SUSTAINABLE MARINE AQUACULTURE:
FULFILLING THE PROMISE; MANAGING THE RISKS

REPORT OF THE MARINE AQUACULTURE TASK FORCE

JANUARY 2007

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MARINE AQUACULTURE TASK FORCE

Richard Pittenger is chairman of the Marine Aquaculture Task Force. Dick Pittenger retired in 2004 as Vice President for Marine Operations and Arctic Research Coordinator for Woods Hole Oceanographic Institution, where he worked for 14 years, devising and carrying out a strategy to modernize its fleet of research vessels and advancing the use of remotely operated vehicles for ocean science. Adm. Pittenger retired from the Navy as a Rear Admiral in 1990. During his 32 years of service, he had a wide range of duties including command of a mine sweeper in Vietnam and a destroyer squadron, Chief of Staff to the U.S. Naval Forces in Europe, director of the Antisubmarine Warfare Division, and Oceanographer of the Navy. He is a frequent lecturer at the Naval War College and the Naval Postgraduate School, and has authored books on antisubmarine warfare and articles on undersea acoustics, nautical charting, and naval oceanography.

Bruce Anderson is president of the Oceanic Institute, a not-for-profit research organization in Hawaii dedicated to sustainable aquaculture development, improved coastal resource management, and marine science education. Dr. Anderson has extensive experience in environmental management and public health issues in Hawaii and the Pacific Islands. Before assuming the leadership of the Oceanic Institute, Dr. Anderson was director of the Environmental Health Program at the University of Hawaii School of Medicine. From 1999 through 2002, he was Director of Health for the State of Hawaii, and served as Deputy Director for Environmental Health for the state from 1987 through 1998. He holds a Ph.D. in biomedical sciences from the University of Hawaii and an M.P.H. in epidemiology from Yale University.

Daniel Benetti is the Chairman of the Division of Marine Affairs and Policy at the University of Miami's Rosenstiel School of Marine and Atmospheric Science, where he is an Associate Professor and the Director of Aquaculture. He has over 25 years experience in aquaculture worldwide and has published numerous articles in aquaculture science and technology. In addition to his academic responsibilities, he carries out R&D and technology transfer projects for the development of sustainable marine hatchery and offshore growout initiatives. He has extensive experience with the industry and has been a consultant for the private and government sectors in Latin America, the U.S., Europe, Asia, the Caribbean, and Australia. Coordinating the NOAA/NSG/NMAI effort in the SE U.S. and the Caribbean, he has partnered with the government and the industry to spearhead advanced technology for hatchery and offshore aquaculture development in these regions. He is the scientific coordinator of Snapperfarm's and Aquasense's offshore aquaculture demonstration projects in Puerto Rico and the Bahamas. Prior to joining the faculty of the University of Miami, he was a research scientist at Harbor Branch Oceanographic Institution in Ft. Pierce, Florida.

Paul Dayton is Professor of Oceanography at the Scripps Institution of Oceanography. His research interests include benthic ecology, marine conservation and policy, evolution, and natural history. He is the author of dozens of publications on topics ranging from kelp forest ecology, ecosystem effects of fishing, to cetacean habitat selection. He teaches numerous courses including natural history of coastal habitats, professional ethics in science, advanced experimental methods, and biological oceanography.

Bill Dewey is the public affairs manager for Washington State's Taylor Shellfish Company, one of the largest producers of farmed shellfish in the United States. During more than 20 years as a shellfish farmer, Dewey has been active in shaping environmental and regulatory public policy as it affects the shellfish culture industry. He is president of the Pacific Shellfish Institute, serves on the Board of Directors of the National Aquaculture Association and was recently appointed by Washington's Governor Gregoire to his third term on the Puget Sound Council advising the State on conservation priorities for Puget Sound. He recently served as a member of the National Academy of Science's Committee on Nonnative Oysters in the Chesapeake Bay and together with his wife Joyce, owns and operates a clam farm in Samish Bay.

Rebecca Goldburg is a senior scientist at Environmental Defense, a national nonprofit research and advocacy organization. Working from New York City, Goldburg is active in public policy issues concerning both marine and terrestrial food production. Among her responsibilities, she leads Environmental Defense's work to increase demand for more sustainably produced seafood. She currently serves as an advisor to the Luce Foundation's Environment Program, as a member of the USDA's task force developing organic standards for aquaculture, and on the Monterey Bay Aquarium Seafood Watch Program's Advisory Board. An author of numerous articles, Goldburg coauthored the Pew Oceans Commission's report on marine aquaculture. Dr. Goldburg has an M.S. in Statistics, a Ph.D. in Ecology, and an honorary Doctorate of Laws, all from the University of Minnesota.

Alison Rieser is the Dai Ho Chun Distinguished Chair in Arts and Sciences at the University of Hawai'i Manoa. She was previously a professor of ocean and coastal law at the University of Maine School of Law. She directed the University of Maine's Marine Law Institute from 1983 until 2001. Her research interests include the use of property and rights-based concepts in ocean and coastal management, ecosystem approaches to fisheries management, and the role of science in marine legal regimes. In addition to her teaching duties, Professor Rieser is a consultant to federal and state agencies and NGOs, and has written and lectured extensively on coastal and ocean law. She is the coauthor of the leading casebook on ocean and coastal law and of numerous articles on the management of marine fisheries, the regulation of aquaculture, and the protection of endangered marine wildlife. Professor Rieser served on the National Academy of Sciences Committee to Review Individual Fishing Quotas and was selected as a Pew Fellow in Marine Conservation in 1999. She was a postdoctoral fellow in marine policy at the Woods Hole Oceanographic Institution and has law degrees from The George Washington University and Yale Law School.

Byron Sher was elected to the California State Senate in 1996 in a special election. He was subsequently re-elected to two four-year terms, and served as the first chairman of the Senate Environmental Quality Committee. Mr. Sher served for over 15 years in the State Assembly, where he chaired the Natural Resources Committee and the Criminal Law and Public Safety Committees. He served two terms as Mayor of Palo Alto during his nine years on the City Council. Mr. Sher graduated from Harvard Law School and is Professor of Law Emeritus at Stanford Law

School. He held academic teaching positions at the law schools of Harvard, Southern Methodist University and the University of Southern California, as well as Stanford.

Arliss Sturgulewski was elected to serve on the Anchorage Charter Commission and the Anchorage Assembly. She served in the Alaska State Senate from 1978 through 1992, when she chose not to stand for re-election. She was the Republican candidate for governor of Alaska in 1986 and 1990. Senator Sturgulewski received a BA in Economics and Business from the University of Washington. She received an Honorary Doctor of Laws degree from the University of Alaska, Anchorage. She has served on many local municipal boards, including Planning and Zoning and the Board of Examiners and Appeals. Ms. Sturgulewski gives frequent speeches on issues dealing with equity and on education issues. She is a trustee for the Anchorage YMCA, Sheldon Jackson College located in Sitka, Alaska, and the University of Alaska Foundation. She serves on the Advisory Council for the University of Alaska School of Fisheries and Ocean Sciences and the University of Alaska, Anchorage Chancellor's Council as well as numerous other statewide boards and commissions.

Staff

Chris Mann, Executive Director
Judy McDowell, Science Director
Amy Kenney, Consultant
Brendan O'Neill, Consultant
Sheri DeRosa, Administrative Assistant

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EXECUTIVE SUMMARY

The Nature of the Problem

According to the U.N. Food and Agriculture Organization (FAO), most capture fisheries are either fully exploited or have been overfished, while demand for seafood continues to grow. Governments, the seafood industry, and consumers look increasingly to aquaculture—the farming of aquatic organisms, including fish, mollusks, crustaceans and plants—to fill the gap between wild fisheries landings and seafood demand. In response, aquaculture has been growing at an annual rate of about nine percent worldwide and, by some estimates, now produces nearly half of the fish and seafood eaten. Aquaculture is also playing a growing role in efforts to restore and maintain depleted stocks of wild fish and other aquatic organisms.

The United States is a net importer of seafood, with a current seafood trade deficit of approximately $8 billion. About 40 percent of the seafood imported into the United States is farm raised, mostly consisting of salmon and shrimp. The U.S. produces aquaculture products worth about $1 billion annually, but the Department of Commerce has called for the development of a domestic industry worth $5 billion by 2025. Although current U.S. production is dominated by pond-raised catfish, technological advances in recent decades have led to a dramatic increase in the production of farmed salmon. Several other marine finfish species are raised in small amounts in U.S. waters and research is being conducted on several more. Marine species—mostly salmon, bivalve mollusks, and shrimp—now constitute about 10 percent of domestic production, but contribute 20 percent of the value of the crop.

With the growth of aquaculture have come environmental impacts, particularly as technology has opened new areas to aquaculture and allowed for increasingly intensive farming methods. Environmental effects from aquaculture include water pollution, introduction of nonnative species, genetic effects on wild populations of fish and shellfish from escapes of farmed animals or their gametes, and concerns about the increasing use of wild forage fish for aquaculture feeds.

Historically, culture of marine species has been done in situ in coastal waters. However, with the dramatic increase in coastal development in the United States in recent decades, clean water and suitable sites for coastal aquaculture are at a premium. As a result, many experts see open ocean waters as the most likely venue for any major expansion of U.S. marine aquaculture. The Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) has developed legislation to expedite the establishment of aquaculture in U.S. marine waters under federal jurisdiction (generally 3 to 200 nautical miles offshore). This legislation was introduced in the Senate in June 2005.

Sustainable development of aquaculture requires that its environmental impacts be addressed effectively, particularly if, as predicted by many experts, a large proportion of the future growth in aquaculture is through in situ culture in marine waters. Most marine waters, in the United States and around the world, are part of the public domain. Public

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policy makers are faced with difficult decisions about how to balance the potential benefits of aquaculture to the nation's economy and food supply with its effects on the environment, particularly where aquaculture may affect the health of marine ecosystems and other uses of the nation's ocean space and resources.

Our Task

With the United States—and the world—poised for a significant expansion in marine aquaculture, the Woods Hole Oceanographic Institution convened the Marine Aquaculture Task Force, consisting of scientists, legal scholars, aquaculturists and policy experts. Its mission was to examine the status and trends in marine aquaculture and to recommend standards and practices for U.S. marine aquaculture to protect the health of marine ecosystems. During regional meetings in Massachusetts, Alaska, Washington state, Hawaii and Florida, the Task Force met with aquaculturists, marine scientists, fishermen, public officials and many others interested in aquaculture and its effects—both positive and negative—on coastal communities and the marine environment. The Task Force also visited a number of public and private facilities to get a sense of the nature and practice of modern aquaculture in the United States.

What We Found

Marine aquaculture is controversial. Shellfish farming along our coasts has been practiced for centuries, but with the dramatic increase in coastal development in recent decades, many marine areas formerly open to shellfish farming have been closed to protect public health. In remaining clean areas, shellfish farmers are finding it increasingly difficult to compete for ocean space and resources with other users. The rapid worldwide growth of salmon farming has raised awareness of the environmental, social and economic effects of finfish farming. It is difficult, if not impossible, to separate discussions of environmental and economic impacts in the coastal communities affected by them. The idea of farming in the ocean, which has been traditionally regarded as a wilderness open to all, adds a complicating dimension to the discussion about marine aquaculture. To address these concerns, government processes for siting, permitting and managing marine aquaculture should be transparent, accountable and accessible to the public.

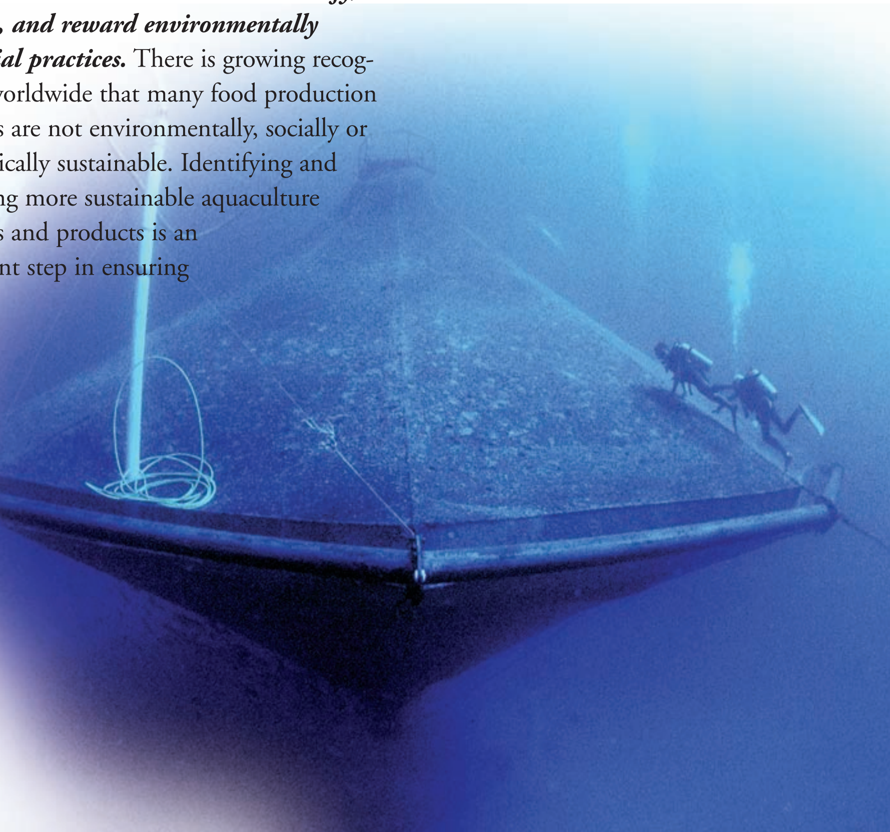
Assessing future environmental impacts of marine aquaculture is challenging. Most of the growth in marine aquaculture is expected to be in the open water cultivation of marine finfish species. Most of the experience with finfish production to date, however, is with culture of salmonids in net pens in coastal waters. While the Task Force believes that the same kinds of risks—water pollution, escapes, disease, etc.—are inherent to all in situ finfish aquaculture, it is challenging to estimate the absolute and relative magnitude of these risks in a different environment in which we have little experience to date. The few demonstration projects conducted to date show negligible to modest impacts on the marine environment. However, these projects were conducted on small-scale operations mostly at low densities of fish, so their application to large-scale and/or concentrated marine fish farming is limited. Additional research needs to be conducted on the effects, including cumulative and secondary impacts, of aquaculture on the marine environment. In addition, government agencies responsible for permitting marine aquaculture should require careful monitoring and reporting of environmental parameters by operators of aquaculture facilities.

Congress should enact legislation ensuring that strong environmental standards are in place to regulate the siting and conduct of offshore marine aquaculture. Regardless of potential impacts, aquaculture is a substantial new use of federal ocean waters. Given known risks to marine ecosystems from aquaculture and the important commercial and recreational uses that depend on ocean space and resources, Congress should enact legislation specifying standards to protect the health and integrity of marine ecosystems in advance of significant federal permitting for marine aquaculture facilities. Establishing a sound, comprehensive governance framework for marine aquaculture at the federal level will protect the public interest in healthy marine ecosystems and provide for meaningful coordination with the states, in whose waters the majority of aquaculture occurs.

Decisions about siting and permitting of marine aquaculture facilities should give priority to protection of the health of the marine environment in the face of uncertainty about effects on this public resource. Little is known about the assimilative capacity of marine ecosystems for the wastes produced by aquaculture operations. Since the oceans are a public trust resource, it is legitimate to hold private uses, such as aquaculture, to a high standard if permission is to be granted for these activities to be conducted in the public domain. This is especially true since many commercial and recreational activities, including aquaculture itself, depend on clean, healthy oceans. Careful siting and technological improvements can reduce escapes and accumulation of wastes, and research on and development of these approaches should be supported. But these approaches can only go so far in an open system, particularly if marine aquaculture operations expand significantly in number, density, and intensity of production. A better understanding of the assimilative capacity of marine ecosystems for nutrients and particulate organic matter, drugs and chemicals, and escapes of live animals from marine aquaculture facilities needs also to be gained. In the meantime, decisions regarding siting, culture methods, species cultured, and number and density of aquaculture facilities within an area should be conservative to ensure protection of ecosystem health.

Culture of native species of the local wild genotype substantially addresses two major concerns regarding marine aquaculture: the introduction of invasive species and genetic effects of escapes on wild populations of marine life. Invasive species are a global environmental and economic problem. In addition, there is growing evidence that escaped farmed salmon are interbreeding with wild Atlantic salmon, spreading their genes within dwindling wild stocks of Atlantic salmon and potentially confounding the recovery of this species. Most of the species currently being used or developed for marine aquaculture are depleted in many areas of their range. To minimize the ecological risk of introducing a species that might become invasive, or of introducing harmful genes to wild populations, marine aquaculture permits should be limited to native species of the local wild genotype unless scientific information and analysis shows the risk of harm from culturing a nonnative species or a native species of nonlocal genotype to be negligible.

In addition to appropriate regulation, development of sustainable marine aquaculture in the United States will benefit from private-sector initiatives to identify, develop, and reward environmentally beneficial practices. There is growing recognition worldwide that many food production practices are not environmentally, socially or economically sustainable. Identifying and rewarding more sustainable aquaculture practices and products is an important step in ensuring that the



Submersible sea cages, like this one manufactured by Net Systems, offer protection from the wind and waves of open-ocean conditions. Such structures open the technological door to offshore aquaculture.

Photo: The Oceanic Institute

Addressing the effects of aquaculture on the marine environment requires…changes to the framework of laws, institutions and policies that dictate how aquaculture is sited, permitted, and operated in marine waters of the United States.

growing marine aquaculture industry contributes positively to the global food supply. Recognizing that corporate purchaser and individual consumer choices play a powerful role in shaping industrial practices and products, development of systems to identify, certify, and label sustainable aquaculture products would be important steps in this regard. The experience with other products indicates that this requires strong partnerships among producers, corporate buyers, and consumers. Early results indicate that consumers will preferentially select more sustainable products when given good information, reasonable choices, and a certification/labeling scheme that they trust.

Summary of Recommendations

In the chapters that follow, the Task Force has identified six key areas that must be addressed to ensure that marine aquaculture poses minimal risks to the health of marine ecosystems and that will promote a more sustainable U.S. marine aquaculture industry. Our review of issues related to governance, escapes, disease and parasites, water pollution, feeds, and market-based incentives, and the resulting recommendations in each of these areas is summarized below.

Governance

Addressing the effects of aquaculture on the marine environment requires specific measures to address specific concerns, such as escapes, disease, or water pollution. It also requires changes to the broader framework of laws, institutions, and policies that dictate how aquaculture is sited, permitted, and operated in marine waters of the United States. This is particularly true if aquaculture in the United States moves increasingly offshore into marine waters under federal jurisdiction.

Two key failings of the current legal regime for marine aquaculture are the lack of clear federal leadership and the lack of standards to protect of the marine environment. Numerous federal agencies have responsibility for aspects of aquaculture regulation, but currently no agency is charged to coordinate the overall process. This creates a confusing and cumbersome process for those seeking permits for aquaculture and results in a lack of accountability among the federal agencies for marine aquaculture activities and its impacts on the marine environment. As a result, greater authority requires greater responsibility on the part of the lead agency. This is best facilitated by a strong signal from Congress that marine aquaculture will not be promoted at the expense of the health of the marine environment.

- Congress should assign NOAA a leading role in planning, siting, and regulating aquaculture in federal marine waters.
- Congress should direct NOAA to establish a federal marine aquaculture program that is precautionary, science based, socially and economically compatible with affected coastal communities, transparent in its decision making, and provides ample opportunity for public input.
- NOAA should evaluate the environmental risks from marine aquaculture prior to permitting.
- NOAA should consult with affected coastal states and regional and interstate fisheries councils during both the planning and permitting stages.
- Congress should ensure environmental standards are in place before permits are issued for aquaculture in federal waters.
- NOAA should implement environmental standards through management, monitoring, and enforcement requirements in permits.
- Aquaculture operators should be required to develop and comply with an operating plan specifying measures taken to achieve environmental standards.
- Operators of aquaculture facilities in federal waters should be liable for damage caused by their activities.

- NOAA should provide incentives to industry for research, development and deployment of species, technologies, and techniques for sustainable marine aquaculture, including sustainable aquaculture feeds.
- Congress should address the growing need for a comprehensive regime for management of aquaculture and other offshore activities affecting federal marine waters and resources.

Escapes

Aquaculture has been a significant source of intentional and unintentional introductions of nonnative species. The harm caused by invasive species is well documented and there is considerable evidence of damage to the genetic integrity of wild fish populations when escaped farmed fish can interbreed with local stocks. Escapes of farmed animals will inevitably occur in any in situ culture situation. This is particularly true of inherently "leaky" net pens or cages and in situations where cultured organisms release viable gametes into the water.

Careful planning and management to prevent introductions of nonnative species and nonlocal genetic strains are more effective than attempting to fix problems after they occur. Therefore, any rational policy for addressing escapes must focus first on prevention, but follow up with strong management measures to eliminate, or at least minimize, ecological damage once escapes occur. These measures must be cost effective, but the benefits of protecting ecosystem integrity should be accounted for as well.

- Limit marine aquaculture to native species of the local wild genotype unless it can be demonstrated that the risk of harm to the marine environment from culturing other species is negligible.
- Culture native species in a manner that ensures escapes will not harm the genetics of local wild populations.
- Use siting criteria and require management measures to minimize risks to marine ecosystems from escapes of aquatic animals or release of viable gametes from aquaculture facilities.
- Support and coordinate research to reduce the risk of harm to the marine environment from escapes from marine aquaculture.

