. 15:593-594.

Hager, R.C. and R.E. Noble. 1976. Relation of size at release of hatchery-reared coho salmon to age, size and sex composition of returning adults. *Progressive Fish Culturist*. 38:144-147.

Hilborn, R. and C.J. Walters. 1992. *Quantitative Fisheries Stock Assessment*. Chapman and Hall, New York and London. 570 pp.

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

Howell, B.R., E. Moksness and T. Svasand (Eds). In Press. *Stock Enhancement and Sea Ranching*. Fishing News Books, Blackwell Science Ltd., Osney Mead, Oxford.

Kitada, S., K. Hiramatsu and H. Kishino. 1992. Effectiveness of a stock enhancement program evaluated by a two-stage sampling survey of commercial landings. *Canadian Journal of Fisheries and Aquatic Science*. 49:1573-1582.

Kristiansen, T.S. and T. Svasand. 1990. Enhancement studies of coastal cod in western Norway. Part III. Interrelationships between reared and indigenous cod in a nearly land-locked fjord. *Journal du Conseil International pour l'Exploration de la mer*. 47:23-29.

Kuhn, T.S. 1970. *The Structure of Scientific Revolutions*, 2nd edition. University of Chicago Press, Ltd., London.

Leber, K.M. 1995. Significance of fish size-at-release on enhancement of striped mullet fisheries in Hawaii. *Journal of the World Aquaculture Society*. 26:143-153.

Leber, K.M. In Press. Rationale for an experimental approach to stock enhancement. *In* Howell, B.R., E. Moksness and T. Svasand (Eds) *Stock Enhancement and Sea Ranching*. Fishing News Books, Blackwell Science, Ltd., Osney Mead, Oxford.

Leber, K.M. and S.M. Arce. 1996. Stock enhancement in a commercial mullet, *Mugil cephalus* L., fishery in Hawaii. *Fisheries Management & Ecology*. 3:261-278.

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

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

Leber, K.M., N.P. Brennan and S.M. Arce. 1995. Marine enhancement with striped mullet: Are hatchery releases replenishing or displacing wild stocks? *American Fisheries Society Symposium*. 15:376-387.

Leber, K.M., N.P. Brennan and S.M. Arce. In Press. Recruitment patterns of cultured juvenile Pacific threadfin, *Polydactylus sexfilis* (Polynemidae), released along sandy marine shores in Hawaii. *Bulletin of Marine Science*.

Leber, K.M. and C-S. Lee. 1997. Marine stock-enhancement potential with striped mullet, *Mugil cephalus*, in Hawaii. *Bulletin of the National Research Institute of Aquaculture* (Supplement 3):117-134. Nansei, Mie, Japan.

Liu, J.Y. 1990. Resource enhancement of Chinese shrimp, *Penaeus orientalis*. *Bulletin of Marine Science*. 47:124-133.

Lockwood, S.J. (Ed). 1991. The ecology and management aspects of extensive mariculture. ICES *Marine Science Symposium*. 192:248 pp.

Main, K.M. 1987. Predator avoidance in seagrass meadows: prey behavior, microhabitat selection and cryptic coloration. *Ecology*. 68:170-180.

Munro, J.L. and J.D. Bell. 1997. Enhancement of marine fisheries resources. *Reviews in Fisheries Science*. 5(2):185-222.

New, M.B. 1997. Aquaculture and the capture fisheries: balancing the scales. *World Aquaculture*. 28:11-31.

Nordeide, J.T., J.H. Fossa, A.G.V. Salvanes and O.M. Smedstad. 1994. Testing of year-class strength of coastal cod, *Gadus morhua* L., can be determined at the juvenile stage. *Aquaculture and Fisheries Management*. 25 (Suppl. 1):101-116.

Okouchi, H., A. Iwamoto, T. Tsuzaki, T. Fukunaga and S. Kitada. In Press. Economic returns from hatchery released flounder *Paralichthys olivaceus* in Miyako Bay—evaluation by a fish market census. *In* Howell, B.R., E. Moksness and T. Svasand (Eds) *Stock Enhancement and Sea Ranching*. Fishing News Books, Blackwell Science Ltd., Osney Mead, Oxford.