Disease and Parasites

Scientists have increasingly found evidence of disease "spillover" from agriculture into natural ecosystems, with associated impacts on wild organisms. Marine aquaculture, as a relative newcomer to the world of agriculture, has not been studied as extensively in terms of its role in the spread of disease, but one would expect that the same mechanisms for disease amplification and transmission exist, especially given the open nature of many aquaculture systems. As marine aquaculture expands in terms of volume and location, management and regulatory strategies should adopt a risk-averse approach to avoid problems before they become crises. Preventative measures are more effective in the long term in protecting the environment and the economic interests of the industry.

- Establish and maintain a database on disease and parasite distribution in marine waters to inform permitting decisions.
- Use siting whenever possible to eliminate or reduce the likelihood and ecological impact of diseases and parasites.
- Establish management practices for the prevention and treatment of diseases in farmed aquatic organisms to minimize impacts on marine ecosystems.
- Support research and development of aquatic animal husbandry and disease management strategies that will reduce the risk of harm to marine ecosystems.

There is a growing realization that if aquaculture of carnivorous species is to expand, alternatives to fishmeal and fish oil—most likely plant-based ingredients—are necessary.

Water Pollution

Marine aquaculture facilities produce a variety of wastes that are potentially harmful to the environment and which are discharged untreated into coastal and ocean waters. Wastes from marine aquaculture generally include dissolved (inorganic) nutrients, particulate (organic) wastes (feces, uneaten food and animal carcasses), and chemicals for maintaining infrastructure and animal health. In the United States, aquaculture discharges are currently small compared to other sources of water pollution, but little is known about the assimilative capacity of the marine environment for these pollutants. Additionally, marine aquaculture operations tend to cluster geographically, raising the potential for cumulative impacts.

If marine aquaculture expands considerably in the U.S., the choices made regarding the species and methods of culture, as well as the location and concentration of facilities, will determine whether pollution effects from marine aquaculture will be substantial or minor. Discharges of pollutants from most marine aquaculture facilities are regulated under the Clean Water Act, which provides a variety of tools to protect marine water quality. If used effectively and creatively, the tools provided by the Clean Water Act can control pollution from marine aquaculture.

- Existing effluent limitations for aquaculture should be reviewed and revised, if necessary, to ensure that concerns particular to the proposed expansion of aquaculture into federal marine waters are addressed.
- EPA should ensure that all coastal states have water quality standards for marine waters, and that those standards protect the health of marine ecosystems.
- EPA should establish water quality standards for federal marine waters or revise guidelines for determining degradation of ocean waters to achieve the same level of protection.
- Regulations for implementing water quality standards and ocean discharge criteria should be clarified to ensure that pollution discharge permits for marine aquaculture facilities address, inter alia, cumulative and secondary impacts at the local and regional level from expansion of the industry.
- EPA and the states should coordinate with NOAA so that management practices and other measures required in pollution discharge permits are integrated, to the extent possible, into operating plans for marine aquaculture facilities called for in the governance recommendations.

Aquaculture Feeds

Aquaculture is seen as a supplement to global seafood supplies as landings from wild fisheries have peaked. Currently, however, the protein and energy needs of farmed carnivorous species, such as salmon and cod, are met mainly through the use of fishmeal and oil obtained from fisheries directed at small pelagic fish. These fisheries, called reduction fisheries, are generally fully exploited or overfished worldwide. Scientists are increasingly concerned about the ecological effects of these fisheries because small pelagic fish are an important food source for predators in marine ecosystems.

Scientific feed formulation and feeding practices, driven in part by the rising price of fishmeal and fish oil, have resulted in substantial improvements in the efficiency of feed use on the farm. There is nonetheless a growing realization that if aquaculture of carnivorous species is to expand, alternatives to fishmeal and fish oil—most likely plant-based ingredients—are necessary. Alternative feed ingredients are under various stages of development and use, from the use of fishery bycatch, terrestrial and marine plants, to animal processing byproducts. As research in this area continues, it will be a major challenge for the industry to continue to grow while reducing its dependence on wild fish for feeds. To do this, marine aquaculture in the United States must focus on the development of feed alternatives that are economical and meet the dietary requirements of fish, as well as encouraging the use of more sustainable feed ingredients.

- Support research and development for alternative feed ingredients.
- Substitute sustainable feed ingredients for unsustainable ingredients.
- Adopt ecosystem-based management approaches for reduction fisheries.
- Develop a traceability system for fishmeal and fish oil.
- Promote sustainable aquafeeds internationally.

Market-based Incentives

By harnessing the enormous power of the marketplace to reward good behavior with respect to the environment, demand-side programs—including environmental certification systems, corporate purchasing policies, and eco-labeling—provide incentives for environmental protection that governments cannot provide. These methods can complement and enhance the effectiveness of government regulation and industry management practices. A well-recognized, widely accepted certification system does not yet exist for marine aquaculture products, although there are a number of efforts underway that may lead to more sustainable aquaculture practices.

The keys to success of purchasing agreements and environmental certification schemes include high standards for sustainability, strong verification procedures to ensure compliance with standards, transparency and accessibility of the process to interested parties, and achieving and maintaining high consumer confidence in the label. Major issues to be resolved for aquaculture include the degree to which organic standards are, or can be, credibly applied to various forms of aquaculture, and whether a widely accepted approach for certifying the sustainability of aquaculture feed ingredients can be developed. In the meantime, corporate purchasing agreements can reward environmentally friendly production practices and offer insights for the development of broader programs.

- Encourage companies to adopt purchasing policies favoring environmentally preferable aquaculture products.
- Encourage the development of a certification system for aquafeeds and aquaculture products.
- A certification system for aquaculture products should contain criteria that require the use of feed derived from sustainable sources.

CHAPTER 1

INTRODUCTION

Fishing is one of mankind's oldest professions, and seafood has long been a staple of the human diet. But nowadays the seafood you eat at your favorite restaurant is nearly as likely to have been raised on a farm as caught wild. Already almost half the seafood produced for human consumption is farm raised, and that percentage is expected to continue to climb.

Global catches of wild fish have leveled off in recent years. Our ability to catch fish has simply exceeded the capacity of marine ecosystems to produce them. Yet demand for seafood continues to grow. To fill this gap, governments and the seafood industry look increasingly to aquaculture. The industry has grown nearly nine percent per year since 1970 and is now responsible for more than 37 percent of worldwide fisheries landings.[1]

In the United States, growth has been slower but aquaculture still produces freshwater fish and seafood worth approximately $1 billion annually. The Department of Commerce has called for an expansion of U.S. aquaculture to $5 billion in annual production by 2025. With such dramatic growth worldwide, and with the United States poised to expand its industry, it is time to take a closer look at how aquaculture—the growing of fish and other aquatic organisms—is changing our diets, our coastal communities, and our oceans.

Finfish account for more than half of aquaculture production, most of this from freshwater fishes, such as carp, catfish, and tilapia. However, the depletion of many marine stocks, combined with consumer demand for salmon and other high-value marine species, has spurred dramatic growth in their culture. Marine species now account for about one third of aquaculture production by weight, and farmed salmon now comprise more than 60 percent of the total salmon market.

Of course, given protection from predators and disease, and the right inputs of nutrients, it is possible to produce far more animal protein through husbandry than nature can produce on its own in a given area. This is the essential logic of agriculture, whether practiced on land or in the ocean. We long ago crossed this threshold on land, and agriculture has produced undeniably great benefits to society. But is has also caused significant—and often needless—damage to terrestrial ecosystems.

We now face a similar decision for the oceans. The economics have shifted to make large-scale farming of the seas—once an unlikely futuristic vision—a potential reality in the decades to come. At the same time, we already depend on our oceans for a variety of other important economic activities, including tourism and recreation, fishing, and energy production. From the reports of two major ocean commissions and numerous

… almost half the seafood produced for human consumption is farm raised, and that percentage is expected to continue to climb.

[1] The vast majority of aquaculture production is for human consumption while about 30 percent of the global wild fish catch is used to produce fish meal and oil for livestock fodder and non-food products. As a result, aquaculture makes up a greater share of the seafood produced for human consumption than it does of total fisheries harvest.

other studies and reports, we know that our oceans are in trouble. The health and integrity of marine ecosystems has been degraded through overuse—and careless use—of the bounty they provide. We have been fooled by the sheer vastness of the oceans into thinking that their resources are inexhaustible. We have finally realized that the oceans, just like our natural resources on land, require careful stewardship if they are to continue to provide the many benefits that society has come to rely on from them.

The philosopher George Santayana said those who cannot remember the past are condemned to repeat it. We cannot afford to make the same mistakes with ocean agriculture that we have made on land. If used properly, this new technology can help address the nutritional needs of a growing population, expand economic opportunities in coastal communities, produce seed stock to restore depleted marine species, and relieve fishing pressure on wild stocks. But if done carelessly, aquaculture can add substantial pollution to the marine environment, damage wildlife habitat, disrupt fisheries, introduce nonnative species and impact the genetic integrity of wild stocks in already-stressed ecosystems.

This is the promise and the risk of any new technology: The outcome depends entirely on whether we apply the technology thoughtfully and conscientiously, or carelessly. With marine aquaculture, we stand on the shore of a new frontier in agriculture. We need to take a careful look before we dive in.

Our Mission

The Marine Aquaculture Task Force is a panel of scientists, aquaculturists and policy experts convened by the Woods Hole Oceanographic Institution with financial support from The Pew Charitable Trusts and the Lenfest Foundation. The Task Force was charged to develop a series of protective, science-based standards to ensure that aquaculture development poses minimal threats to the ocean environment. Over the last 18 months, the Task Force explored the status and trends of marine aquaculture in the United States. Together, we examined the potential effects of aquaculture on our oceans and developed recommendations for how the U.S. industry can grow in an economically and environmentally sustainable manner.

Aquaculture is a diverse, worldwide industry. Although the United States is the world's second largest seafood importer, it produces less than one percent of worldwide aquaculture output. For this study, we chose to focus on aquaculture in marine waters of the United States because it is the industry sector most likely to expand significantly in this country and because of the potential effects of that expansion on the health and vitality of marine ecosystems, which are already threatened by a variety of human activities. The introduction of legislation to encourage development of aquaculture in marine waters under federal jurisdiction makes it clear that the Administration and Congress expect significant growth in this area. That makes it especially timely for the Task Force to examine the risks from aquaculture and recommend solutions that would enable the industry to grow without harming the marine environment.

The Task Force held five regional meetings—in Woods Hole, Massachusetts; Anchorage, Alaska; Seattle, Washington; Waimanalo, Hawaii; and Tampa, Florida. In Anchorage and Seattle, we held public forums to discuss the merits of, and concerns about, marine aquaculture. At our regional meetings we had extensive dialog with fishermen, marine scientists, environmental advocates, aquaculture practitioners, and state and federal government regulators. We also visited numerous aquaculture facilities, including hatcheries for salmon ranching, mussel rafts and a shellfish hatchery, state-of-the-art aquaculture research facilities, and even an ancient Hawaiian fish pond that is being restored on Oahu.

Levels of concern about the environmental effects of aquaculture varied from region to region, and different concerns were paramount in different regions. However, issues related to water pollution, genetic and ecological effects of escapes, the spread of disease and parasites from farms to wild fish and other marine life, and the ecological effects of the use of wild fish for aquaculture feeds were of common concern everywhere we went.

The Task Force also came to understand that the current ocean governance framework does not adequately assess and address the threats to the marine environment posed by the expansion of aquaculture. At the same time, the current regulatory framework is, in effect, an impediment to development of a responsible marine aquaculture industry. As a result, in addition to addressing the environmental concerns regarding marine aquaculture, the Task Force developed recommendations to improve the governance framework for marine aquaculture to promote the development of a sustainable industry.

In the chapters that follow, the Task Force offers its analysis of the environmental risks presented by marine aquaculture and its recommendations for addressing those risks. The function of the Task Force is neither to promote aquaculture nor to hamper its development. Rather, our goal is to provide a blueprint for environmentally responsible, sustainable development of the industry so that it can continue to grow, in this country and worldwide, without harming the already-fragile health of marine ecosystems.

Frozen wild tuna at a market in Tokyo. Capture fisheries landings have leveled off in recent years while aquaculture production continues to expand to meet growing demand for seafood.

Photo: Getty Images

CHAPTER 2

THE STATUS OF AQUACULTURE: GLOBAL AND NATIONAL PERSPECTIVES

Introduction

According to the U.N. Food and Agriculture Organization (FAO), most capture fisheries are either fully exploited or have been overfished, but demand for seafood is expected to increase in the future (FAO 2004). Most experts believe that aquaculture is the only means to produce the additional seafood that the world's consumers are demanding. In response, aquaculture has been growing at an annual rate of nearly nine percent worldwide and is now believed to produce nearly half of the fish and seafood eaten (FAO 2006).

The FAO has defined aquaculture as "the farming of aquatic organisms, including fish, mollusks, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production as well as ownership of the stock being cultivated" (FAO 2000). Aquaculture is a diverse activity with roots that go back several thousand years. Early aquaculture was most likely a simple form of animal rearing in which human intervention led to increased production, but today it is developing into a highly technological and efficient industry, which is expected to continue to expand and increase its contribution to the worldwide seafood supply.

Status of Global Aquaculture Production

Worldwide, aquaculture has grown at an average compounded rate of 8.8 percent per year since 1950, which is more rapid growth than all other food animal producing sectors, including capture fisheries and terrestrial farmed meat production systems over the same time period. Global aquaculture production (including aquatic plants) in 2004, the latest year for which FAO statistics are available, was reported to be 59.4 million metric tons (mt)[2], worth an estimated U.S.$70.3 billion (FAO 2006). Asian countries account for the vast majority of global aquaculture production, supplying over 90 percent of the worldwide total in 2004. China is the world's largest aquaculture producer and several other Asian countries are ranked in the top 10 producers (Table 2-1). In 2004, China is estimated to have produced over 69 percent of the total world aquaculture production. The FAO has cautioned, however, that China's reported capture fisheries and aquaculture production figures may be too high (FAO 2004).

Aquaculture production has grown more in developing countries than in developed countries. While China has contributed the most growth, aquaculture production in several other countries has grown considerably in recent decades. According to the FAO, developing countries accounted for about 59 percent of aquaculture production in 1970. By 2002 their share had risen to over 90 percent. In Asian countries, most aquaculture production is in the form of low-value carp and seaweed for domestic consumption, and marine shrimp and mollusks for export.

Global aquaculture production (including aquatic plants) in 2004…was reported to be 59.4 million metric tons, worth an estimated U.S.$70.3 billion.

[2] A metric ton (mt) is equal to 1000 kg or 2200 pounds. We will present aquaculture production data in metric tons throughout the report unless otherwise noted.

TABLE 2-1

Top ten aquaculture producers in the world in 2004 (from FAO 2006)

Country	Production (million mt)	% of Global Production	Value (billion US$)	% of Global Value
China	41.329	69.6	35.997	51.2
India	2.472	4.2	2.936	4.2
Philippines	1.717	2.9	0.795	1.1
Indonesia	1.469	2.5	2.163	3.1
Japan	1.261	2.1	4.242	6.0
Viet Nam	1.229	2.1	2.459	3.5
Thailand	1.173	2.0	1.587	2.3
Republic of Korea	0.953	1.6	1.212	1.7
Bangladesh	0.915	1.5	1.363	1.9
Chile	0.695	1.2	2.815	4.0
Top ten subtotal*	**53.212**	**89.6**	**55,568**	**79.0**
United States	0.607	1.0	Not available	

*Columns may not add due to rounding.

Sales of U.S. aquaculture products in 2005 are estimated to have exceeded $1 billion.

A wide variety of species is used in aquaculture. FAO reports that 336 different species of aquatic organisms were farmed in 2004, but the majority of aquaculture production is based on a very limited number of these. Just 10 species made up about 69 percent of the total global production and the top 25 species accounted for over 90 percent. In 2004, fish made up 47.4 percent of the total global production, followed by aquatic plants (23.4 percent), mollusks (22.3 percent) and crustaceans (6.2 percent). Based on 2003 data, freshwater fish, mainly carps, comprised more than 85 percent of farmed fish production by weight.

Seafood Supply and Demand in the United States

The U.S. is dependent on seafood imports, about 40 percent of which are farmed species, primarily shrimp and salmon (USDOC 2005). Some have suggested addressing the substantial U.S. seafood trade deficit, which is estimated at about $8 billion, by increasing domestic seafood production through aquaculture (USDOC 1999).

Annual consumption of seafood in the U.S. has remained relatively stable at about 15 pounds per person for the past decade. Domestic seafood consumption is expected to increase in the future, however, due to population growth, the aging of the population (older people generally consume more seafood), and greater emphasis on eating seafood as part of a healthy diet. It has been estimated that the U.S. seafood market will require an additional 1.8 million mt (4 billion pounds) of seafood by the year 2020, with aquaculture potentially providing most of the needed production (Johnson 2003). Increasing costs of fossil fuels and biosecurity concerns are increasing demand for locally produced food supplies, including seafood.

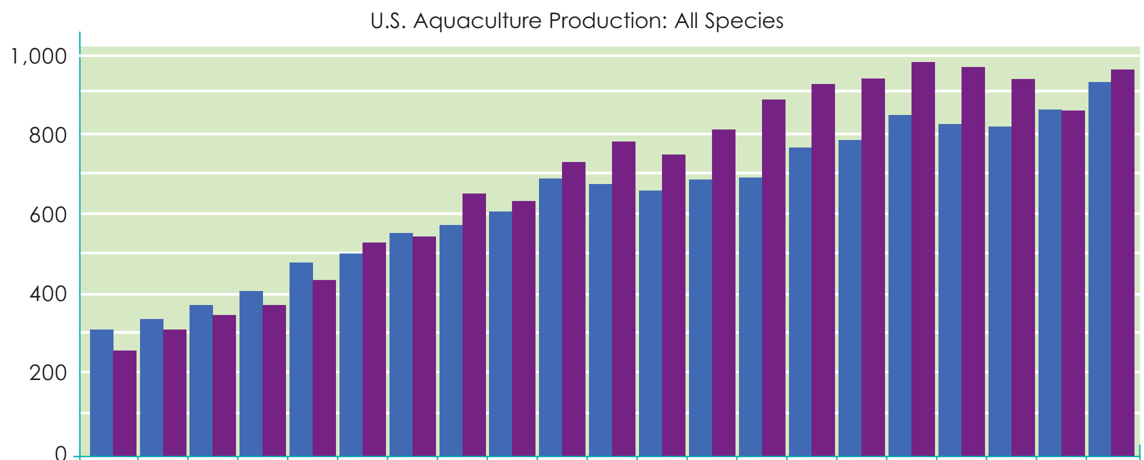
Status of Aquaculture in the United States

Production

The U.S. aquaculture industry produces a wide range of organisms, although it produces less than one percent of worldwide supplies. Perhaps more importantly, domestic aquaculture produces only a small portion of the domestic seafood supply. According to

FIGURE 2-1.

U.S. aquaculture production (millions of pounds and millions of dollars) (Data from NMFS 2005)

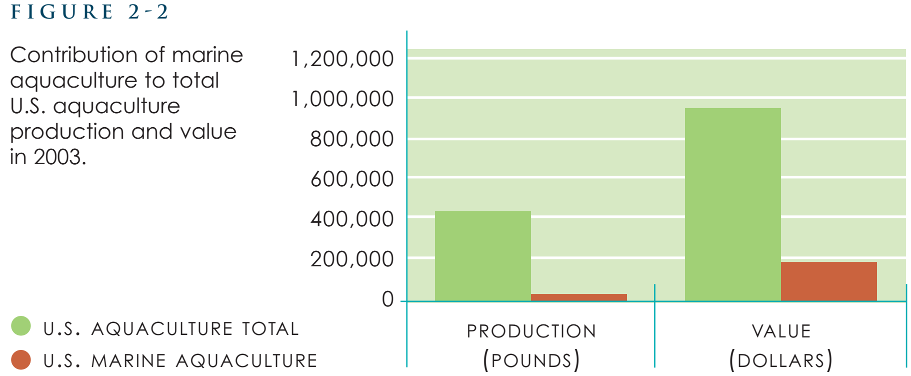


YEARS	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03
POUNDS	308	336	376	409	484	500	548	573	604	691	679	666	690	694	767	790	842	823	819	867	926
VALUE	259	307	348	372	437	520	540	655	636	724	782	751	806	886	910	939	987	973	935	866	961

National Marine Fisheries Service data, total U.S. aquaculture production in 2003 was over 420,000 mt (926 million pounds) with a value of nearly $961 million (Figure 2-1).[3] Sales of U.S. aquaculture products in 2005 are estimated to have exceeded $1 billion (USDA 2006). These figures represent significant growth over the past 20 years. In 2003 marine species made up less than 10 percent of total aquaculture production, but because some marine species are high in value, contribution to total aquaculture value was about 20 percent (Figure 2-2).

FIGURE 2-2

Contribution of marine aquaculture to total U.S. aquaculture production and value in 2003.



Currently, the U.S. aquaculture industry is dominated by catfish production (Table 2-2). Catfish production in 2003 was over 300,000 mt (661 million pounds), or over 71 percent of the total U.S. production, and was valued at $384 million, or about 40 percent of the total value. Several other freshwater species make up large portions of domestic aquaculture production, including: crawfish (33,498 mt, 74 million pounds), trout (23,005 mt, 51 million pounds), and tilapia (9,000 mt, 20 million pounds). Southern states with well-developed catfish industries, such as Mississippi, Arkansas, and Alabama, are leaders in terms of aquaculture production. Several coastal states with well-developed marine aquaculture industries, however, rank high in the value of aquaculture products. Maine, which leads the nation

[3] FAO reports 2004 U.S. production of 607,000 mt (FAO 2006), which seems at odds with the 2003 NMFS figure. Differences in the number of taxa included and the way product weight is recorded may account for this discrepancy. In this section we have relied on NMFS data because they provide an internally consistent time series of data on U.S. aquaculture production.

TABLE 2-2

U.S. aquaculture production and value data for 2003 (from NMFS 2005)

Species (marine species in bold)	Metric tons	Thousand pounds	Thousand dollars
Catfish	300,056	661,504	384,305
Crawfish	33,498	73,851	48,515
Trout	23,005	50,716	55,361
Salmon	**16,315**	**35,967**	**54,706**
Oysters	**9,272**	**20,440**	**63,574**
Tilapia	9,000	19,841	37,699
Baitfish	6,329	13,954	45,790
Striped bass	5,192	11,447	30,423
Clams	**4,894**	**10,790**	**53,966**
Shrimp	**4,627**	**10,200**	**19,891**
Mussels	**293**	**645**	**3,521**
Miscellaneous (includes ornamental fish and other high-value products)	7,688	16,949	163,222
Total	**420,169**	**926,304**	**960,973**

in farmed salmon production, and Washington state, which has well-developed salmon farming and shellfish farming industries, are leaders in marine aquaculture production (USDA 1998).

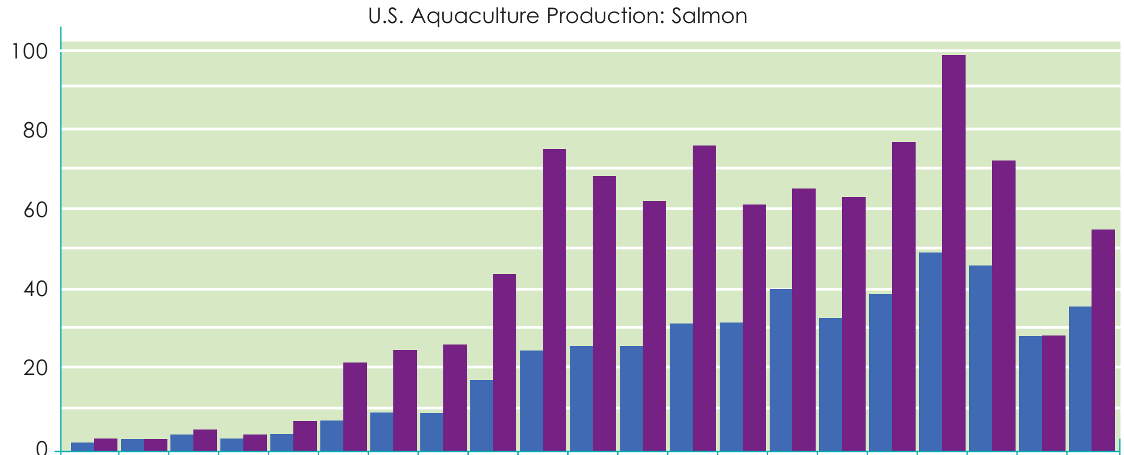
Marine aquaculture production in the U.S. is primarily comprised of just four taxa:

- Atlantic salmon – Salmon farming, which is practiced only in the states of Maine and Washington, grew rapidly in the 1990s and peaked in production (22,395 mt, 49 million pounds) and value ($99 million) in 2000 (Figure 2-3). Since then, production has declined, possibly as a result of setbacks to the industry, including adverse court rulings, diseases, and competition from imports. After dipping to very low levels in 2002, production rebounded in 2003 to 16,315 mt (36 million pounds) of salmon with a value over $54 million. Recently released USDA data show 2005 sales of 20.7 million pounds of farmed salmon valued at $37.4 million (USDA 2006).
- Oysters – The farming of oysters is a long-established industry in coastal states. For the past decade, U.S. farmed oyster production has remained around 8,000 to 9,000 mt (17.5 to 20 million pounds) per year after reaching a peak of about 12,700 mt (28 million pounds) in 1994 (Figure 2-4).[4] In 2003, over 9,200 mt (20 million pounds) of farmed oysters were harvested at a value of more than $63 million. Washington is the largest producer of farmed oysters, followed by Oregon, California, and Massachusetts. Several species of oysters are produced, but Pacific oysters, a nonnative species, are primarily farmed along the West Coast while native Atlantic oysters are the dominant species produced along the East Coast and Gulf of Mexico.
- Clams – Clam farming, while still a small industry compared to wild clam harvest, is an important segment of the U.S. aquaculture industry. In the mid-1990s U.S. clam production doubled from an average annual production of

[4] NMFS reports aquaculture production of mollusks as meat weight (exclusive of shell).

FIGURE 2-3

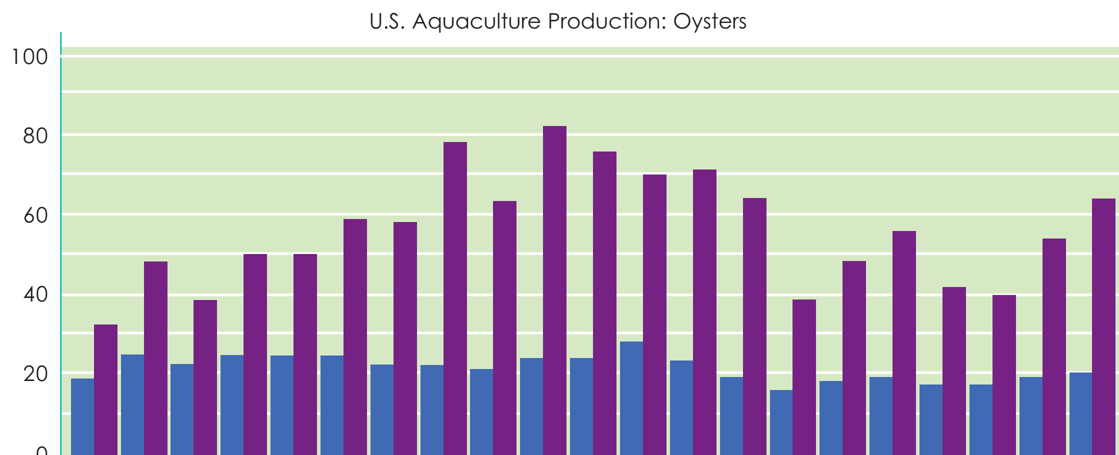
U.S. aquaculture production of salmon (millions of pounds and millions of dollars) (data from NMFS 2005)



YEARS	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03
POUNDS	2	3	4	3	4	7	9	9	17	24	25	25	31	31	40	32	39	49	46	28	36
VALUE	3	3	5	4	7	21	24	26	44	75	68	62	76	61	65	63	77	99	72	28	55

FIGURE 2-4

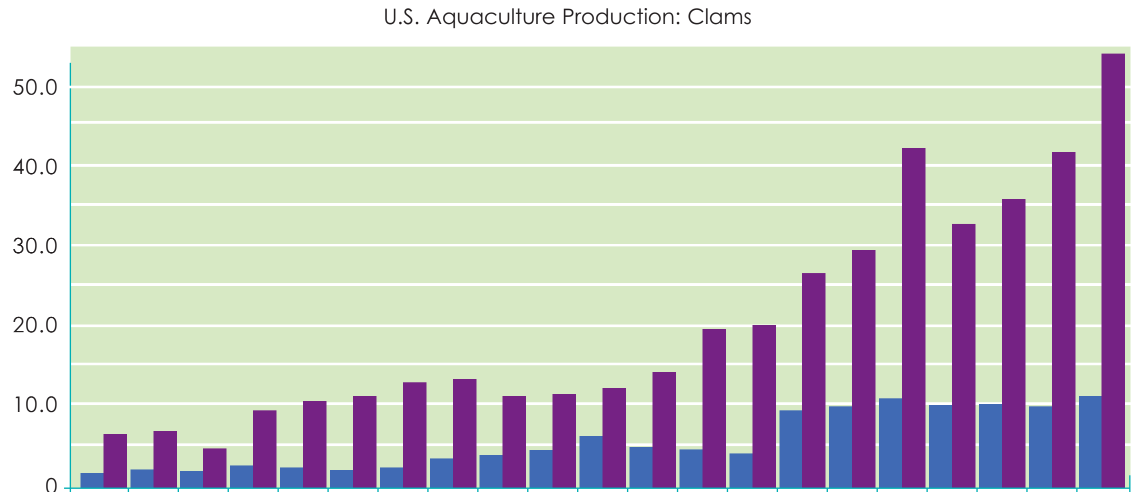
U.S. aquaculture production of oysters (Meat weight in millions of pounds and value in millions of dollars) (data from NMFS 2005)



YEARS	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03
POUNDS	19	25	22	24	24	24	22	22	21	24	24	28	23	19	16	18	19	17	17	19	20
VALUE	32	48	39	50	50	59	58	78	63	82	76	70	71	64	39	48	56	42	40	54	64

FIGURE 2-5

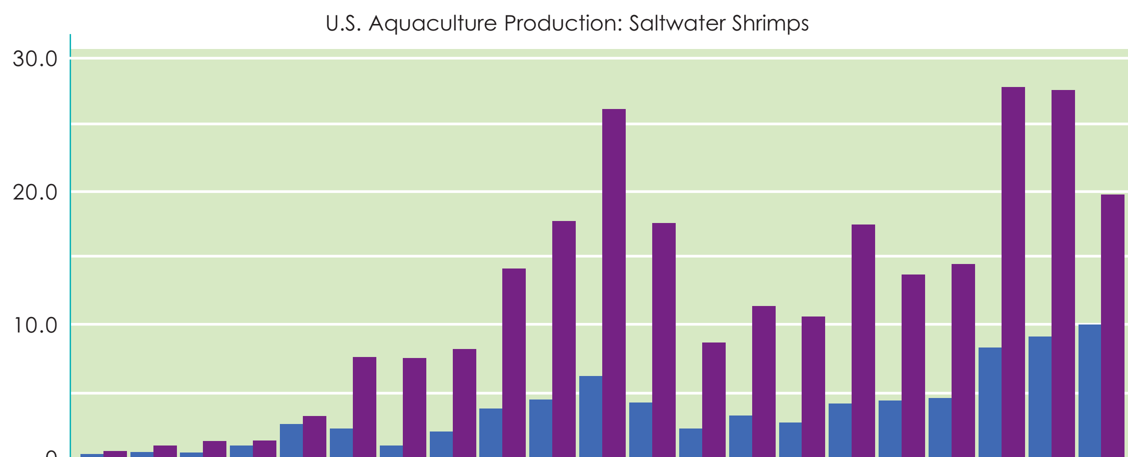
U.S. aquaculture production of clams (meat weight in millions of pounds and value in millions of dollars) (data from NMFS 2005)



YEARS	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03
POUNDS	1.7	2.1	2.0	2.6	2.4	2.1	2.4	3.7	3.8	4.3	6.1	4.9	4.3	3.8	9.2	9.7	10.7	9.9	10.0	9.9	10.8
VALUE	6.4	6.7	4.7	8.2	10.3	11.3	12.7	13.5	11.1	11.5	12.1	14.0	19.7	20.3	26.8	29.6	42.1	32.6	35.4	41.8	54.0

FIGURE 2-6

U.S. aquaculture production of saltwater shrimp (millions of pounds and millions of dollars) (data from NMFS 2005)



YEARS	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03
POUNDS	0.3	0.5	0.4	1.4	2.7	2.2	1.5	2.0	3.5	4.4	6.6	4.4	2.2	2.9	2.6	4.4	4.6	4.8	8.0	9.0	10.0
VALUE	0.5	0.9	1.6	1.7	3.4	7.6	7.6	7.9	14.1	17.6	26.5	17.6	8.8	11.5	10.6	17.6	13.7	14.6	27.8	27.6	19.9

about 2,200 mt (5 million pounds) to close to 4,500 mt (10 million pounds), where it has remained relatively constant (Figure 2-5). In 2003, nearly 5,000 mt (11 million pounds) of farmed clams were harvested with a value of nearly $54 million. The states of Florida, Virginia, and Washington lead the U.S. in farmed clam production.

- Shrimp – U.S. shrimp aquaculture production has steadily increased in the last decade, but value fluctuated (Figure 2-6). In 2003, shrimp farmers produced slightly more than 4,600 mt (10 million pounds) of shrimp with a value of nearly $20 million. About 75 percent of U.S. farmed shrimp are produced in ponds along the coast of Texas. Hawaii, the second largest farmed shrimp producer accounted for about 20 percent of the total U.S. production in 1998. U.S. aquaculture production of shrimp pales in comparison to shrimp imports, which in 2004 exceeded 502,722 mt (1.1 billion pounds) and were valued at $3.7 billion.

Several other marine species also are produced, including mussels, abalone, cobia, and moi, but at relatively low levels. Additionally, research is under way to explore the ability to, and profitability of, producing many additional species through aquaculture. Species that may be farmed in the U.S. on a commercial scale in the near future include halibut, cod, flounder, sablefish, tuna, and snapper. Several of these species have been suggested as candidates for offshore aquaculture.

Facilities and Culture Practices

There are over 4,000 aquaculture facilities in the United States, primarily dominated by catfish farms in the southern states (USDA 1998). Consistent with the general trend in livestock operations, there has been increased concentration in the aquaculture industry in recent years (USDA 2000). In 1998, 5 percent of the farms accounted for over 60 percent of the total U.S. aquaculture sales, indicating a high level of concentration similar to other livestock industries. The salmon farming industry in particular is controlled by a few large multinational companies. These same companies would likely also lead the industry as it diversifies to include other species, such as cod, halibut, and tuna.

A wide variety of production facilities are used by the U.S. aquaculture industry, including:

Ponds – Worldwide, ponds, which can be either natural or man-made, are the most popular type of aquaculture system. In the U.S., inland ponds are used to farm freshwater fish, such as catfish and hybrid striped bass, and coastal ponds are used for shrimp production. Pond aquaculture production practices vary widely, primarily depending on the species farmed.

Closed/recirculating systems – Land-based systems, usually referred to as closed or recirculating systems are primarily used to grow freshwater fish such as tilapia and hybrid striped bass. They are often used for the hatchery stage for many aquaculture species. Currently, researchers are developing recirculating systems for marine species as well. These systems generally consist of tanks to hold the fish and a series of filters that continuously clean water that circulates through the system. Recirculating systems have a high degree of control over waste discharges and they

Catfish farm ponds in Alabama. Native channel catfish comprise more than two thirds of U.S. aquaculture production by volume.

Photo: istockphoto

can be integrated with other forms of agriculture. For example, plants can be used to filter nutrients out of the water before it is recycled back into the system. High startup and operational costs have limited the extent to which these systems have been used.

Flow-through – In the U.S., the trout farming industry almost exclusively uses flow-through systems. These systems, which consist of concrete or earthen raceways, are land based, but water is not reused to the extent that it is in recirculating systems. There is less control over discharges with flow-through systems, though waste discharges can be treated to varying degrees. While flow-through systems are used primarily to farm freshwater fish, there is potential to use them to grow marine fish. For example, in Europe, some species of marine fish are farmed in land-based systems that pump water out of the ocean, run it through tanks holding the fish, and then discharge the water back to the ocean.

Net pens/cages – Worldwide, many different species of fish are farmed in net pens and cages. In the U.S., net pens are used by the salmon farming industry. Submerged cage systems are used to raise some relatively new aquaculture species such as moi, cobia, amberjack, and cod. Both of these systems consist of a mesh enclosure, which is designed to keep fish in but allow water to flow through, taking wastes away and providing a constant flow of clean water. Net pens are limited to the water surface but sea cages can be submerged in the water column. Researchers are currently working on techniques and systems to improve net pen and cage aquaculture, such as improved mooring systems and automated feeding systems. There is also interest in developing techniques to use decommissioned oil platforms to support cage aquaculture systems.

Mollusk culture – A wide variety of culture methods is used to farm mollusks, such as oysters, clams, and mussels. Techniques can be generally divided into two groups—on bottom and off bottom. On-bottom aquaculture involves the seeding of mollusks, usually oysters or clams, in nursery and growout areas where they can be protected from predators and allowed to mature. When the mollusks reach the desired size they can be harvested. Off-bottom culture involves suspending mollusks in the water column, either in enclosures, such as cages, nets, or bags, or attached to ropes.

Non-Food Production Segments of Marine Aquaculture

In addition to the food fish production that has been described, the aquaculture industry in the U.S. includes several other segments, including restoration programs and the production of ornamental fish. Aquaculture can play an important role in restoration efforts for marine fish species, especially those that have declined from overfishing and habitat destruction. While it does not address the root causes of the decline of wild stocks, aquaculture can assist in restoration efforts by supplying hatchery-raised individuals to supplement wild populations. Efforts to restore endangered stocks of salmon rely heavily on hatchery programs, although these programs have been costly, controversial and have met with only mixed success. Aquaculture has been an important part of the restoration efforts for many other species of finfish and shellfish, such as striped bass, sturgeon, and oysters.

Ornamental fish production is another important aspect of aquaculture in the U.S. Collection of live fish from the wild for the aquarium trade has caused widespread damage to coral reef ecosystems, particularly in Southeast Asia. The ornamental aquaculture industry provides alternatives to wild-caught tropical fish. In Florida, which currently dominates the domestic industry, about 200 producers raise over 800 varieties of freshwater fish using ponds and indoor closed systems (USDA 1998). The development of marine ornamental fish aquaculture is an area of much research interest. Techniques for farming seahorses, ornamental shrimp, and a wide variety of coral reef fish are under development and should offer a potentially lucrative and more environmentally sound alternative to wild-caught marine aquarium species in the near future.

Looking Toward the Future

While marine aquaculture currently makes up a small portion of the total U.S. aquaculture production, there are government and industry initiatives to increase marine production in the coming years. For example, the Department of Commerce adopted as part of its aquaculture policy the goal of increasing the value of domestic aquaculture production from the present $900 million annually to $5 billion by 2025. Seemingly little progress has been made in implementing this policy since its adoption. With the recent introduction of legislation it has become clear that the government is interested in expanding aquaculture production to include federal marine waters.

What is not clear, however, is whether the technology is in place or whether the economics will make it feasible for the industry to venture to offshore waters. For example, the Task Force's discussions with marine engineers indicate that sea cages become prohibitively expensive to deploy and maintain in water depths greater than 200 meters. Research continues, however, on single-point moorings for sea cages, advanced free-floating cage designs, and other innovations that could overcome this obstacle. Rising prices for fuel and for fishmeal and fish oil pose additional economic and research challenges for the industry. As has been the case with offshore energy development, improvements in both technology and the profitability of marine aquaculture will likely be required to make true deepwater deployment a sound business model.

A likely trend in future marine aquaculture, whether it is in nearshore or offshore waters, will be diversification in cultured species. Salmon may continue to play a major role in the aquaculture industry, but there is great interest in developing the techniques and knowledge needed to commercially grow other species, primarily finfish. Research is already underway on several marine finfish species, including: cod, halibut, cobia, snapper, pompano, and tuna. Successful shellfish producing companies have realized the value of species diversification as well. In the Pacific Northwest there has been considerable effort to culture the giant geoduck clam in recent years.

As has been the case with other forms of agriculture, as marine aquaculture expands it is likely to become more consolidated and automated. The economic pressures for automation and consolidation are especially great for offshore aquaculture because the energy and labor costs associated with feeding and facility maintenance increase with distance from shore.

While some forms of aquaculture, salmon farming for example, have experienced consolidation and offshore investment, mollusk culture has been much less affected by these trends. Much of the domestic shellfish industry is made up of smaller, family-run, labor-intensive operations providing considerable rural employment. Small-scale producers can find it difficult to compete with large corporations and the need to reduce labor costs, usually the second highest operating cost behind feeds, often leads to increased automation. Research into automation is already taking place as computer-operated cages and feeding systems are under development. Mollusk culture has made some strides in automating processing in particular. Shellfish culture, however, remains labor intensive, providing considerable employment in rural coastal economies. Formerly a local or regional product, farmed shellfish

As has been the case with offshore energy development, improvements in both technology and the profitability of marine aquaculture will likely be required to make true deepwater deployment a sound business model.

products are increasingly marketed nationally and internationally, bringing outside dollars in to fuel local economies.

A large question looming as we begin to farm the sea is how will it transform coastal communities? Fitting into coastal communities will be a major challenge for the marine aquaculture industry as it expands into new areas and interacts with a variety of stakeholders. Coastal communities in many areas suitable for aquaculture have traditionally depended on fisheries and have, in recent decades, increasingly depended on tourism. The jobs and revenue that aquaculture brings have been welcomed in some coastal communities, including some hit hard by the decline of wild fisheries. Others, however, have rejected aquaculture development. By its nature, aquaculture requires dedicated space for pens, cages, rafts, or tanks. These uses can compete for space with other uses such as recreational boating and commercial and recreational fishing. These same floating structures when located in nearshore areas with developed shorelines also raise visual impact concerns. The subjective nature of these aesthetic impacts makes them challenging to resolve. Moreover, coastal communities will bear the brunt of any ecosystem damage resulting from marine aquaculture. Some of the most dramatic impacts of aquaculture on commercial fishermen may be in the marketplace, as large-scale production of seafood by aquaculture, regardless of where it is produced, creates competition with fisheries products. Such competition in salmon markets led to lower prices for consumers, but also to depressed wholesale prices overall making it harder for traditional fishermen to make ends meet.

Realizing the promise of the blue revolution and developing truly sustainable marine aquaculture will depend on addressing both the environmental effects of marine aquaculture—the issues on which this report focuses primarily—but also on addressing its social and economic effects.

CHAPTER 3

GOVERNANCE

Introduction

Addressing the effects of aquaculture on the marine environment requires specific measures to address specific concerns, such as escapes, disease, or water pollution. It also will require changes to the broader framework of laws, institutions, and policies that dictate how aquaculture is sited, permitted, and operated in marine waters of the United States. This will be particularly true if aquaculture in the United States moves increasingly offshore into marine waters under federal jurisdiction. The need for a coherent governance structure for marine aquaculture has been noted by numerous studies and reports (NRC 1992, Pew Oceans Commission 2003, U.S. Commission on Ocean Policy 2004, Cicin-Sain et al. 2005).