Parker, N.C., A.E. Giorgi, R.C. Heidinger, D.B. Jester, E.D. Prince and G.A. Winans (Eds). 1990. *Fish-Marking Techniques*. American Fisheries Society, Bethesda, MD. 7:1-879.

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

Popper, K.R. 1959. *The Logic of Scientific Discovery*. Basic Books, New York.

Popper, K.R. 1965. *Conjectures and Refutations, the Growth of Scientific Knowledge*. Harper and Row, New York.

Ray, M., A.W. Stoner and S.M. O'Connel. 1994. Size-specific predation of juvenile queen conch *Strombus gigas*: implications for stock enhancement. *Aquaculture*. 128:79-88.

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

Schramm, H.L. Jr. and R.G. Piper (Eds). 1995. Uses and effects of cultured fishes in aquatic ecosystems. *American Fisheries Society Symposium*. 15:1-608.

Secor, D.H., E.C. Houde and D.M. Monteleone. 1995. A mark-release experiment on larval striped bass *Morone saxatilis* in a Chesapeake Bay tributary. ICES *Journal of Marine Science*. 52:87-101.

Sokal, R.R. and F.J. Rohlf. 1981. *Biometry*. W.H. Freeman, San Francisco.

Svasand, T., K.E. Jorstad and T.S. Kristiansen. 1990. Enhancement studies of coastal cod in western Norway. Part I. Recruitment of wild and reared cod to a local spawning stock. *Journal du Conseil International pour l'Exploration de la Mer*. 47:1-12.

Svasand, T. and T.S. Kristiansen. 1990a. Enhancement studies of coastal cod in western Norway. Part II. Migration of reared coastal cod. *Journal du Conseil International pour l'Exploration de la Mer*. 47:13-22.

Svasand, T. and T.S. Kristiansen. 1990b. Enhancement studies of coastal cod in western Norway. Part IV. Mortality of reared cod after release. *Journal du Conseil International pour l'Exploration de la Mer*. 47:30-39.

Tsukamoto, K., H. Kuwada, J. Hirokawa, M. Oya, S. Sekiya, H. Fugimoto and K. Imaizumi. 1989. Size-dependent mortality of red sea bream, *Pagrus major*, juveniles released with fluorescent otolith tags in News Bay. *Journal of Fish Biology*. 35:59-69.

Walters, C.J. and R. Hilborn. 1978. Ecological optimization and adaptive management. *Annual Reviews of Ecology and Systematics*. 9:157-188.

Appendix III

The issue of enhancing stock with hatchery-reared fish can be approached from various perspectives. Steve Ross has examined the idea from a fisheries management viewpoint and offers a summary assessment.

STOCK ENHANCEMENT: A FEW QUESTIONS

Steve W. Ross
Center for Marine Science Research
University of North Carolina at Wilmington
Wilmington, NC 28403

Is stock enhancement through aquaculture an admission of failed management?

While not specifically endangered species, populations so low that they are in danger of extinction (e.g., sturgeons) may be the best candidates for stock enhancement.

Exploiting wild stocks can match market/ public demands. However, increased human population and/or increased demand could outstrip wild stock capacity even with adequate management. Are we there yet in North Carolina, or are our resources just poorly managed? I believe that management could be much more effective and could rebuild and maintain stocks to support the current demand.

If we have failed in management, what is the best strategy in response? Two options are (1) to back up and fix the management as an attempt to let stocks rebuild (possible) or (2) to rebuild stocks through aquaculture-based enhancement (dubious). It seems we are giving up on management options without giving them a fair trial — but a fair trial would assume a strong political commitment.

Examples of successful management exist. Additionally, a stock being overexploited is not, in itself, sufficient reason to justify stocking. There is no question that large numbers of many species can be successfully reared in captivity, and there is limited proof that some species (e.g., red drum) in some areas (e.g., Texas) have been enhanced or had numbers added to local wild stocks. However, those findings do not mean that enhancement would work in North Carolina — or with all species. Also, very little information is available on how stocked fish may impact general multispecies ecology or ecological systems in the long term.