The U.S. Commission on Ocean Policy and the Pew Oceans Commission both recommended managing our oceans on an ecosystem basis and the application of a precautionary approach when making resource use and management decisions. If marine aquaculture is to develop and expand in an environmentally sustainable manner, it must be integrated into precautionary, ecosystem-based management in state and federal waters. Managed appropriately, aquaculture can contribute positively to ecosystem-based management. Managed poorly, aquaculture can harm water quality, fish populations, and marine wildlife.

The current legal regime for marine aquaculture does not provide for clear federal leadership. Numerous agencies have responsibility for aspects of aquaculture regulation, but currently no agency is charged to coordinate the overall process. Not only does this create a confusing and cumbersome process for those seeking permits for aquaculture, but it results in a lack of accountability among the federal agencies for marine aquaculture activities and its impacts on the marine environment. As a result, greater authority requires greater responsibility on the part of the lead agency. This is best facilitated by a strong signal from Congress that marine aquaculture will not be promoted at the expense of the health of the marine environment.

In this chapter, the current governance framework for marine aquaculture is explored. We look at how aquaculture is regulated at the federal level and in several states, and examine the environmental track record of these approaches. We also examine the legislation pending before Congress to authorize aquaculture in waters under federal jurisdiction. A thorough review of aquaculture governance was done by Cicin-Sain et al. (2001, 2005). The purpose is not to re-examine their work, but to build on it to make the case for substantial

Managed appropriately, aquaculture can contribute positively to ecosystem-based management. Managed poorly, aquaculture can harm water quality, fish populations, and marine wildlife.

Task Force members and staff deliberate at the Oceanic Institute, Waimanalo, Hawai'i.

reform of aquaculture law and policy at the federal level, which will lay the groundwork for effective environmental protection as aquaculture grows and expands in U.S. marine waters. Provided with the appropriate legal authority, financial and technical resources, and a clear legal mandate, government agencies with responsibility for marine aquaculture can make decisions regarding its future development that protect the integrity of marine ecosystems, reduce conflicts with other users of marine resources, and ensure that the use of ocean space and resources is in the long-term public interest.

The Federal Role in Marine Aquaculture

A number of federal laws affect marine aquaculture, but none was really crafted with the regulation of marine aquaculture in mind. In several cases, an individual law may require actions by more than one federal agency. The major federal statutes addressing environmental aspects of marine aquaculture are summarized in Table 3-1.

The National Aquaculture Act of 1980 established a national policy to encourage development of aquaculture in the United States. It required the creation of a National Aquaculture Development Plan, established an interagency body—the Joint Subcommittee on Aquaculture—to increase the effectiveness of federal aquaculture programs, and created a national information center to provide a clearinghouse for the collection and dissemination of aquaculture research and development information. The National Aquaculture Act functions as a promotional and coordinating instrument. It does not establish regulatory requirements for the industry.

The Clean Water Act (CWA) is arguably the major federal law regulating environmental aspects of marine aquaculture, yet it is limited to controlling water pollution. Its role in addressing the effects of aquaculture on the marine environment is discussed in detail in Chapter 6. Under the Clean Water Act, most net pen or sea cage aquaculture facilities require a permit to discharge pollutants into U.S. waters. Operations growing molluscan shellfish that do not add feed to the water are not required to obtain a permit.

The Magnuson-Stevens Fishery Conservation and Management Act is the fundamental statute regulating fisheries in federal marine waters. The act defines "fishing" to include landing or possession of fish species managed under the processes established by the Act regardless of whether they are wild caught or harvested from a net pen. As a result, fishery management plans must be amended to allow for the commercial culture of managed species. Although this appears to be an unintended consequence of the particular wording of the Act, current law nonetheless gives the National Oceanic and Atmospheric Administration (NOAA) and the regional fishery management councils established by the Act authority over marine aquaculture unless the species cultivated is not covered by a fishery management plan.

To date, the regional fishery management councils have taken limited action with respect to marine aquaculture (GMFMC 2005). The Gulf of Mexico Fishery Management Council issued a special permit for an experimental aquaculture facility adjacent to an oil and gas platform in 1997. In 2005, it proposed amendments to fishery management plans to allow for the potential commercial culture for species under its purview. In 1996, the New England Fishery Management Council amended a fishery management plan to allow for the closure of a nine square mile area off Massachusetts for the culture of sea scallops on the ocean floor.

The Endangered Species Act (ESA) requires federal agencies to consult with NOAA or the U.S. Fish and Wildlife Service, depending on the species involved, regarding agency actions that might jeopardize an endangered species. Private citizens wishing

TABLE 3-1

Major Federal Statutes Affecting Marine Aquaculture.

Statute	Primary Agency	Description/Key Provisions
National Aquaculture Act (16 U.S.C. 2801 et seq.)	U.S. Department of Agriculture	—Establishes a national aquaculture development plan —Requires federal coordination of aquaculture activities.
Clean Water Act (33 U.S.C. 1251 et seq.)	Environmental Protection Agency (EPA)	—Pollution discharge (NPDES) permits (33. U.S.C. 1342) —Ocean discharge criteria (33. U.S.C. 1343)
	U.S. Army Corps of Engineers (COE)	—Placing fill material in navigable waters of the United States (33 U.S.C. 404)
Federal Insecticide, Fungicide and Rodenticide Act (7 U.S.C. 136 et seq.)	EPA	Regulates use of pesticides
Rivers and Harbors Act of 1899 (ch. 425, 30 Stat. 1121)	COE	Siting of structures in navigable waters (33 U.S.C. 403)
Marine Protection, Research and Sanctuaries Act (33 U.S.C. 1401 et seq.)	COE	Disposal of dredged material at sea (33. U.S.C. 1431)
The Migratory Bird Treaty Act (16 U.S.C. 703 et seq.)	U.S. Fish and Wildlife Service (FWS)	—Protects migratory birds —Requires permits for take of protected species
Endangered Species Act (16 U.S.C. 1531 et seq.)	National Oceanic and Atmospheric Administration (NOAA) and FWS	Protects federally listed species and their habitat
Marine Mammal Protection Act (16 U.S.C. 1361 et seq.)	NOAA and FWS	Protects marine mammals
Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. 1801 et seq.)	NOAA	Manages harvest and possession of marine fish in federal waters
Food, Drug and Cosmetic Act (21 U.S.C. 301 et seq.)	Food and Drug Administration	Animal drug approval and regulation (including GMO approval)
Energy Policy Act of 2005	Minerals Management Service, Department of the Interior	Approve use of offshore areas for aquaculture under the procedures of the Outer Continental Shelf Lands Act
Coastal Zone Management Act of 1972 (16 U.S.C. 1451 et seq.)	NOAA	Requires federal activities (including permits) to be consistent with state coastal management plans

to take actions that might harm an endangered species must get an incidental take permit from the appropriate federal agency and develop a plan to minimize the harm to the species involved. The Marine Mammal Protection Act establishes review and approval responsibility for NOAA and the Fish and Wildlife Service regarding activities that may result in the killing, injury or harassment of marine mammals. For both of these laws, whether consultation is with the Fish and Wildlife Service or NOAA depends on the endangered species or marine mammal involved. Should Congress give NOAA substantial permitting authority for marine aquaculture, as has been requested by the Administration, it will be a significant political, legal, and administrative challenge for the agency to carry out its new duties while upholding its numerous conservation responsibilities under existing law. Congress will need to provide careful guidance to NOAA so that new responsibilities do not undermine longstanding conservation mandates.

Net pens or sea cages are potential hazards to navigation and hence fall under the purview of the U.S. Army Corps of Engineers (COE) in its responsibility to administer the Rivers and Harbors Act of 1899. Under this act, the COE must conduct a public interest review and provide a permit under section 10 of the Act for hazards to navigation in U.S. waters. Although the COE typically considers environmental effects in its review and must also comply with the National Environmental Policy Act by considering environmental impacts of granting the permit, it has broad discretion and little specific direction from Congress regarding how to address environmental impacts. Under current law, the section 10 permit amounts to a siting permit for marine aquaculture facilities. Siting is an important determinant of the environmental impacts of marine aquaculture (Box 3-1).

A provision of the Energy Policy Act of 2005 authorizes the Secretary of the Interior to grant a lease, easement, or right of way under the Outer Continental Shelf Lands Act for use of offshore areas if activities undertaken in those areas support energy-related purposes or "other authorized marine-related purposes." It is not clear exactly what was meant by "other authorized marine-related purposes," but it could include federal leases for aquaculture if those activities were considered to be authorized by law.

The Coastal Zone Management Act (CZMA) provides a tool the states can use to ensure that federal activities are not in conflict with state efforts to manage coastal areas and resources. The CZMA requires federal activities, including issuing a permit for private activities, within or affecting the coastal zone of a state to be consistent "to the maximum extent practicable" with enforceable policies of a state's coastal zone management plan. Activities affecting a state's coastal zone must be evaluated for consistency with the state plan and a state may dispute the so-called consistency determination. If necessary, disputes among permit applicants, permitting agencies, and a state or states can be adjudicated by the Secretary of Commerce. In practice, however, most consistency issues are resolved by modifications to the proposed permit or activity.

A state's coastal zone management plan is a comprehensive plan for managing coastal resources and the human activities that affect them in state marine waters as well as coastal land areas specified by the state. Congress envisioned aquaculture as part of state coastal zone planning by authorizing special funding to encourage states to improve their federally approved coastal plans in one or more of nine specific areas. One of these is to "enhance existing procedures and planning processes for siting marine aquaculture facilities while maintaining current levels of coastal resource protection."

BOX. 3-1

The Importance of Siting

Location, location, location—so goes the old real estate maxim. It turns out that the same is true for marine aquaculture. Time and again, as the Task Force has examined the environmental effects of marine aquaculture, siting has emerged as at least part of the solution to adverse impacts. The location of a marine aquaculture facility can make the difference between an operation that is opposed by the local community, fails economically and/or causes severe environmental impacts and one that is sustainable—economically, environmentally and socially. Although good siting is not a substitute for good management and appropriate regulation, it is clearly a key component of environmentally sound marine aquaculture.

For marine aquaculture to develop in a sustainable manner it is clear that criteria and guidelines are needed for where to proceed with aquaculture development and, possibly more importantly, where not to move forward. Whether this occurs as a part of broader regional efforts to manage ocean uses on an ecosystem basis, as has been called for by the U.S. Commission on Ocean Policy and the Pew Oceans Commission, or for aquaculture on its own, developing criteria to guide siting and density of aquaculture facilities will be crucial in avoiding environmental damage and user conflicts. At the very least, siting criteria for marine aquaculture should consider:

- Potential conflicts with other commercial and recreational uses of the oceans;
- The ability of the area to disperse and/or assimilate nutrients and other waste inputs, from single farms as well as on a cumulative basis;
- The proximity of sensitive habitats;
- The potential for escaped organisms to interact with wild populations;
- Risks of diseases spreading among farms, and from farms to wild populations; and
- Interactions with wildlife.

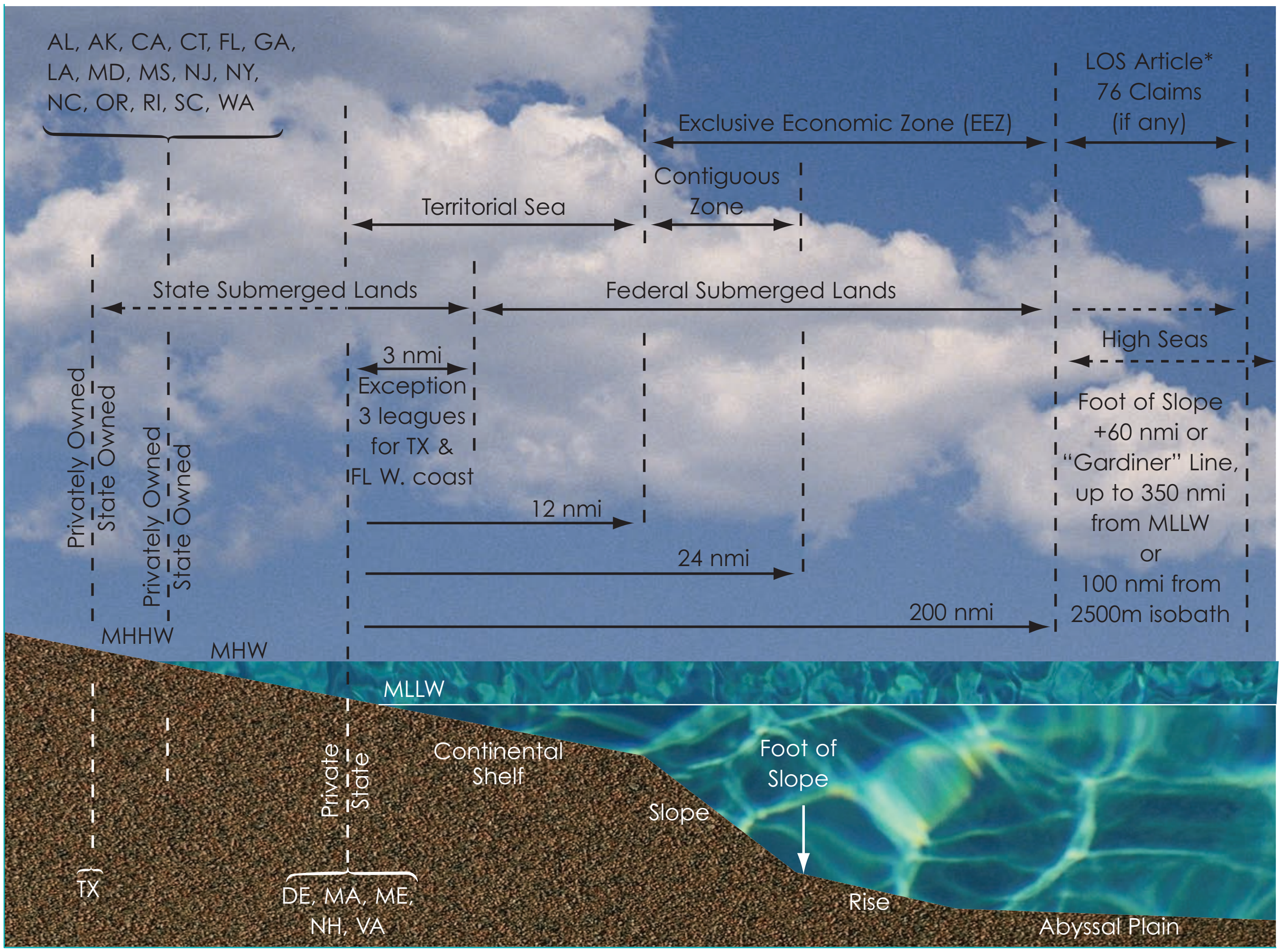
Jurisdiction Over Ocean Space and Resources: Legal and Political Considerations

Legal jurisdiction over ocean space and resources is fragmented and does not correspond to marine ecosystem boundaries (Pew Oceans Commission 2003, U.S. Commission on Ocean Policy 2004) (Figure 3-1). The Submerged Lands Act of 1953 conveyed authority over submerged lands and ocean waters from the shoreline out three nautical miles for most states.[5] Important exceptions are Texas and Florida, which, under the terms of their statehood, retained jurisdiction over marine waters and resources to nine miles offshore in the Gulf of Mexico. Florida's jurisdiction on its Atlantic coast extends the standard three miles offshore. The United States exerts territorial sovereignty over marine waters from 3 to 12 miles offshore, and it exerts economic and environmental jurisdiction over marine resources at least 200 miles offshore. This latter area is referred to as the Exclusive Economic Zone (EEZ), consistent with the United Nations Convention on the Law of the Sea. To avoid confusion, in this report the term marine aquaculture refers to aquaculture in salt water regardless of jurisdiction. Where we wish to distinguish between federal and state jurisdiction, we will refer to aquaculture in federal or state marine waters, respectively.

The practical implications of the jurisdictional map are that the oceans are legally divided into an inshore and an offshore region, the latter falling under the control of the federal government and the former falling mostly under the control of the states. To develop an integrated policy for managing the environmental risks from marine

[5] One nautical mile equals 1.15 statute miles. As used in this report, miles means nautical miles unless otherwise indicated.

FIGURE 3-1
Jurisdiction over ocean space.



MHHW – mean higher high water **MHW** – mean high water **MLLW** – mean lower low water
nmi – nautical mile = 1.15 statute miles
*The U.N. Convention on the Law of the Sea allows nations to claim jurisdiction beyond 200 nmi in certain cases.

aquaculture will require coordination among the various federal agencies involved, as well as coordination among the federal government, coastal states, and Indian tribes.

Concern over states rights and interests has caused some stakeholders to propose that the regional fishery management councils established under the Magnuson-Stevens Act should retain authority over aquaculture in federal marine waters. Although management of aquaculture in federal waters by the regional councils would ensure coordination of aquaculture and fisheries policies, many in the wild-catch fisheries community are opposed to marine aquaculture. If granted management authority over marine aquaculture, the regional councils might simply squelch it, at least for the time being. Substantial reforms enacted in 1996 and additional reforms currently under consideration in Congress offer the hope that federal fisheries management will be better grounded in scientific and ecological principles in the future. As the councils struggle to implement these reforms it seems imprudent to add responsibility for management of marine aquaculture to their duties. Nonetheless, marine aquaculture policy should be closely coordinated with fishery management to ensure that marine aquaculture activities do not undermine conservation efforts for wild fish stocks and marine ecosystems, and so that the benefits of aquaculture for wild stock restoration and enhancement can be maximized.

The consistency provisions of the Coastal Zone Management Act provide states with another tool to ensure coordination of state and federal aquaculture policy. If the states are to use this tool effectively, however, it will be essential for them to ensure that policies relating to aquaculture, water quality, fisheries management, invasive species, and other policies related to the potential environmental impacts of marine aquaculture are fully integrated into their coastal zone management plans. The State of Florida, for example, has a broad coastal plan incorporating more than 20 state laws, which it believes will provide a strong basis for ensuring the consistency of any marine aquaculture development that may occur in adjacent federal waters.

State Management of Marine Aquaculture

At present all commercial marine aquaculture in the United States occurs in waters under the primary jurisdiction of the states. The Department of Commerce is encouraging a substantial expansion of aquaculture into federal marine waters, but economics, engineering, and logistics are significant constraints on the pace and scope of that development. Without substantial subsidy, most aquaculture in U.S. marine waters will continue to be in state waters for some time to come. To assess the environmental impact of marine aquaculture in the U.S., it is essential to understand how it is being regulated by the states, and what the environmental results of that regulation have been. During its regional meetings, the Task Force learned as much as it could about how marine aquaculture was managed in the states we visited. Snapshots of four of these regulatory programs are presented below. This is not intended to serve as an exhaustive survey, but we hope it will provide an overview of some of the different approaches that have been used.

Alaska: Aquaculture for Wild Stock Enhancement and Shellfish Production

In 1990, Alaska enacted a ban on finfish aquaculture in state waters. The ban was enacted to protect Alaska's wild fisheries and aquatic ecosystems from any harmful effects of finfish aquaculture. Whether the motivation was primarily economic or environmental is the subject of considerable debate, and the truth most likely resides somewhere in between. Whatever the motivations, the state ban has not stopped the dramatic expansion of marine fish farming—mostly of nonnative Atlantic salmon—in British Columbia to the south. Nor did it shield the state's fisheries from the economic blow resulting from the massive increase in farmed salmon production worldwide in the 1990s.

Despite its antipathy to commercial finfish farming, the State of Alaska is not opposed to aquaculture. In fact, it fostered what may be the world's largest aquaculture program to produce juvenile salmon to supplement wild stocks. Natural salmon runs decreased substantially in the late 1960s, and starting in the early 1970s the state built a series of hatcheries concentrated in the central and southeastern parts of the state to produce smolt and fry of all salmon species, but mostly pink and chum salmon.

The early years of the program saw problems with siting, as well as production and genetics practices. In the modern program, however, the genetics of the hatchery fish are closely monitored and hatcheries have been sited to avoid competition with existing runs. All hatchery fish are marked and returns are monitored to gauge the relative health and contribution to catches of wild

> … marine aquaculture policy should be closely coordinated with fishery management to ensure that marine aquaculture activities do not undermine conservation efforts for wild fish stocks and marine ecosystems, and so that the benefits of aquaculture for wild stock restoration and enhancement can be maximized.

and hatchery stocks. The contribution of hatchery fish varies from year to year, but up to a third of the pink and chum salmon harvest is from hatchery-released fish. As a result, these hatcheries contribute substantially to the economy of coastal Alaska. Some hatcheries—those producing mainly sport fish—are still state financed, but most hatcheries now meet expenses through a self-imposed landings tax paid by fishermen and through the sale of fish that make it back to the hatchery. In recent years, it has become more challenging for hatcheries to make ends meet as low market prices for salmon—driven by competition from fish farms—have resulted in decreased revenue from landings and sale of hatchery returns. High salmon prices this year may slow or reverse this trend, at least for the short term.

Alaska also has a small but growing shellfish farming industry facilitated by state-sponsored shellfish hatcheries, which provide seed for commercial growers. It has a well-developed, community-based regulatory program for shellfish aquaculture, which is discussed in more detail in Chapter 4.

Hawaii: Offshore Leasing

The State of Hawaii leases submerged lands and overlying waters for the purpose of marine aquaculture under a system that emerged in its modern form through legislation enacted in 1999. Unlike most states, land-use zoning is administered primarily at the state level in Hawaii, and the marine leasing program is derived from this authority. The state has four land use zones: urban, agricultural, rural, and conservation. Zone 4, conservation, has four subzones: protected, limited, resource, and general. All 2.8 million acres of state marine waters are designated "resource", in which aquaculture can take place if a lease and conservation use permit are granted. Hawaii does not appear to have put any state waters, including areas within a national marine sanctuary, off limits to aquaculture a priori. This places heavy emphasis on a case-by-case evaluation of aquaculture permits and siting decisions.

With three offshore leases for 193 acres of submerged lands, Hawaii has a fledgling marine aquaculture industry. Because of the state's oceanography, facilities operating just a few hundred yards offshore may be operating in currents, wave exposure, water depth, and other parameters more indicative of oceanic than coastal conditions. Currently, one operator, Cates International, produced 300,000 lbs. (136.4 mt) of moi (Pacific threadfin) in submerged cages off Oahu. Moi production is projected to increase to 500,000 lbs. (227.3 mt) in 2006. A second operator, Kona Blue Farms, raises kahala (amberjack) in submerged sea cages 0.8 km off the island of Hawaii. Exact production figures are not available, but Kona Blue stocked 140,000 fish to date and harvested them at an average weight of 3.5 kg in 2005.

The permit applicant is responsible for site selection, although site suitability and other environmental issues are evaluated by the state through its environmental assessment process. An environmental assessment is conducted on a completed application and a determination is made whether to require an environmental impact statement (EIS). None of the currently permitted projects has required an EIS. To operate in Hawaii state waters, an applicant needs a submerged lands lease and a conservation district use permit, both administered by Department of Land and Natural Resources. Hawaii state law limits marine aquaculture to native species, and the applicant must file an emergency response plan, a business plan, and a facility management plan with the permit application. A public hearing is required at a venue near the proposed lease site before a use permit can be issued.

The state has broad discretion over the terms of the submerged lands lease. Although it can publicly auction lands available for leasing, the current aquaculture leases were granted directly under the state's discretion.

Of the current leases, only two have been assigned terms: one for a term of 15 years with an option to extend for 10 years and another for a term of 20 years. The state charges a fixed annual fee for the lease and has discretion to specify in the lease a charge of a percentage of gross revenues, although none of the current leases do so. Revenues from the leases go into a special fund for management of submerged lands. Additional lease provisions include:

- A requirement for a performance bond for removal of the facility at the end of the lease term;
- Stipulation that escapes from the facility become common property;
- Measures to be taken to eradicate escapes;
- A statement of the degree of exclusivity of the lease (i.e., the degree, if any, of public access to the lease site); and
- Restrictions on reassignment of the lease.

Public concern in Hawaii about marine aquaculture appears to have less to do with environmental impacts than with traditional and Common Law rights of access to fishing grounds. The superimposition of a modern property rights regime—the leasing of ocean space—on what had previously been either common property resources or rights-based fisheries derived from Hawaiian cultural traditions has raised sensitive issues regarding access and privilege. However, it appears that the current leaseholders have been able to address most of these concerns through negotiation and dialogue with stakeholders (Suryanata and Umemoto 2003).

Unpublished monitoring data indicate that current marine aquaculture activities in Hawaii are having no significant impact on water quality. Recently published research, described in more detail in Chapter 6, documents substantial changes to seafloor biology in the vicinity of one of these operations. It remains to be seen whether current levels of environmental impact, and the current level of comity in the leasing process, are maintained if marine aquaculture expands significantly in Hawaii.

Florida: Emphasizing Best Management Practices

Florida's marine aquaculture industry consists mainly of shellfish farming. Its aquaculture production ranks third in the nation in value. There are currently no finfish aquaculture facilities in marine waters of the state, although a few applications have been filed in the past but have been denied for various reasons. Because the continental shelf is so shallow along the Gulf Coast and because of the ever-present threat of hurricanes, conditions might not be conducive for cage culture of finfish in the state's Gulf waters. Nonetheless, Florida has taken a proactive approach in preparing for the possibility of finfish aquaculture in its marine waters. In response to requests from various stakeholders the state convened a working group in 2005 to develop best management practices (BMPs) for net pen aquaculture in state waters. Although the proposed BMPs have not been finalized, the thrust of these recommendations is clear.

Net pen operations in state marine waters must obtain:

- A state operational permit;
- A lease from the state for the aquaculture site; and
- A pollution discharge permit if the facility will produce more than 100,000 lbs. of live weight product annually.

The threshold for obtaining a pollution discharge permit corresponds with criteria established by EPA for such permits for aquaculture facilities, as described in detail in Chapter 6. Bivalve mollusks for human consumption can only be cultured within state-designated shellfish harvesting areas. Net pen operators who do not comply with lease terms and specified BMPs may have their lease or operating permit revoked and may be fined for violations. The proposed BMPs for net pen aquaculture will be administered by the State Department of Agriculture and Consumer Services. They will include criteria and procedures for site selection, feed management, solid waste management and disposal, escape management, facility operations and maintenance, fish health, and record keeping.

Although the proposed BMPs broadly cover the usual areas of environmental concern, they may lack adequate specificity to provide meaningful management should commercial marine finfish aquaculture occur in Florida. For example, the siting BMPs do not prohibit siting in marine protected areas or other sensitive habitats, establish buffer zones to protect fragile areas, or require the use of siting to mitigate user conflicts. Although broodstock must be collected in the same region as the proposed facility, cultured fish are not required to be marked or tagged in any way. The culture of genetically modified organisms (GMOs) is not restricted. However, anyone culturing fish in Florida waters will likely need a special activities license from the Florida Fish and Wildlife Conservation Commission, thus making the Commission's rule banning GMOs applicable to marine aquaculture. The Florida Fish and Wildlife Conservation Commission may impose additional requirements on net pen finfish farming under its authority to protect Florida fish and wildlife.

Maine: Lessons Learned

Maine leads the nation in marine aquaculture production. In 2004, aquaculture in the state produced nearly 19 million pounds of Atlantic salmon, 1 million pounds of blue mussels and between 300,000 and 500,000 pounds of oysters (DMR 2006). This harvest was produced on about 1,290 acres of leased submerged lands. Salmon farming in Maine began in earnest in the 1980s. Production peaked in 2000 at over 36 million pounds, but by 2003, a combination of market factors, litigation, and disease had reduced production to 13.2 million pounds. Aquaculture employment figures are not available for all sectors, but commercial salmon farming, hatcheries, and processing provided about 800 jobs in Maine in 1997 (Alden 1997).

Nearly all the controversy surrounding aquaculture in Maine has concerned salmon farms, which comprise 58 percent of the acreage leased for aquaculture and are concentrated in the state's two northernmost coastal counties. Industry critics have cited water pollution, esthetics, and the effect of salmon farming on endangered wild Atlantic salmon as major concerns.

Atlantic salmon runs have been on the decline in the northeastern United States since the 19th century and efforts to supplement natural reproduction with hatcheries began in the 1870s (NRC 2004a). Wild Atlantic salmon from the lower Kennebec River to the border with Canada (excluding the Penobscot River) were listed as a federal endangered species under the Endangered Species Act in November 2000. In 2002, it is estimated that less than 900 salmon returned to spawn in Maine rivers. The Dennys River empties into Cobscook Bay—one of the most concentrated areas of salmon farming in Maine. From 1993 to 2001, the percentage of escaped farmed fish in salmon runs on the Dennys River ranged from 44 to 100 percent (NRC 2004a). An outbreak of infectious salmon anemia (ISA) in Cobscook Bay forced the destruction of all farmed salmon in the bay in early 2002.

Litigation between public interest groups and salmon farm operators resulted in substantial changes in the industry and its regulation. The history of this litigation and its implications for environmental management of aquaculture are discussed in Chapter 6. One key change forced by the litigation is a prohibition on the use of European strain salmon for farming, as had been common practice previously. Maine salmon farming is nonetheless still concentrated in close proximity to endangered salmon runs. Growth in the industry has reportedly increased interactions with marine mammals, particularly seals, but seal populations continue to increase (DMR 2003). Improvements in feed formulation and feeding methods have reduced feed use and wastage per ton of fish produced.

Leasing and monitoring are overseen by the Maine Department of Marine Resources (DMR), which also manages marine fisheries and other marine resources. DMR emphasizes outcome-based standards instead of numeric "triggers" in an effort to provide flexibility to operators to determine how to achieve results. Water pollution from salmon farms is addressed in most areas through a general pollution discharge permit administered by the Maine Department of Environmental Protection (DEP). Maine DEP believes this approach is suitable for waters with a high assimilative capacity for water pollution relative to the level of anticipated discharges (DEP 2002). Farms in areas eligible to use this system are not required to obtain an individual pollution discharge permit but must comply with the terms of the general permit. The general permit does not specify numerical effluent limitations. It establishes broad conditions such as minimum current velocity for the farm site, no "significant degradation of water quality", and a requirement that discharges not result in violation of water quality standards more than 30 meters from the edge of the net pens.

In 1991, the Maine legislature established a mandatory finfish aquaculture monitoring program to provide for consistent and comprehensive monitoring of salmon and steelhead farming. Given the broad nature of the state's aquaculture permitting, monitoring becomes especially important. A review of the program in 2003 suggested changes to improve its ability to assess effects of marine aquaculture on the environment (DMR 2003). The review recommended clearer definition of the spatial and temporal extent over which water quality standards must be attained and development of methods to determine the carrying capacity of a water body for aquaculture. It urged examination of far-field pollution effects and better characterization of nutrient and organic inputs from aquaculture facilities. It recommended the use of quantitative measures of benthic effects and evaluation of numerical standards.

The Context for Federal Reform

A number of studies have found that federal agencies have "limited, and often unclear, statutory authority with respect to offshore aquaculture" (Cicin-Sain et al. 2001). With no clear, overarching authority, individual federal agencies are left to regulate particular aspects of aquaculture operations, such as discharge of pollutants, hazards to navigation, and impacts on marine fish and wildlife. The resulting "regulatory uncertainty," according to NOAA, is a major barrier to growth of the industry. On the other hand, only one permit—a siting permit from the Army Corps of Engineers—is always required for offshore aquaculture facilities. This and other applicable laws are unlikely to address comprehensively the environmental risks of offshore aquaculture (Hopkins et al. 1997).

In 1992, the National Research Council conducted a study to assess the technology and opportunities for marine aquaculture. Even at that time, it was clear that wild-catch fisheries were reaching their limits of production. Among the major recommendations of this study were changes in federal and state agency roles "to provide a regulatory and funding framework that encourages the industry's growth while ensuring that environmental concerns are addressed" (NRC

1992). In particular, the NRC recommended that Congress create a legal framework to:

- Foster appropriate development of marine aquaculture;
- Anticipate potential conflicts over use of ocean resources;
- Assess potential environmental impacts of marine aquaculture;
- Develop appropriate mitigation measures for unavoidable impacts; and
- Assign fair rents and returns on marine aquaculture operations.

NOAA articulated a clear view of aquaculture governance when it produced the *Code of Conduct for Responsible Aquaculture Development in the U.S. Exclusive Economic Zone* (NOAA 2003). This document was developed with extensive input from aquaculture scientists, government regulators, the aquaculture industry, and the conservation community. It draws heavily on the FAO Code of Conduct for Responsible Fisheries, which itself includes a section on aquaculture. Like the FAO Code, compliance with the NOAA Code is voluntary.

The NOAA Code calls for offshore aquaculture to "adopt the guiding principle of a precautionary approach combined with adaptive management to achieve sustainable development in offshore waters." It calls for the designation of one agency as the "overall authority" to coordinate, support, regulate, and promote all aquaculture activities in federal marine waters. The Code recommends the development of a management plan for aquaculture in federal waters that:

- Clearly specifies management objectives, assessment of impacts, and monitoring and mitigation requirements;
- Includes predetermined standards or allowable limits of impact;
- Develops siting criteria to "promote clarity, consistency, and precaution in the permit process";
- Identifies areas suitable for aquaculture after a thorough environmental review; and
- Provides for participation of stakeholders in planning and permitting decisions.

Regarding the permitting process for offshore aquaculture, the Code is quite specific. It recommends establishment of:

- A single, consolidated permit for EEZ aquaculture facilities;
- A guide for site assessments for use by permit applicants;
- Long-term leases for offshore aquaculture;
- BMPs for offshore aquaculture and their inclusion as enforceable permit conditions;
- Performance-based management plans for aquaculture operations to provide an objective basis for monitoring and enforcement;
- Standards for specific culture systems which could serve as conditions for permits and references for monitoring compliance;
- Use permits to prescribe interim management measures until regulations are in place; and
- Transparent processes involving public participation in planning and permitting decisions.

While the 1992 NRC report basically recommended strengthening existing agency roles to promote marine aquaculture, Cicin-Sain et al. (2005) recommended a more substantive overhaul of federal aquaculture governance. Among other sources of information, these authors surveyed the experience of other nations in managing marine aquaculture (Box 3-2). Cicin-Sain et al. recommended giving NOAA primary authority over aquaculture in federal marine waters. They proposed that Congress establish leasing authority for offshore areas for aquaculture and that NOAA administer this program as well as taking a lead role in coordinating among the various federal agencies with responsibility for evaluating the environmental effects of marine aquaculture.

BOX 3-2.

International Experience with Marine Aquaculture Governance.

Marine aquaculture has grown much more rapidly in a number of other countries than it has in the United States. As a result, other nations have more experience addressing development of marine aquaculture as an industry and in addressing the environmental, social and economic consequences of that development. Cicin-Sain et al. (2001) surveyed the experience of Norway, the United Kingdom, Ireland, Canada, Chile, Australia, New Zealand, and Japan in the management of aquaculture in their marine waters. In addition, they examined guidance provided for marine aquaculture by the U.N. Food and Agriculture Organization (FAO) and the International Council for the Exploration of the Seas (ICES). These authors point to several broad conclusions that can be drawn from the international experience in marine aquaculture:

- Marine aquaculture tends to fall under the purview of a number of government agencies. The designation of a lead government agency to coordinate a well-defined interagency process has been found useful in several countries.
- Government agencies need to have well-trained and technically competent staffs overseeing marine aquaculture so that they can administer a flexible regulatory process and keep up with rapidly changing technology and industry dynamics.
- A two-step permitting process in which a lease for an area of the ocean or seabed is applied for and issued first, followed by a license to operate within the leased area, seems to be a common and workable approach.
- Conflicts involving the siting of fish farms and other uses of marine space and resources were a major problem in all countries surveyed. The development of siting criteria for marine aquaculture appears to be important to minimize these conflicts. Several countries have undertaken a formal process for determining areas of marine waters suitable for aquaculture.
- "Carrying capacity" of marine areas for aquaculture, both in terms of the number of cages or pens and the density of fish in those structures, has been controversial. Norway, for example, has developed procedures to assess permissible organic loading of marine areas, availability of suitable sites, density of fish farms, and distance of fish farms from sensitive habitat.
- The development of broad aquaculture management plans by authorities in advance of consideration of applications for individual permits has been found useful.
- FAO and ICES emphasize a precautionary approach to aquaculture development and placement of the responsibility for providing information about the potential impacts of aquaculture on those proposing the development and on government agencies managing the development.

Among the key environmental recommendations of Cicin-Sain et al. (2005) were:

- Comprehensive mapping of offshore areas should be carried out to identify areas suitable for offshore aquaculture;
- Congress should confirm that the National Environmental Policy Act applies to federal waters;
- Environmental review of offshore aquaculture activities should be guided by a commitment to—
    - Sustainability,
    - The precautionary approach,
    - Concern for environmental carrying capacity,
    - Comprehensive assessment and monitoring,
    - Management that is ecosystem-based and adaptive, and
    - Extensive public participation and transparency;
- Monitoring and regulation of offshore aquaculture should—
    - Ensure that it does not exceed environmental standards or the carrying capacity of the environment, and
    - Be flexible and adaptive so they can respond to changes in operating procedures or environmental conditions; and
- Operators of offshore aquaculture facilities should be responsible for environmental remediation, restoration, or monetary damages.

Recent and Pending Legislation Affecting Marine Aquaculture

In June 2005, NOAA proposed legislation that would authorize the Secretary of Commerce to issue permits to site and operate aquaculture facilities in federal marine waters and to improve coordination among the federal agencies of other required permits. At the request of the Administration, Senator Ted Stevens (R-AK) introduced this legislation (S. 1195) in June 2005. Concerns over the effects of aquaculture in federal waters on wild fish stocks and marine ecosystems led to resolutions being passed by the legislatures of Oregon and Alaska urging changes to the federal proposal, and to the introduction of federal legislation by Senator Lisa Murkowski (R-AK).

A bill governing finfish aquaculture in state marine waters of California was recently signed into law in California. The Sustainable Oceans Act establishes standards for environmental review and permitting of finfish facilities in California state waters. These conditions would be in addition to an existing ban on the culture of salmon, nonnative fish, and genetically modified organisms in California state marine waters.

S. 1195

On June 8, 2005, Senator Ted Stevens (R-AK) with cosponsor Senator Daniel Inouye (D-HI) introduced the Administration's proposed offshore aquaculture legislation. The bill:

- Authorizes the Secretary of Commerce to issue permits to site and operate aquaculture facilities in federal waters.
- Authorizes the Secretary to establish environmental requirements for offshore aquaculture where the Secretary finds existing environmental controls are inadequate.
- Exempts permitted offshore aquaculture from regulation under the Magnuson-Stevens Fishery Conservation and Management Act.
- Requires concurrence of the Secretary of the Interior for aquaculture facilities on or near offshore oil and gas platforms.
- Creates a research and development program in support of offshore aquaculture.
- Requires the Secretary to work with other federal agencies to develop a streamlined and coordinated permitting process for offshore aquaculture.
- Authorizes the Secretary to establish a schedule of fees for permits and requires permit applicants to post bonds to cover unpaid fees, removal costs, and other financial risks identified by the Secretary.
- Provides for enforcement of the Act.

As introduced, the bill does not adequately address environmental concerns related to marine aquaculture. First, the Secretary's authority to condition permits on environmental compliance and performance beyond what is required by existing law is discretionary. Secondly, the promotion of offshore aquaculture by the bill is not balanced by concrete procedures to protect the marine environment. Given the importance of a healthy marine environment to commercial and recreational fishing and a number of other important economic activities, the legislation as introduced would not seem to promote the kind of balanced, precautionary policy called for by the Pew Oceans Commission and the U.S. Commission on Ocean Policy, and by NOAA's own Code of Conduct for Responsible Aquaculture.

The sponsors of the legislation seem to have similar concerns. At the same time S. 1195 was introduced, Senators Stevens and Inouye introduced two key amendments to the bill. One would prohibit the issuance of the necessary permits for aquaculture in federal waters off any state if the governor of that state provides written notice that the state does not want it to occur. The second would require—not just authorize—the Secretary to develop additional permit requirements "needed" to address environmental concerns about offshore aquaculture.

S. 1195 clearly states that the new authority granted to the Secretary of Commerce does not supersede the authority of other agencies to regulate aspects of aquaculture. In that regard, the legislation does not establish the "one-stop" permitting long sought by the industry. While the site and operating permits envisioned by the bill would convey the legal authority to build and operate a facility, it is not clear that these permits, in and of themselves, convey a suite of property rights in the sense that a lease for offshore oil and gas development does. It would seem that establishing clear property rights is one of the fundamental requirements for economically viable aquaculture in federal marine waters (Rieser 1996). Lastly, the bill directs the Secretary to consult with other federal permitting agencies to develop a coordinated and streamlined permitting process, but it does not give the Secretary of Commerce authority to overhaul that process.

S. 796

Aware that the Administration was working on legislation to promote offshore aquaculture and mindful of strong concerns from the powerful commercial fishing industry in her state, Senator Lisa Murkowski (R-AK) introduced S. 796 on April 14, 2005. This bill is similar to legislation she introduced in the previous Congress. The bill in effect bans federally permitted marine aquaculture until Congress enacts legislation specifying what the permit process would look like and what specific requirements it would include.

The bill prohibits federal agencies from issuing a permit for an aquaculture facility in federal marine waters until Congress enacts legislation specifying the types of analyses that must be carried out prior to issuing such a permit, including studies on:

- Disease control;
- Engineering;
- Pollution;
- Biological and genetic impacts (presumably on marine fish and wildlife);
- Access and transportation;
- Food safety; and
- Social and economic impacts of offshore aquaculture on fishing and other marine activities.

The bill also requires federal agencies to consult with the governor of each state located within 200 miles of the proposed facility and that any permit or license be approved by the relevant regional fishery management council.

If enacted, this legislation could impose a substantial barrier to permitting offshore aquaculture. Given the difficulty in enacting legislation in the first instance, requiring Congress to pass another bill before an executive agency can act is potentially a highly effective obstruction. On the other hand, the studies required by this legislation would ensure a thorough analysis of the economic, environmental, and social implications of marine aquaculture prior to its permitting by federal agencies.

California's Sustainable Oceans Act

This bill was first introduced by California Senator Joe Simitian on February 22, 2005. Existing law in California authorizes areas of state marine waters to be leased for aquaculture if the California Fish and Game Commission (CFGC) determines that the lease is in the public interest. The CFGC is a five-member panel appointed by the governor and confirmed by the state senate. It deals with regulation, permitting, licensing, and management related to conservation of fish and wildlife in California. State law in California already prohibited the culture in state waters of salmon and genetically modified organisms. The Sustainable Oceans Act (SOA) requires finfish farmers to obtain a lease from the Commission to operate in state marine waters and would require leases and regulations for the conduct of marine finfish aquaculture to meet certain standards.

It is likely that a programmatic environmental impact report will be prepared pursuant to the California Environmental Quality Act (similar to the federal National Environmental Policy Act) before any significant leasing of California marine waters for finfish aquaculture. Although the SOA does not require a programmatic environmental impact report to be prepared, it does stipulate that if such a report is prepared, it must ensure that aquaculture is "managed in a sustainable manner" and that a variety of environmental factors are adequately considered. The law also requires leases and regulations governing those leases to meet standards designed to protect marine resources and the users of those resources, including:

- Ensuring the suitability of the site;
- Minimizing effects on marine fish, wildlife, and environmental quality;
- Minimizing disruption of other uses of ocean space and resources;
- Minimizing use of fish meal and oil in feeds;
- Providing for monitoring of environmental effects;
- Establishing liability for damages resulting from aquaculture activities; and
- Establishing the environmental carrying capacity, in terms of the total number and density of farmed fish, for marine aquaculture.