What are reasons for stock enhancement?

One of the justifications for enhancement is that stocks are stressed or declining for reasons other than normal cycles. However, we do not have adequate information for our fisheries over a long enough time period. Most sampling programs are generally inadequate to assess prestocking populations and later success and impacts. We should not use guesswork, seat-of-the-pants judgments and incomplete analyses to evaluate or manage fisheries. In our evaluation, we should assess the consequences of not taking action as well as the consequences of being wrong.

Another reason may be recruitment limitations. Some evidence suggests recruitment limitation (not enough fish getting to primary nursery areas) and limited food resources for some offshore, winter-spawned species (e.g., flounder) in North Carolina. However, these data need more precise assessment, and the concept of surplus carrying capacity is hotly debated in the scientific community. Since the use of estuarine primary nursery areas may be highly influenced by oceanographic processes, it is difficult at this time to predict which habitats will be most important or have higher densities for a given year. It may be that to support the high productivity in North Carolina estuaries, a large number of seemingly underutilized primary nursery areas may be required. Therefore, increasing the density of fishes through stocking may be a significant ecological mistake.

Summer inshore spawning species (e.g., red drum) may follow a different scenario. Their populations seem smaller, and the juveniles often use different habitats than the winter spawners. However, assessment of these species lags behind that for the winter spawners, which support more than 90 percent of the state's landings.

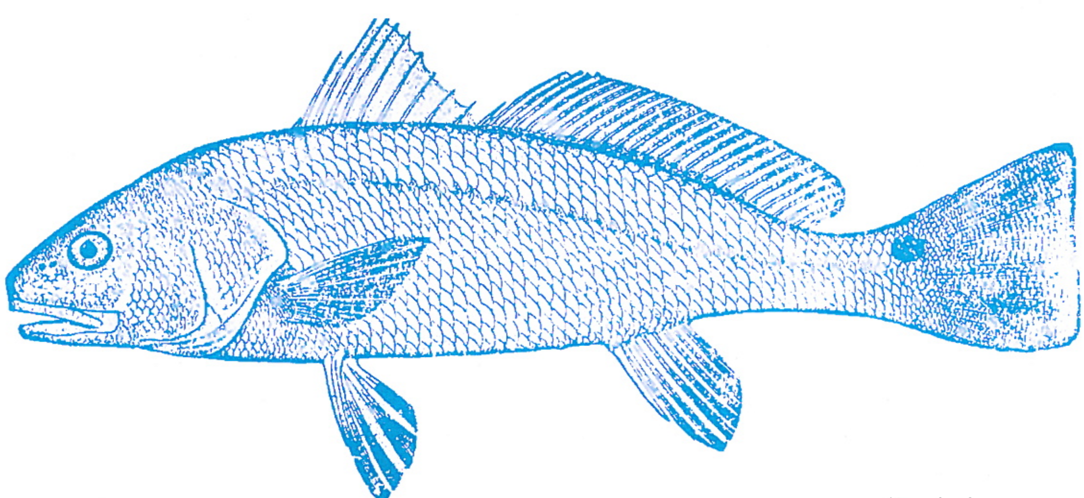
Perhaps many habitats could support a higher density of animals and production could be increased. That, however, is an insufficient reason to stock these species until concerns over possible long-term impacts to the general ecosystem are explored.

Even if habitats could handle additional fish density, can we produce enough fish in a hatchery to impact the population?

Because we are dealing with very large populations of migratory species and very large estuarine and oceanic systems, fish stocked in North Carolina may end up in other states' waters. While this could enhance the overall population, this may not be a good use of North Carolina taxpayers' money. In addition, such large-scale movement will make assessing stocking success extremely difficult and costly.

Should we stock flounder and red drum in North Carolina?

This is the critical question. I can endorse a pilot program with appropriate research components to address critical issues and provide needed information. Once the questions raised above are addressed, a better decision can be made. Therefore, I cannot recommend proceeding directly to a stocking program (especially for flounders or any other winter-spawned species) as other states have done without better assessing both need and risks. I am skeptical that we know enough about our environment to make this type of expenditure worthwhile except in a research mode.



Red drum