In addition to these conditions, the bill requires the Fish and Game Commission to act to prevent significant harm to the marine environment, including—if necessary—shutting down an aquaculture facility or revoking its lease. See Box 3-2 for more details on the environmental requirements of the Sustainable Oceans Act.

Discussion and Conclusions

A number of studies have examined marine aquaculture and come to very similar conclusions. While marine aquaculture can contribute to the supply of seafood and plays a role in stocking and restoration efforts, careful management is required to ensure that it is done in a way that does not harm marine life or the ecosystems on which it depends. Key features of such a governance regime, such as a precautionary approach, careful siting and high standards for environmental performance implemented through flexible, adaptive mechanisms, have been repeatedly articulated after careful examination of the issues.

Aquaculture is a form of agriculture, and agriculture is going to have an impact on the ecosystems in which it takes place. The question is what are the nature and magnitude of these impacts and can they be managed to an acceptable degree so that society can get the benefit of farmed seafood without significant harm to marine resources and other uses of the oceans? We believe the answer to this question is yes and below we make recommendations consistent with the spirit of the foregoing studies and reports to achieve this balance.

The fact that the oceans are public space adds another dimension to the discussion. Most farming takes place on private land. Agricultural activities, such as timber harvesting and grazing, that take place on public land are subject to additional scrutiny—and appropriately so. This is also the case with most marine aquaculture: with the exception of some nearshore shellfish culture on privately owned tidelands, it is a private activity occurring in public "space." As a result it is legitimate to hold these activities to a high standard for environmental performance. Lastly, it is also appropriate to err on the side of environmental protection where uncertainty exists regarding the effects of aquaculture on marine life and ecosystems.

BOX 3-2

The Sustainable Oceans Act: Environmental Assessment and Standards

The Sustainable Oceans Act was signed into law on May 26, 2006. The law allows areas of California's marine waters to be leased for finfish aquaculture under certain conditions. Environmental protections in the bill operate through two primary mechanisms. First, the law requires enhanced assessment of the potential environmental effects of marine aquaculture by requiring the environmental impact report for the leasing program to take into consideration the following factors:

- Appropriate siting to avoid or minimize adverse impacts on marine resources and users of marine resources;
- Effects on sensitive habitats;
- Effects on human health, marine life, fishing, and other ocean uses;
- Cumulative effects of multiple fish farms on marine ecosystems;
- Effects of the use of fishmeal and fish oil on marine ecosystems;
- Effects of escaped farmed fish on wild fish and the marine environment; and
- Design of facilities to minimize adverse environmental impacts.

Secondly, leases and regulations for marine finfish aquaculture must meet the following standards:

- The site must have been judged appropriate in the programmatic environmental impact report;
- The lease must not unreasonably—
  - Interfere with fishing or other uses of the ocean,
  - Disrupt wildlife and marine habitats, or
  - Harm the ability of the marine environment to support "ecologically significant flora and fauna;"
- A lease shall not have "significant adverse cumulative impacts;"
- Use of fishmeal and fish oil shall be minimized, and alternatives to these feed ingredients shall be utilized where feasible;
- Lessees must develop and implement best management practices to ensure environmental protection and compliance with the law;
- The California Fish and Game Commission may take action to prevent or stop damage to the marine environment and must take "immediate remedial action to avoid or eliminate significant damage, or the threat of significant damage, to the marine environment." Measures that may be taken to mitigate environmental damage include—
  - Removing fish stocks,
  - Closing facilities, or
  - Terminating a lease;
- Fish number and density must be limited to what can be safely raised while protecting the marine environment;
- The use of drugs and chemicals shall be minimized and shall be used only as approved by the federal Food and Drug Administration for marine aquaculture use;
- All farmed fish must be marked, tagged or otherwise identified unless the Fish and Game Commission determines this is not necessary for the protection of wild stocks;
- Facilities and operations shall be designed to prevent the escape of farmed fish and lessees are responsible for damage to the marine environment caused by more than de minimis escapement; and
- Lessees shall meet all applicable requirements imposed by state and federal water quality laws.

Summary of Recommendations

- Congress should assign NOAA a leading role in planning, siting, and regulating aquaculture in federal marine waters, including preparation of a programmatic environmental impact statement.
- Congress should direct NOAA to establish a federal marine aquaculture program that is precautionary, science based, socially and economically compatible with affected coastal communities, transparent in its decision making, and provides ample opportunity for public input.
- NOAA should evaluate the environmental risks from marine aquaculture prior to permitting.
- NOAA should consult with affected coastal states and regional and interstate fisheries councils during both the planning and permitting stages.
- Congress should ensure environmental standards are in place before permits are issued for aquaculture in federal waters.
- NOAA should implement environmental standards through management, monitoring, and enforcement requirements in permits.
- Aquaculture operators should be required to develop and comply with an operating plan specifying measures taken to achieve environmental standards.
- Operators of aquaculture facilities in federal waters should be liable for damage caused by their activities.
- NOAA should provide incentives to industry for research, development and deployment of species, technologies, and techniques for sustainable marine aquaculture, including sustainable aquaculture feeds.
- Congress should address the growing need for a comprehensive regime for management of aquaculture and other offshore activities affecting federal marine waters and resources.

DETAILED RECOMMENDATIONS

1. **Congress should authorize NOAA to develop a national program of marine aquaculture, including both strong environmental safeguards and provisions to balance offshore aquaculture with other ocean uses.**

   1.1. Congress should authorize NOAA to issue implementing regulations and site and operating permits for aquaculture in federal marine waters.[6]

   1.2. After making institutional changes to ensure the integrity of its decision-making process, NOAA should take a leading role in planning, permitting and regulating aquaculture in federal marine waters, and in coordinating aquaculture in all marine waters with other federal agencies, the states, tribes, and the regional and interstate fisheries management councils.

   1.3. Congress should direct NOAA to establish a program for marine aquaculture that:

   - Uses relevant and timely scientific and technical information in a precautionary manner to protect the health of marine ecosystems;
   - Is socially and culturally compatible with coastal communities and existing uses of the marine environment; and
   - Is economically beneficial to coastal communities.

   1.4. Congress should direct the Joint Subcommittee on Aquaculture to update the National Aquaculture Development Plan to incorporate the national marine aquaculture program.

2. **Congress should lay the groundwork for the orderly, well-planned and environmentally sustainable development of offshore aquaculture by requiring NOAA to:**

   2.1. **Make organizational arrangements to separate its regulatory, permitting, monitoring, and enforcement functions from its aquaculture research and development activities;**

   2.2. **Establish a transparent process for making aquaculture siting and permitting decisions** that—

   - Provides ample opportunity for stakeholder input, including public hearings,
   - Requires all information pertinent to the environmental impacts of permits to be made publicly available, and
   - Ensures that potential environmental, social, economic, and cultural impacts of offshore aquaculture are considered in the permitting process;

   2.3. **Prepare a programmatic environmental impact statement;**

   2.4. **Evaluate the environmental risks from marine aquaculture prior to issuance of each site and operating permit.** Marine aquaculture risk assessments should—

   - Be conducted according to formal guidelines developed by NOAA,

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[6] By "federal marine waters" the Task Force means those marine waters and submerged lands under exclusive federal control for purposes of domestic law (i.e., waters outside of state control). The area of marine waters under federal jurisdiction is often referred to as the Exclusive Economic Zone (see, e.g., the Magnuson-Stevens Act), but since that term is sometimes used to describe all marine waters under the jurisdiction of the United States (both state and federal jurisdiction, 0-200 n. mi. offshore) the Task Force has avoided use of that term.

- Be conducted by NOAA or by permit applicants,
- Be required to include a worst-case scenario and evaluate the risks at various levels of contingency planning and preparedness, and response effectiveness,
- Include public review and input, and
- Be made part of the public record of the marine aquaculture permitting process;

2.5. **Consult with affected coastal states and regional and interstate fisheries management councils during program development and on individual permitting decisions.** Such consultation should ensure that the national marine aquaculture program and any permits issued to carry it out—

- Are integrated with any regional marine planning aimed at managing U.S. marine waters on an ecosystem basis,
- Are consistent, to the maximum extent practicable, with enforceable policies of adjacent states, and
- Do not undermine the effectiveness of conservation measures under the jurisdiction of the states or the fisheries management councils; and

2.6. **Provide technical and financial assistance to states to review and, if necessary, revise their coastal zone management plans to address aquaculture activities in state and federal ocean waters.**

3. Congress should require that standards are in place to protect marine wildlife and ecosystems before permits may be issued for offshore aquaculture.

3.1. Congress should set general standards for, and require the appropriate agencies to issue detailed standards to address:

- Genetic and biological interactions with escaped farmed organisms;
- Disease and parasites that may be present in aquaculture facilities;
- Water pollution, drug and chemical use, and alteration of marine habitat; and
- Marine wildlife interactions.

3.2. Congress should require that such standards be adopted by NOAA and other appropriate agencies before site and operating permits may be issued for offshore aquaculture.

3.3. Congress should require that agencies issuing permits required for marine aquaculture ensure compliance with these standards as a condition of those permits.

4. NOAA, in collaboration with other agencies with jurisdiction over offshore aquaculture, should establish management, monitoring and enforcement requirements to achieve environmental standards (as described in recommendation 3) and require their inclusion as enforceable conditions of site and operating permits.

4.1. NOAA should set standards for environmental performance, which could serve as conditions for site and operating permits and provide points of reference for monitoring. (The Task Force's recommendations for environmental standards are discussed in greater detail in chapters addressing escapes, water pollution and pathogens.)

- Where numerical or narrative standards for environmental performance are feasible, NOAA should establish such standards and require compliance with them as a condition of offshore aquaculture site and operating permits.
- Where establishing numerical or narrative standards is not feasible, NOAA should require implementation of management practices and/or deployment of specified technologies as a condition of offshore aquaculture site and operating permits.
- If NOAA issues permits for marine aquaculture before regulations are in place to implement environmental standards, such permits should prescribe interim management measures needed to uphold the environmental standards.

4.2. NOAA should require offshore aquaculture facilities, as a condition of their site and operating permits, to be operated according to an approved operational plan designed to ensure compliance with environmental standards.

- Applicants for site and operating permits for offshore aquaculture should be required to develop and submit to NOAA an operational plan for any aquaculture facility for which an operating permit is sought. The operational plan should describe management practices, monitoring, reporting and other measures needed to comply with environmental standards for offshore aquaculture.
- NOAA should develop, and periodically revise, guidance for preparation of operating plans for offshore aquaculture facilities and for compliance with environmental standards for offshore aquaculture.
  - Guidance should include instructions for preparation, submission, and review of operational plans and appeal of decisions related to the approval of such plans.
- Prior to issuing an operating permit for offshore aquaculture, NOAA should review the operational plan submitted by the permit applicant and determine if operating the aquaculture facility according to the plan will result in negligible harm to the marine environment.
- If NOAA determines that permitted activities will result in negligible harm to the marine environment if conducted in accordance with the proposed operating plan, NOAA should approve the plan and require compliance with it as a condition of the operating permit.
  - If NOAA finds deficiencies in a submitted operating plan, it should promptly inform the permit applicant of such deficiencies and suggest changes in the operating plan required for compliance with environmental standards for offshore aquaculture.

5. Congress should include provisions in marine aquaculture legislation to ensure mitigation of damage to marine resources resulting from the private use of ocean space and ecosystem services.

5.1. Permittees should be required to post bond to cover the cost of any unpaid fees and for removal of aquaculture facilities at the end of their use for permitted activities.

5.2. Congress should ensure that permittees are liable for mitigating environmental damage resulting from aquaculture facilities or operations. The legislation should:

- Establish liability of permit holders for the costs of mitigating environmental damage, including the reasonable costs of assessing damages; and
- Ensure that recovered funds are used first for the restoration of the damaged resources. If any funds remain after all practicable efforts to restore damaged resources, such funds should be dedicated to other marine conservation activities in the region.

6. **Congress should provide incentives for activities and projects that protect the marine environment and promote sustainable marine aquaculture.** To support this goal, Congress should direct NOAA to:

6.1. Develop criteria for sustainable marine aquaculture, including development of sustainable aquaculture feeds;

6.2. Provide technical and financial support for research, development, and demonstration projects meeting these criteria;

6.3. Give preference in permitting for projects meeting these criteria

- Preferences might include preapproved siting and/or expedited operating permitting for projects demonstrating new technologies, culture methods, and species showing promise for sustainable aquaculture; and

6.4. Establish a sliding scale of application or permit fees to encourage such projects.

7. **In the long term, Congress needs to address the growing need for a comprehensive management regime for U.S. marine waters in which marine aquaculture and other uses can be managed in a way that protects the health, integrity, and productivity of marine ecosystems.** Both the Pew Oceans Commission and the U.S. Commission on Ocean Policy called for comprehensive management of U.S. ocean waters on an ecosystem basis. Even a well-planned approach to offshore aquaculture cannot provide rational planning and management of the variety of new and existing ocean uses, nor deal with the cumulative and secondary impacts of all these issues. Aquaculture both relies on marine environmental quality and has impacts on it. To restore and maintain the health of marine ecosystems, there is a need for an integrated, comprehensive offshore management regime.

CHAPTER 4

ECOLOGICAL EFFECTS OF AQUACULTURE ESCAPES

Introduction

The introduction of nonnative species is a global concern with ecological impacts that are frequently severe, though often unpredictable. Risks associated with nonnative species introductions include degradation of the host environment, disruption of the host community, genetic degradation of the host stock, introduction of diseases, and socio-economic effects (Welcome 1988). The global trade and transport of living aquatic organisms, of which marine aquaculture is just one player, have led to the introduction and establishment of many nonnative aquatic species. Recent reports have identified the growing threat to coastal resources and have documented impacts on assemblages of native species from introduced species of aquatic organisms (Carlton 2001; Pimentel et al. 2000; Simberloff et al. 2005). New species arrive in U.S. waters on a regular basis, with potentially devastating effects on ecosystems and economics. There are many pathways for new species to be introduced to coastal waters, including through ballast water, hull fouling, fisheries activities, aquaculture, and other human activities (Table 4-1).

Species have been introduced by aquaculture through purposeful introductions and accidental releases, or escapes. Many documented negative effects are from introductions attributed to aquaculture that occured prior to science making us aware of the harmful consequences. Laws and regulations have subsequently improved which ensure intentional introductions undergo far more thorough review than in years past. Finfish aquaculture systems sited in marine waters are comprised of net pens or cages, which are prone to damage from storms, predators, human error, or other causes. Once damage has been done, whether it is a small hole torn in a cage by a shark looking for an easy meal or damage caused by a collision with a boat, the organisms inside these cages are capable of escaping into the environment. These escapes can be costly for the farmer as well as the environment and it is generally considered in the farmer's best interest to protect, as much as possible, against escapes. Another type of "escape" is one in which viable gametes are released into the environment. This type of release can be associated with net pen and cage systems when marine species are farmed, as well as other systems in which there is no solid enclosure, for example shellfish farms where water flows freely between the farm and the surrounding environment.

As a result of both of these types of escapes, aquaculture has been an important route for the introduction of nonnative species and the introduction of nonnative genetic strains, most often

… aquaculture has been an important route for the introduction of nonnative species and the introduction of nonnative genetic strains.

An Atlantic salmon farm in British Columbia. Substantial numbers of Atlantic salmon, which is not a species native to the Pacific Northwest, have escaped from farms in Washington and British Columbia.

Photo: ©Natalie Forbes /Corbis

TABLE 4-1:

Impacts from Introduction and Translocation of Aquatic Species

Species and region of introduction or translocation	Native or nonnative	Mode of introduction	Documented and suspected impacts
Atlantic salmon in the North Atlantic ocean	Native	Aquaculture (also hatcheries)	Loss of productivity, reduced genetic diversity as a result of genetic introgression, resource competition, displacement of wild offspring, and reduced fitness in wild population (Fleming et al. 2000; McGinnity 2003).
Atlantic salmon in the Pacific ocean	Nonnative	Aquaculture (historically hatcheries as well)	Reproducing in the wild with potential competitive interactions with native species (Volpe et al. 2000; Volpe et al. 2001)
Pacific salmon in the Pacific ocean	Native	Hatcheries	Genetic changes and reduced fitness in native populations (Reisenbichler and Rubin 1999).
Zebra mussels in North America	Nonnative	Ballast water	Ecosystem impacts, competition with native species, impacts on native plant and animal communities. Considered a nuisance species, especially because of biofouling, can cause significant economic impacts (Benson and Raikow 2005).
Trout (several species) in many areas of North America	Nonnative	Stocking for recreational fishing	Competition, displacement, and genetic introgression with native species and introduction of disease (Behnke 2002).
Carp in North America	Nonnative	Intentional stocking and aquaculture	Considered nuisance species, alters habitat and can compete with and negatively impact native species (Nico and Maynard 2005).
Oysters (worldwide)	Nonnative	Oyster aquaculture, introductions, and transfers	Introduction of oyster diseases and pests causing extensive mortalities in wild oyster populations and impacts on aquaculture industry (Farley 1992).
Herpesvirus (pathogen) of pilchard in Australia	Nonnative	Aquaculture feeds (probable cause)	Mass mortalities in native pilchards (Gaughan 2002).
Sabellid worm along Pacific coast (abalone parasite)	Nonnative	Aquaculture	Infestation of wild abalone and snails and negative impacts on the commercial aquaculture industry (the parasite apparently has been eradicated in recent years) (Cohen 2002).

(continued)

TABLE 4-1:

Impacts from Introduction and Translocation of Aquatic Species

(continued)

Species and region of introduction or translocation	Native or nonnative	Mode of introduction	Documented and suspected impacts
Shrimp diseases (several worldwide)	Native and nonnative	Aquaculture and seafood trade	Significant losses (hundreds of millions of dollars) to the aquaculture industry, unknown impact on wild populations (Lightner et al. 1992)
Green crab along Atlantic and Pacific coasts	Nonnative	Ballast and live transport in seafood packing materials	Predation on and competition with native species (Perry 2005).
Tilapia (many areas worldwide)	Nonnative	Aquaculture and intentional stocking	Competition with native species and habitat alteration (Nico 2005).

nonlocal genetic strains and/or semidomesticated genetic strains of native species that are capable of interbreeding with native wild populations. In some ways the introduction of foreign genetic material may have more insidious impacts on wild populations because of the potential for these genes to spread within the native population and weaken its genetic structure. This is especially true when the wild populations are already depressed for a variety of other reasons and when the level of farm escapes is high relative to the wild population size.

Careful planning and management to prevent introductions of nonnative species and strains, including contributions from escapes and release of gametes from marine aquaculture facilities, are more effective than attempting to fix problems after those species have become established or after foreign genetic material has been introduced. While prevention of introductions via aquaculture is of the utmost importance, escapes will inevitably occur in any in situ culture situation. This is particularly true of inherently “leaky” net pens or cages and in situations where cultured organisms release viable gametes into the environment. Therefore, any rational policy for addressing escapes must focus first on prevention, but follow up with strong management measures to eliminate, or at least minimize, ecological damage once escapes occur. These measures must be cost effective, but the benefits of protecting ecosystem integrity should be accounted for as well.

Introduction of Nonnative Species for Aquaculture

Aquaculture has played a role in the introduction of nonnative species through escapes of organisms and the release of viable gametes from facilities. In fact, it was noted in 1988 that since the 1970s aquaculture was the leading cause of introduction of aquatic species in inland waters worldwide, with well over half of all introductions made for aquaculture purposes (Welcome 1988). Many nonnative species introductions, intentional and unintentional, by way of aquaculture have taken place in freshwater. For example tilapia and carp have been introduced in many areas outside their native ranges. Aquaculture also has played a significant role

BOX 4-1.

State policies on species introductions.

There is a lack of clear federal policy regarding introduced species. Current state policies regarding introduced species are primarily based on a "dirty list" approach. The dirty list approach places the burden on the government to prove an introduced species will cause harm, not on the importing industry to prove the species is safe. Under this approach, species proposed for importation or introduction are assumed to be "innocent until proven guilty." Regulators are required to identify species known to be harmful and prohibit their importation (Van Driesche and Van Driesche, 2001; Simberloff, 2005). The fundamental problem with a dirty list approach is that it fails to fully account for the risk that a species not previously released will cause harm. It allows for importation of organisms for which there is very little scientific understanding of invasion potential, and has thus been of limited utility in preventing the introduction of invasive species (Van Driesche and Van Driesche 2001). Often by the time governments have enough information to place a species on a list to prevent its introduction, the organism has been introduced and damage has already been done. There has been little success at eradicating invasive species once they become established.

A more risk adverse approach is to use a "clean list," in which only species known to carry a very low risk of invasion are allowed for importation or introduction. This approach has been adopted by other countries, including Australia and New Zealand, and some states, for example Massachusetts. Individuals wishing to cultivate fish in Massachusetts may only do so if the species is on a special exemption list, which is created with environmental safeguards in mind, including a provision that the accidental release of the organism will not result in an adverse effect on the ecology of the commonwealth (Mass. G.L. Ch. 131 s. 23). Other states have developed a hybrid approach that combines the use of both prohibited and allowed lists (Simberloff et al. 2005). In Minnesota, for example, any unlisted species proposed for introduction must be evaluated and the risks must be fully assessed prior to introduction. The results of the risk assessment lead to the placement of the species on one of the lists at which time a decision regarding the fate of the proposed activity is made.

in species introductions in marine waters, though there are relatively few scientific studies documenting the impacts from these introductions (Carlton 2001; Carlton 1992).

Some segments of the marine aquaculture industry are based on the use of exotic species. For example, salmon farming in the Pacific Northwest has used almost exclusively Atlantic salmon and there are exotic species of oysters, clams, and mussels that are farmed in a variety of places outside their native ranges. Of note, however, is the apparent lack of interest in farming marine species of finfish—other than salmon—outside of their native range. Thus far, demonstration projects and small commercial operations in U.S. marine waters have been using locally native species.

> ... any rational policy for addressing escapes must focus first on prevention, but follow up with strong management measures to eliminate, or at least minimize, ecological damage once escapes occur.

Risks Associated with Aquaculture's Use of Native Species

Even when native species are used in aquaculture there are potential environmental risks with escapes. To improve production, aquaculturists may use selectively bred and/or nonlocal genetic strains of native species resulting in farm organisms that, while still of the native species, are not as ecologically fit as the local wild populations. Evidence suggests that when these types of organisms escape from farms, they can interbreed with and reduce the genetic integrity of the native population. Much of what is known in this respect comes from Atlantic salmon farming where the escape of organisms that have been selectively bred or developed from nonlocal genetic strains poses a significant risk to the genetic integrity of river-specific populations of wild Atlantic salmon. Because much of the expansion of marine aquaculture is likely to occur in the culture of exclusively marine fish, the salmon example provides a cautionary tale. While most marine fish do not appear to show the degree of genetic endemism that salmon do, there is evidence of genetic differentiation among subpopulations of some species. At this stage of their culture, marine species will likely be very close genetically to their wild counterparts, but this could change quickly with commercialization and under the intentional and unintentional selective pressures.

Risks from Aquaculture Escapes

The environmental risks associated with aquaculture escapes can vary with the type of aquaculture system used, the species farmed, the scale and intensity of the operation, and the management practices employed (Myrick 2002). The science of many aspects of introduced species is incomplete and introductions via aquaculture are no exception. Many unknowns remain, especially when it comes to species recently brought into culture and new production systems. Most reports conclude that there are significant risks to ecosystems through escapes from aquaculture and that management measures should be taken to eliminate or minimize those risks. The risks associated with escapes of Atlantic salmon in the Pacific Northwest have, however, been disputed by some researchers.

Ecological Interactions

The escape of farmed organisms into the ecosystem can result in ecological interactions, such as competition for food and space and predation on native species by escaped fish. These interactions can create an added stress on wild populations, especially those already affected by a variety of other disturbances, such as fishing and habitat alteration.

Gross (1998) reviewed the potential interactions between escaped farmed salmon and wild salmon, and made several important findings, including: farmed salmon can outcompete wild salmon for food and habitat and displace wild salmon; farmed salmon grow faster than wild salmon leading to competitive advantages over wild fish; and farmed salmon enter rivers and spawn later than wild salmon, which can result in farmed salmon digging up the eggs of wild salmon and replacing them with their own. Other research has identified the potential for escaped Atlantic salmon to establish populations on the west coast of North America and to compete for food and habitat with native salmonids. Successful reproduction by small numbers of escaped farmed Atlantic salmon on the Pacific coast of North America has been documented (Volpe et al. 2000), raising concerns about possible establishment of the nonnative species.

It is believed that the numbers of escapes from aquaculture have been reduced significantly in recent years, though there are continued questions about chronic "leakage" from cages and there are concerns that many escapes go unreported (Naylor 2005). Though large-scale escapes are relatively rare, they occur from storm damage, human error, or other mishaps. In Puget Sound, Washington, escapes of over 100,000 Atlantic salmon in 1996 and over 360,000 in 1997 have been documented (Gross 1998). Additionally, escaped Atlantic salmon have been caught in commercial fisheries in Alaska since the early 1990s, including as far north as the Bering Sea (Brodeur and Busby 1998), showing that escapees are capable of surviving for long periods in the wild and migrating long distances after their escape from aquaculture facilities in British Columbia or Washington. Risks of escapes are likely greatest when the local wild population is most vulnerable, for example threatened or endangered, and harmful effects on wild populations likely rise as the number of escapes increases relative to the size of the wild population.

The ability of escaped fish to disperse from and survive outside of the farm setting has been disputed by some researchers. One study observed that experimentally released farmed steelhead trout are likely to remain in the general area of the farm (Bridger et al. 2001). In the study, 75 percent of released farmed fish stayed within 500 meters of the farm for 32 days. Additionally, observations that escaped farm salmon often have empty stomachs when caught may indicate that farmed fish lack knowledge required for foraging, and therefore surviving in the wild (McKinnell and Thomson 1997).

In a literature review assessing the risk of interactions between Atlantic salmon and populations of native salmon in Puget Sound, Washington, Waknitz et al. (2003) described many possible effects of aquaculture escapes. The authors argue that Atlantic salmon escapes from commercial aquaculture facilities likely have a very low risk of impacting the ecosystem, especially when compared to the many other species introductions, including deliberate introductions of nonnative species and the stocking of hatchery-reared Pacific salmon. The authors note that over the last century governments in the Pacific Northwest have led programs to introduce Atlantic salmon to the area with no success (Waknitz et al. 2003). Other researchers, however, question whether the historical introductions are an appropriate model for the present. A far different ecological landscape now exists in Pacific Northwest rivers, with many populations of Pacific salmon at all time lows, possibly freeing up habitats for Atlantic salmon to invade (Volpe et al. 2001).

Genetic Interactions

The introduction of nonnative genetic strains of aquatic organisms from aquaculture has been a concern for some time (Hutchings 1991), but relatively little research has been completed on the topic. What has been completed is primarily investigations into the impact of escapes from salmon farms in areas with native Atlantic salmon. This research shows that there is considerable risk to wild stocks from salmon farm escapes. Farm-raised salmon, while not completely domesticated, have undergone selection for traits that are preferred in the farm setting and the basis for farmed salmon stocks often includes nonlocal genetic strains. For example, Norwegian strains of Atlantic salmon were formerly widely cultivated in Maine. As a result, the farmed stocks differed from local wild fish genetically. Scientific studies and modeling have shown that when the genes of farmed aquatic organisms enter the wild population through interbreeding it can decrease the ability of the wild fish to survive and adapt and may eventually lead to extinction of wild populations.

Researchers have identified, and attempted to measure, negative impacts from escaped farmed Atlantic salmon within their native range. For example, in a Norwegian study, Fleming et al. (2000) found that escapes of farmed salmon in their native range resulted in risks, including loss of productivity, loss of local adaptations, and reduced genetic diversity. The authors found significant one-way gene flow (from farm fish to wild fish) and it was noted that this type of genetic interaction can eventually lead to a wild population in which all individuals are descended from farm escapes. Additionally, the authors observed evidence of significant resource competition between farmed and wild offspring, including considerable (82 percent) diet overlap, larger size in farm offspring, and possible displacement of wild offspring. Considering that earlier studies in Norway observed that more than 80 percent of the salmon in some Norwegian rivers are of farm origin (Fleming 2000), these types of interactions threaten the continuity of wild stocks.

In another study designed to measure genetic interactions between farmed and wild salmon, McGinnity (2003) used an experimental river segment to track multiple generations of farmed and wild salmon. This experiment simulated repeated escapes from salmon farms and their interaction with a native population of salmon. The results indicate that survival of farm salmon is lower than wild salmon, with hybrids (crosses of farm with wild) having intermediate survival. This is important because in a natural setting in which farmed salmon have invaded, they are likely to create hybrids with wild salmon. These hybrids, as well as offspring from future crosses of the hybrids with wild salmon will have lower survival and will contribute to reduced fitness in the wild population. The study provides empirical support for predictions on the reduction of fitness in wild populations following invasion by nonnative genetic strains from salmon farm escapes.

Genetic interactions with native wild populations are also a concern when farming shellfish since viable gametes can be released from farms, but as with finfish, little comprehensive research has been completed on the topic. Where molluscan shellfish are broadcast spawners with free-swimming larval periods that last for weeks, wild populations tend to be homogeneous over broad areas unlike salmon where individual river systems have unique populations.

In one clam farming area in Florida, however, genetic interactions have been documented and these interactions may have harmed the genetic structure of a closely related wild population of clams. In this case, the clam species selected for farming in the Cedar Key area can hybridize with the locally abundant wild species. The composition of the clam population in the area around the farms has changed since the advent of the clam farming industry with the farm species and hybrids between the farm species and the local species becoming much more abundant (Arnold et al. 2004).

In general, little is known about the potential genetic impacts on wild populations from the many other species that are in culture or are under development for marine aquaculture, including offshore aquaculture. It is reasonable, however, to expect that when farmed stocks are developed from nonlocal genotypes or selected for traits that are preferred in the farm setting the result will be genetic strains that differ from the local wild populations. These differences could result in deleterious ecological effects if the farmed stocks escape and interbreed with their wild counterparts.

Genetically Modified Organisms

In addition to effects of nonnative species and strains of aquatic organisms, many questions remain about the use of transgenic, or genetically modified organisms, in aquaculture (Hallerman 2000; Hedrick 2001; NRC 2002). Genetically modified organisms (GMOs), in which genes are inserted from other organisms to improve characteristics such as growth rate and tolerance to harsh environments, are under development in many parts of the world, including the U.S. No transgenic species are currently used in commercial aquaculture in the U.S., but there is an application pending for approval of a genetically modified salmon. Escapes of GMOs from aquaculture facilities pose risks from both genetic and ecological interactions with wild populations, including a scenario in which the interbreeding of escaped transgenic organisms with wild organisms could lead to the collapse of the wild population (Muir and Howard 1999). In the case of aquaculture organisms that are genetically modified to grow larger, scientists fear that escapees from fish farms could have a mating advantage due to their larger size and attractiveness to mates, but their offspring could be less likely to survive to adulthood. Under a worst-case scenario, known as the "Trojan gene effect", the population could become extinct in just a few generations.

Progress in Limiting the Impact of Escapes

Without moving to fully closed systems, escapes are inevitable in marine aquaculture. Catastrophic events (e.g., hurricanes or other storms), human error, and even vandalism will remain potential paths for farmed fish to escape into the wild. Advancements in technology are likely to continue to reduce the frequency and severity of escape events but it is unlikely that the ecological and economic threat will ever disappear entirely. Submerged

… when the genes of farmed aquatic organisms enter the wild population through interbreeding it can decrease the ability of the wild fish to survive and adapt and may eventually lead to extinction of wild populations.

cage designs instead of surface net pens, stronger cage and net material, and systems for dealing with predators are all improvements that the aquaculture industry has begun to embrace as ways to reduce the level of escapes. Interestingly, much of the research and development on improved system design is taking place in the U.S. In addition to gaining acceptance in some segments of the domestic industry, it also has been exported to other areas of the world.

Since technological fixes—with the exception of fully closed, land-based systems—cannot completely eliminate escapes, regulations and management practices are needed to limit their impact. Regulations and management practices vary by state, and federal waters are not covered by a comprehensive framework in this regard. However, there are several examples from the U.S. aquaculture industry that may provide useful models for addressing escapes as the industry expands.

The Developing Marine Finfish Aquaculture Industry

The nascent marine finfish aquaculture industry, in particular for cobia in the Caribbean off Puerto Rico and of moi (also known as Pacific threadfin) and kahala (amberjack) off the coast of Hawaii, is based on the use of native wild broodstock and appears to be developing in a way that poses a minimal risk to wild populations of fish through escapes. In the Caribbean, escapes have occurred as a result of sharks tearing holes in nets as they attempt to gain access to an easy meal. While culturing native species may substantially reduce ecological risks, it does nothing to reduce the economic risk to the producer from escapes. As a result, predator management strategies and technology, such as predator nets, solid barriers, electromagnetic fields, and repellants have been employed or are under development (Benetti et al. 2006). In the case of the moi farm in Hawaii, the fish used in the commercial operation are obtained from the same hatchery that produces fish for a stock restoration program, meaning that escapes, though costly for the farmer, could be viewed as adding more fish to the restoration effort. As the industry expands, however, broodstock management may become more of an issue. The pressure to produce more fingerlings may require substantial harvest of wild fish for broodstock, and there may be economic pressure to reduce turnover of broodstock in the hatcheries to improve volume and efficiency of fingerling production.

Shellfish Aquaculture in Alaska

Although Alaska has banned the farming of finfish in its coastal waters, shellfish farming has developed into a significant industry with stringent regulations designed to protect the environment and wild fishery resources. Regulations in Alaska limit the shellfish aquaculture industry to the use of native species, such as mussels, scallops, and clams, and the seed stock must be captured from wild populations (RaLonde 1993). The one exception to this rule is that the culture of Pacific oysters, a nonnative species, is allowed as long as the young oysters are obtained from a certified disease-free hatchery. Although allowing the culture of Pacific oysters means that a nonnative species has been introduced to Alaskan waters, the risk of colonization and impacts on native species is very low. Alaskan waters, though ideal for growing Pacific oysters, are too cold for the species to successfully reproduce. In addition to the restrictions on nonnative species, there are other controls in place in Alaska to prevent interactions between farmed and wild organisms. One of these, the shellfish transport permit, is required for individuals wishing to transport or hold shellfish. Permit review, completed by the Alaska Department of Fish and Game, must assure that "the shellfish are disease free, not genetically harmful to the existing wild populations of the same species, and that the intensity of culture will not significantly effect biodiversity of the marine life in the area" (RaLonde 1993).

Salmon Farming in Maine

The decline of Atlantic salmon populations in coastal Maine, which culminated in 2000 with the listing of Atlantic salmon in Maine as an endangered species, has raised concerns about the farming of the species in coastal net pens (NRC 2004). Atlantic salmon farming began in Maine in the 1980s and despite the efforts of producers to limit the number of escapes, unintentional releases are known to occur, sometimes resulting in greater numbers of farm-origin fish than wild fish migrating up rivers to spawn (Baum 2001). Given the status of the wild Atlantic salmon populations, it was especially worrisome to managers and geneticists that farms were using nonnative (European) strains of Atlantic salmon. This posed a serious risk to the health of the native Atlantic salmon populations.

Significant changes have occurred in the regulation of Maine's salmon farms in the past few years. First, a U.S. District Court ruling in 2003 banned the use of European strain salmon and forced the industry to switch to North American strains (Firestone and Barber 2003). In addition to the court ruling, the adoption of a Pollutant Discharge Elimination System General Permit for Atlantic Salmon Aquaculture (general permit) has changed the way the industry is managed in terms of genetic strains that are allowed to be used and practices that must be employed. As a result, it has likely reduced the genetic risks associated with the escape of salmon from farms. The general permit prohibits the use of non-North American strain Atlantic salmon in farms, requires the marking of fish so they can be identified to the farm from which they escaped, and requires farms to take measures to prevent the accidental or consequential escape of fish to open water. The new general permit also bans the farming of genetically modified salmon.

Discussion and Conclusions

The introduction of nonnative species is a global problem with potentially severe, though often unpredictable, ecological impacts. Along with other industries, such as shipping and the aquarium trade, marine aquaculture has been an important route for the introduction of nonnative species and genetic strains. The environmental impacts associated with escapes can vary with the type of aquaculture system used, the species farmed, the scale and intensity of the operation, and the management practices employed. These impacts are generally classified as ecological interactions and genetic interactions. Ecological interactions, such as competition for food and habitat and predation on native wild species, can result in declines in wild populations of aquatic animals, especially those already affected by a variety of other disturbances, such as fishing and habitat alteration. Genetic interactions occur when farm-raised aquatic organisms escape and interbreed with the same species or closely related species in the wild. Many species used in aquaculture have undergone some domestication and selection for traits that are preferred in the farm setting. In some cases nonlocal genetic strains are used on farms, meaning that farmed organisms differ genetically from local wild organisms of the same species. These traits, while desirable in the farm setting, can be harmful to the wild population and when farmed organisms escape and interbreed with wild populations it may reduce the ability of the wild population to survive and adapt. It is clear that with the expected growth of marine aquaculture in the future, steps must be taken to prevent introduction of invasive species and to prevent damage to the health—ecological and genetic—of wild populations of marine organisms.

Summary of Recommendations

- Limit marine aquaculture to native species of the local wild genotype unless it can be demonstrated that the risk of harm to the marine environment from culturing other species is negligible.
- Culture native species in a manner that ensures escapes will not harm the genetics of local wild populations.
- Use siting criteria and require management measures to minimize risks to marine ecosystems from escapes of aquatic animals or release of viable gametes from aquaculture facilities.
- Support and coordinate research to reduce the risk of harm to the marine environment from escapes from marine aquaculture.

DETAILED RECOMMENDATIONS

8. Permits for marine aquaculture should be limited to native species of the genotype native to the geographic region, unless NOAA or the lead state permitting agency determines that scientific information and analysis demonstrates that the risk of harm to the marine environment from the permitted activity is negligible.[7] Since escapes from marine aquaculture are inevitable, marine culture of a nonnative species must be considered an intentional introduction. Animals that are capable of flourishing in culture in situ already possess significant characteristics, such as temperature and water chemistry tolerance, contributing to survival in the wild. Despite the problems caused by invasive species, we still have little capability to predict whether a given non-native species will become invasive if introduced into a new marine environment.

8.1. Federal enabling legislation for marine aquaculture should prohibit NOAA from issuing a permit for aquaculture in federal waters of a species not native to a geographic region and not previously cultured in the proposed region unless:

- **The agency conducts a public hearing on the permit; and**
- **The agency determines that scientific information and analysis demonstrate that the risk of harm to the marine environment from such culture is negligible.**

8.2. NOAA should, in coordination with the states, develop and apply a risk assessment protocol to determine the potential for harm to marine ecosystems from the culture of nonnative species. In developing such a protocol, the *ICES Code of Practice on the Introductions and Transfers of Marine Organisms 2004* is a useful point of departure.

8.3. In addition to requirements specified in the recommendations on governance, risk assessments for marine aquaculture of nonnative species and genetic strains should include consideration of risks to marine ecosystems from:

- **Establishment of feral populations;**
- **Competition with other species for space, prey, and other resources;**
- **Hybridization and loss of genetic diversity; and**
- **Pathogen and parasite transmission.**

8.4. The spawning, incubation or culture of genetically modified organisms (GMOs) should be prohibited in net pens, cages or any other systems open to marine waters of the United States unless the permitting agency:

- **Conducts a public hearing on the proposed activity; and**
- **Determines that scientific information and analysis demonstrates that the risk of harm to marine fish and wildlife from the proposed activity is negligible.**

[7] The Task Force does not intend this statement to apply to species that are already being commercially cultured in marine aquaculture in a region. Environmental risks from the culture of nonnative species already in culture in a region should be managed based on the risk assessment and other procedures outlined in this report.

9. **Culture native species in a manner that ensures that escapes will not significantly alter the genetic profile of local wild stocks.** The culture of the local wild genotype (not more than two generations removed from the wild) of native species is preferable from an environmental standpoint to the culture of nonlocal and nonwild genotypes and nonnative species. When culturing the local wild genotype of species within their native range, steps should be taken to ensure that the genetic profile of farmed stocks does not diverge from that of local wild stocks.

   9.1. **The marine aquaculture permittee should, as a condition of the permit, be required to provide access to farmed stocks by the responsible government agencies as needed to monitor the genetic profile of the farmed stock.**

   9.2. **Hatcheries producing juveniles for aquaculture should be required to replenish broodstock frequently from the wild.** This should be done consistent with management and restoration plans for the wild stock.

10. **Create a management framework to evaluate and minimize risks to marine life and ecosystems from escapes of mobile aquatic animals and the release of viable gametes from marine aquaculture facilities into marine waters.** Escapes of farmed species or the release of their gametes may expose marine wildlife and ecosystems to colonization by invasive species, introgression of genes not found in local wild populations, and disease. In addition, escape of farmed aquatic animals can potentially harm the long-term economic viability of commercial marine aquaculture operations. However, escapes cannot realistically be eliminated if net pen or sea cage systems are used. Therefore, the goal of escapes policy should be to eliminate or minimize the risk of harm to marine ecosystems.

   10.1. **For marine waters under their respective jurisdictions, clear responsibility and authority should be vested in NOAA and one state agency (for each state having jurisdiction over marine waters) to require aquaculture facilities to control escapes and to eliminate or minimize the risk from escapes.** Both native and nonnative species may pose risks to marine wildlife and ecosystems when they escape from culture. Risks should be evaluated based on ecosystem and site characteristics, culture methods used, and the species to be raised. To be effective, control methods, including management practices and control technologies, should be designed based on these specific risks. NOAA and the lead state aquaculture permitting agencies should have clear authority to require these practices and technologies and a mandate to use this authority to protect marine ecosystems.

   10.2. **Consistent with risk assessment guidelines called for in the governance recommendations, NOAA or the lead state permitting agency should be required to ensure that the risks posed by escapes are evaluated before it issues site and operating permits.** Risks that should be assessed include: the viability of the cultured organism in the surrounding ecosystem, such as its ability to colonize habitat, establish a feral population, and compete with wild stocks; the likelihood of transmission of disease or parasites to wild stocks; and, through hybridization with wild individuals, the reduction in fitness of wild populations. These risks should be evaluated in cooperation with other federal and state agencies with management responsibility for fish and wildlife.

- Risk assessments may be streamlined or waived for facilities that will contain only populations of native species of the genotype native to the geographic region that are not more than two generations removed from the wild.
- Risk assessments should not be waived if the species proposed to be cultured is endangered or threatened in the geographic region where culture will occur.

10.3. In consultation with other federal and state agencies, the aquaculture industry, scientists, engineers, and the public, NOAA or the lead state permitting agency, for their respective jurisdictions, should develop siting criteria and guidelines for best management practices (BMPs) to minimize the number and frequency of escapes and the ecological risks resulting from any escapes that occur.

- Siting criteria might include separating farms from habitat suitable for colonization to reduce the likelihood of colonization, excluding farms from marine protected areas and sensitive habitats, excluding areas critical to the survival of species of management concern, particularly threatened or endangered species, and locating facilities likely to discharge mature gametes of cultured organisms so that genetic and ecological risks to native species are negligible.
- BMPs for finfish might require use of predator-resistant cage materials, stocking of sterile fish or single sex stocks, and accurate methods for counting fish stocked in and harvested from net pens.
- BMPs for shellfish might require the use of sterile animals.

10.4. NOAA and the lead state permitting agency should be required to ensure implementation of measures at the farm level to eliminate or minimize risks associated with escapes. Such measures should be required as a condition of site and/or operating permits and be consistent with the level of risk. Some or all of these measures may be waived by the lead permitting agency if the facility in question will contain, as a condition of its operating permit, only populations of species of the wild genotype native to the region that are not more than two generations removed from the wild. At a minimum, NOAA or the lead state permitting agency should be required to take the following precautions to eliminate or reduce risks associated with escapes:

- Require farms culturing finfish or other mobile aquatic animals to include, in operating plans required for operating permits, measures to prevent, reduce and mitigate the impact of escapes. Such measures may include BMPs to be followed, containment technologies to be deployed and contingency plans to mitigate harm from escapes.
- In issuing operating permits for marine aquaculture facilities, make use of siting criteria whenever possible to eliminate or reduce the likelihood and ecological impact of escapes.
- Require monitoring for and reporting of escapes so that the permitting agency can verify compliance with the operating plan.

- Specify meaningful penalties for violation of permit conditions, including the possibility of permit revocation, and provide for liability for ecological and economic damage resulting from escapes using natural resource damage assessment methodologies where appropriate.
- Require farms containing finfish or other mobile aquatic animals to take measures so that animals from a farm can be identified should they escape.
  - Such measures may include marking or tagging, and should, at a minimum, include collection and retention of genetic material sufficient for identification to the farm level of escapes. Collection and retention of genetic material is not necessary if the farmed fish have been demonstrated, to the satisfaction of NOAA or the lead state permitting agency, to be genetically indistinguishable from local wild stocks.

11. Provide federal leadership in supporting and coordinating research to reduce the risk of harm to marine ecosystems from escapes. Research on the genetics of wild populations of species under development for aquaculture is essential to understanding the risks from hybridization between wild and farmed populations. If escapes cannot survive or reproduce in the wild, they pose far less of a threat to marine ecosystems. Advancing such traits is desirable from the standpoint of environmental protection, but it may be difficult to determine at what point the "domesticated" varieties no longer pose substantial risk. In the interim, they should subject to all measures necessary to mitigate escapes.

11.1. NOAA should coordinate and support research on:

- **The genetic structure of wild populations under consideration for aquaculture;**
- **Genetic, behavioral, and reproductive traits (e.g. triploidy) that would reduce the risk to marine ecosystems from escapes; and**
- **Identification of gaps in knowledge of and information on the factors affecting the likelihood of colonization by an introduced species.**

CHAPTER 5

AQUACULTURE DISEASE INTERACTIONS WITH THE ECOSYSTEM

Introduction

Farmers have long been concerned about the spread of disease, parasites, and pests among farm animals and from wild animals to livestock. Only recently, however, has attention been paid to the role that farm animals play in the introduction and spread of diseases to wildlife. Scientists have increasingly found evidence of disease "spillover" from agriculture into the ecosystem and the associated impacts on wild organisms (Power and Mitchell 2004). Several important examples have been found that highlight the role of terrestrial agriculture practices in the introduction of new diseases or the amplification of existing diseases and their transmission and retransmission to wild organisms, including some threatened and endangered species.

Marine aquaculture, as a relative newcomer to the world of agriculture has not been studied as extensively in terms of its role in disease spread, but one would expect that the same mechanisms for disease amplification and transmission exist, especially given the open nature of many aquaculture systems. Disease has been a problem with some forms of freshwater aquaculture. For example whirling disease has spread from fish culture operations and stocking efforts to populations of trout throughout North America (Nickum 1999). There are indications of disease transfer problems in marine aquaculture, including diseases of shrimp, oysters, and most recently evidence that salmon farms can act as reservoirs for parasitic sea lice, which can infect wild fish that migrate past farms.

In a recent study of the increase in diseases in ocean organisms, Harvell et al. (2004) suggest that aquaculture is likely a source of new pathogens entering wild populations in the ocean. Assessing the role of aquaculture and other modes of introduction of pathogens in the ocean is difficult, however, because of the paucity of information on the presence and distribution of pathogens in aquatic ecosystems. For example, very little is known about the distribution and role of pathogens in wild populations of fish (Blazer and LaPatra 2002). In contrast to aquaculture systems, where diseased fish are easily observed and diagnosed, sick fish in the wild are rarely observed. Additionally, since so little is known about diseases in wild populations it is often difficult to determine whether diseases have been introduced, by aquaculture or other means, to wild populations of organisms.

The transmission of disease between wild animals and farm animals is unequivocally known. Although it is a more recent phenomenon, the transfer of disease between wild aquatic organisms and farmed aquatic organisms is also known. While there has been little research into the mechanisms of transfer, the severity of impacts, or even the nature and prevalence of pathogens in the marine environment, there are several examples of transmission of pathogens from farmed aquatic organisms to marine wildlife. As marine aquaculture expands in terms of both volume and location, a risk-averse approach is to implement management and regulatory strategies to avoid problems before they become crises. These preventative measures are more effective in the long term in protecting the environment and the economic interests of the industry.

Ecological Risks from Aquaculture Diseases

According to Blazer and LaPatra (2002), "intensive fish culture, particularly of nonnative species, can and has been involved in the introduction and/or amplification of pathogens and disease in wild populations." The environmental effects associated with disease interactions between farmed and wild aquatic organisms can vary with the type of aquaculture system used, the species farmed, the scale and intensity of the operation, and the management practices employed. Generally, three types of disease interaction have been identified (Blazer and LaPatra 2002). These include:

- Introduction of novel pathogens to an area through the importation of exotic organisms for culture;
- Transfer of pathogens between areas through the movement of cultured aquatic organisms; and
- Amplification of pathogens that already exist in an area and their transmission from cultured to wild populations.

Disease and Parasite Interactions between Aquaculture and Wild Organisms

Over the past several years, the role of commercial salmon farms in transferring parasitic sea lice to wild salmon has become a research focus in both North America and Europe. A recent study (Krkosek et al. 2005) examined the impact of a single salmon farm along the migratory route of wild salmon in British Columbia and assessed the extent of parasite transfer between the farm and wild fish. The study examined sea lice infestations on wild juvenile salmon as they migrated past a salmon farm and mathematical models were used to estimate infection pressure on wild salmon from parasites emitted from the farm. Based on the model calculations, the authors concluded that the infection pressure near the farm was approximately 70 times greater than natural background levels. Additionally, as the salmon continued moving downstream, the infection levels exceeded background levels for 30 km past the farm along the migration route. Other researchers have found correlations between levels of sea lice in wild populations of fish and proximity to salmon farms in both the Atlantic and Pacific oceans (Penston et al. 2004; Butler 2002; Morton et al. 2004).

The introduction or transfer of disease has also occurred in shellfish aquaculture. There is evidence that disease introduction from bivalve mollusk transfers has been a problem in the past, though there are few recent reports, possibly because of improved management practices. Farley (1992) provides an overview of bivalve mollusk disease introductions resulting from geographic transfers, and concludes that diseases can and have been introduced by geographic transfer of mollusks, mostly oysters, resulting in mass mortalities in wild populations. For example, the parasite that causes the oyster disease MSX was inadvertently introduced to the East Coast of the United States from Asia through small-scale introductions of the Pacific oyster (NRC 2004b). The parasite, which is lethal to the native Eastern oyster and is now widespread along the entire East Coast, began causing mortalities in oysters in the Delaware and Chesapeake bays in the 1950s. The introduced parasite contributed to severe declines in populations of native oysters, with devastating impacts on the oyster industry.

Cohen (2002) reviewed the introduction by the abalone aquaculture industry of a nonnative parasitic worm to the coast of California in the early 1980s. The worm was accidentally introduced with imported South African abalone and quickly spread to and harmed native populations of abalone by weakening and deforming their shells, leaving them vulnerable to predation and leading to reduced growth and reproductive rates. After several years of monitoring and careful management, scientists are hopeful that the parasite has been eradicated.

Shrimp aquaculture has had many problems with diseases, which spread from one shrimp farming area to the next as the industry developed. The diseases have been devastating to the farmed shrimp stocks and at times have severely affected the industry in various parts of the world. Little is known, however, about the effect of these diseases on wild populations of shrimp in areas where they may have been introduced.

The feeds provided to some farmed fish have been implicated as another possible route of disease introduction. A study by Gaughan (2002) suggests that aquaculture may be responsible for a disease outbreak among sardines in waters off Australia in the late 1990s. The disease outbreaks in wild sardines occurred in the area of tuna feedlots, which used imported sardines as feed for the tuna. The imported fish are believed to have been the source of the exotic pathogen that rapidly spread through the population of wild sardines causing mass mortalities. The study extends concerns about the translocation of aquatic organisms to those used as unprocessed food products, and the biosecurity of aquaculture facilities, especially open systems such as cages and net pens.

Aquaculture Disease and Animal Health Management

Problems with diseases cause significant economic losses in aquaculture (Lee 2003). Diseases caused by viruses, bacteria, and fungi, as well as parasitic infections are common in farmed aquatic organisms and management measures are of the utmost importance in keeping them under control. As with other forms of animal health management, preventative measures are the most effective, cost efficient, and long lasting (Meyer 1991). The following have been suggested by Meyer (1991) as important preventative measures: preventing the introduction of pathogens, maintenance of good water quality, avoidance or reduction of environmental stressors, adequate nutrition, immunization, and isolation of cultured animals from feral stocks. Isolating cultured animals from wild populations is only possible with closed systems. This can not be accomplished with the use of marine aquaculture systems in which water flows freely between the farm and the surrounding environment. Proper siting of these types of systems, however, may provide a means of geographically limiting the interactions between farmed and wild stocks.

Biosecurity

The tools for the prevention, control, and eradication of infectious disease and the preservation of human, animal, and environmental health are referred to as biosecurity (O'Bryen and Lee 2003, cited in Lee 2003). Biosecurity is an important part of day-to-day operations as well as national and regional planning and regulation. This concept has become common in many sectors of the agriculture industry and is gaining acceptance in aquaculture. A variety of management strategies are employed to ensure biosecurity at aquaculture facilities. For example, finfish farmers generally use strategies such as cleaning and disinfecting, health inspections to ensure pathogen-free stock, and immunizations (Lee 2003). While the primary focus of biosecurity is on prevention of disease introduction, it is also important to have plans in place for control and management of diseases.

The Pacific Shellfish Institute (PSI) in 1996 developed a

Sea lice attached to a pink salmon. Research has linked the presence of salmon farms along salmon migratory routes to increased incidence of these harmful parasites in wild salmon.

Photo: ©Natalie Forbes /Corbis

health manual for the Pacific coast shellfish industry which is being implemented by hatcheries in particular. Most states and foreign countries require import permits documenting health status of animals crossing their borders. Shellfish hatchery and nursery facilities that ship interstate and/or internationally follow PSI High Health and Office International des Epizooties (OIE) protocols for routine disease screening and reporting.

Aquaculture Drugs

The lack of disease treatments available for aquaculture has been suggested as a possible constraint on the industry (Duff et al. 2003; NRC 1992). Though there is great interest in increasing the number of available drugs, currently only a limited number of aquaculture drugs are available for use in the U.S. Aquaculturists are primarily limited to 10 drugs that are approved by the U.S. Food and Drug Administration (FDA) for use in food-producing aquatic species (JSA 2004). Each of these drugs is approved for specific species, for specific disease conditions, and at specific dosages. The Minor Use Minor Species Act, enacted in 2004, created new mechanisms to facilitate the availability of drugs for "minor species" such as fish. One drug, the antibiotic florfenicol, has been approved for use in catfish under this law. Also available are investigational new animal drugs, which can be used in studies to collect efficacy and safety data, as well as other animal or human drugs that can be prescribed by a veterinarian for "extra-label" purposes. Aquaculturists may also use a variety of common substances, such as ice, salt, and carbon dioxide, which are considered unapproved new animal drugs of low regulatory priority.

Meyer (1991) suggested that the use of drugs or other chemicals to treat diseases in aquaculture should be considered an emergency or last resort measure. It is clear that there are environmental risks associated with the use of drugs in the aquaculture setting, especially in open systems. For example, Cabello (2006) provides a review of the human health, animal health, and environmental problems created by the use of antibiotics in aquaculture. According to the review, the use of large amounts of antibiotics in aquaculture, often in a prophylactic manner, "has resulted in the emergence of antibiotic-resistant bacteria in aquaculture environments, in the increase of antibiotic resistance in fish pathogens, in the transfer of these resistance determinants to bacteria of land animals and to human pathogens, and in alterations of the bacterial flora both in sediments and in the water column" (Cabello 2006). These problems are likely greatest in developing countries where antibiotic use often goes unchecked. In addition to antibiotics, the drugs used to treat parasites, such as sea lice, in marine aquaculture can cause ecological problems when they are released into the environment. Depending on the compound, parasite treatments can be added to food or used as a bath, but in either case there can be toxic effects on organisms in the surrounding environment. For a thorough review of the effects of chemical use in marine aquaculture see Chapter 6.

International Guidelines for Aquatic Animal Health

The Office International des Epizooties (OIE), also known as the World Animal Health Organization, was created in 1924 to promote awareness of disease problems associated with international trade in live animals and assist in their control and prevention. The OIE recommends processes and procedures by which animal health is managed and coordinated throughout the world. This includes the OIE Aquatic Animal Health Code, which provides recommendations to member countries, including the U.S., for measures to control the introduction and proliferation of aquatic animal diseases. Member countries agree to abide by the international standards established by the

OIE to reduce the risks of spreading aquatic animal diseases through trade. These measures include:

- Assessment of the health of aquatic animals in a production site, based upon inspections and standardized sampling procedures followed by laboratory examinations conducted in accordance with OIE guidelines;
- Restocking of open waters and farming facilities with animals of a health status equal to or greater than those in the area concerned;
- Eradication of diseases of socio-economic importance whenever possible; and
- Notification by every member country of additional national requirements, in addition to those provided by the Aquatic Code, for the importation of aquatic animals and aquatic animal products (OIE 2001).

National Aquatic Animal Health Plan

The National Aquaculture Development Plan created by the Joint Subcommittee on Aquaculture (JSA) identified several challenges related to aquatic animal health. The plan identified the need to protect the health of farmed and wild aquatic animals from the introduction of foreign animal diseases, reduce the proliferation and impact of diseases already existing in the U.S., and be proactive in developing and implementing programs of preventative medicine. Recognizing these needs and the fact that there is no coordinated management plan for federal waters, the JSA commissioned a national task force to develop a health plan for aquatic animals. Some coastal states do have aquatic animal health programs in place for state regulated waters, but a national plan could coordinate them in addition to providing protection for federal waters.

The National Aquatic Animal Health Task Force (NAAHTF) first met in 2001 and is led by the three federal agencies with primary responsibility for aquatic animal health: the Department of Agriculture, the Department of Commerce, and the Department of the Interior. The mission of the NAAHTF is to develop and implement a national aquatic animal health plan (NAAHP) for aquaculture in partnership and in cooperation with industry; regional organizations; state, local, and tribal governments; and other stakeholders. The goals of the NAAHP are to:

- Facilitate the legal movement of all aquatic animals, their eggs, and products in interstate and international commerce;
- Protect the health, and thereby improve the quality and productivity of, farmed and wild aquatic animals;
- Ensure the availability of diagnostic, inspection, and certification services; and
- Minimize the impacts of diseases when they occur in farmed or wild aquatic animals.

It is expected that the NAAHP will be completed by June 2007. Anticipated recommendations center on import protocols, indemnity, and control/management programs. The NAAHP, however, is a guidance document and any programs and regulations that are recommended must go through the federal rulemaking process before being implemented.

Effect of Marine Aquaculture Disease and Parasites on Wild Populations: Status and Progress.

As with any intensive animal husbandry, disease outbreaks in aquaculture are a constant threat that can affect the economic viability of the industry and create potential risks in the surrounding environment. The use of open systems in marine aquaculture, in which farmed organisms are in close contact with wild organisms, creates paths for disease transmission from farms to wild organisms and vice versa. It is unlikely that

As with any intensive animal husbandry, disease outbreaks in aquaculture are a constant threat that can affect the economic viability of the industry and create potential risks in the surrounding environment.

Vaccines…offer a way for the aquaculture industry to prevent disease in aquatic animals without the use of chemicals that ultimately end up in the marine environment.

these risks will ever be completely eliminated. Proper management and technological innovations, however, may decrease the level of risk. The following examples illustrate our current level of understanding of these phenomena and where progress has been made in addressing them.

State Disease Management Programs

As previously noted, a National Aquatic Animal Health Plan is being developed to manage aquaculture diseases and risks posed to wild aquatic organisms through aquaculture diseases. This plan could be especially important in developing policies and regulations if aquaculture operations move to federal waters and also in coordinating plans already in place for managing these problems in state waters. All states along the Atlantic coast, for example, have in place shellfish disease management policies, which are intended to reduce the risk of importing diseases and prevent the spread of diseases to cultured and wild shellfish (Anderson 2002). At present, however, there is a lack of coordination of these policies among states.

In the state of Maine, the outbreak of infectious salmon anemia (ISA) in 2001 in salmon farms that were in close proximity to endangered populations of Atlantic salmon created the risk of transferring this contagious and often fatal disease to the wild fish (NMFS 2005). As a precaution, the Maine Department of Marine Resources (DMR) implemented new fish health regulations. The new regulations included: mandatory surveillance and reporting of tests for ISA at salmon culture facilities; remedial actions for sites with confirmed ISA presence; restrictions on movements of vessels and equipment; husbandry standards, such as a prohibition on the mixing of different year-class stocks and minimum fallowing periods between production cycles; as well as regular third party biosecurity audits (NMFS 2005). Despite these improved measures, ISA virus was detected at salmon farms in Maine in 2003 and 2004. Thus far ISA has not been detected in wild salmon in the U.S.

Aquatic Animal Vaccines

Vaccines, though certainly not a substitute for management practices and biosecurity protocols at aquaculture facilities, offer a way for the aquaculture industry to prevent disease in aquatic animals without the use of chemicals that ultimately end up in the marine environment. Vaccines show the most promise for finfish—as opposed to crustaceans or mollusks—and are used to provide long-term protection against specific pathogens. A limited number are currently available for aquatic species (JSA 2004), but research and development are proceeding on additional vaccines (Haskell et al. 2004) and on more effective methods to administer them. In addition to their role in preventing disease outbreaks at farms, and therefore the potential spread of diseases, the use of vaccines in aquaculture could lead to reduced use of therapeutic chemicals. For example, the salmon farming industry in Norway has greatly decreased its use of antibiotics, from a high of nearly 50 metric tons in 1987 to current levels of less than one metric ton per year (Norwegian Directorate of Fisheries 2001). Much of this improvement has been attributed to the increased availability and use of vaccines combined with better husbandry practices.

Integrated Pest Management

Historically, strategies to deal with sea lice on salmon farms involved treatment with chemicals when infections became a problem. In recent years, the industry has begun testing other techniques, including integrated pest management, which involves preventative management strategies, monitoring, and treatment when necessary.

While the preventative strategies may vary based on species, location, and other variables, there are several that appear to be especially effective in salmon aquaculture and may provide a useful model for other segments of the industry. For example, it is important to site facilities in areas where oceanographic conditions make infections less likely as well as avoiding areas, such as at the mouths of salmon spawning rivers or along migratory routes of salmon, where transmission to and from wild salmon is likely. Other important strategies include: year-class separation, in which new fish are not added to a facility holding older fish because diseases or parasites could be passed on from one generation to the next; fallowing, in which facilities are left empty for several weeks to months in order to break the life cycle of pathogens or parasites; and other management strategies, such as maintenance of proper fish densities (Health Canada 2003). Integrated pest management, with its increased reliance on preventative measures and decreased dependence on chemical treatments, may provide a more economically and environmentally sustainable way of controlling diseases in marine aquaculture.

Probiotics

Propbiotics refers to the use of microorganisms in a positive way to benefit health. Probiotics have been used in fish farming to prevent bacteria that cause disease from attacking stocks. The Pacific Shellfish Institute has supported research investigating the use of probiotics to increase the efficiency and production of seed shellfish (oysters, clams, and other bivalves) in U.S. hatcheries by preventing bacterial diseases. Disease prevention is accomplished by the replacement of disease-causing bacteria by safe and beneficial (priobiotic) bacteria.

Discussion and Conclusions

Although there currently is very little information regarding the distribution of pathogens and parasites in wild populations of marine fish, there are significant risks to wild populations of fish through the introduction and amplification of diseases from aquaculture. Based on the experience in aquaculture and agriculture to date, diseases can and have been introduced to new areas by farming activities and in some cases these diseases have had dramatic impacts on wild populations. The "spillover" effect of aquaculture diseases, in which farms can amplify a disease and spread it to the surrounding environment, has recently been identified as a threat to wild populations of aquatic organisms. Additionally, wild populations may act as reservoirs for disease and continuously reinfect farm stocks, creating a dangerous cycle where the ecosystem and aquaculture stocks, and consequently the economic viability of farms, are put at risk.

As the marine aquaculture industry expands in volume and location, it is reasonable to assume that there will be disease interactions with the ecosystem. A risk-adverse approach is to implement management and regulatory strategies to avoid problems before they become crises. Experience indicates that preventative measures are more effective in the long term in protecting the environment and the industry. Careful management and monitoring are needed to address disease interactions between aquaculture and the ecosystem. Additional research is needed to better understand the nature and pathways of disease transmission in the marine environment and to better assess the risks to marine ecosystems from pathogens mediated by aquaculture.

Summary of Recommendations

- Establish and maintain a database on disease and parasite distribution in marine waters to inform permitting decisions.
- Use siting whenever possible to eliminate or reduce the likelihood and ecological impact of diseases and parasites.
- Establish management practices for the prevention and treatment of diseases in farmed aquatic organisms to minimize impacts on the marine ecosystem.
- Support research and development of aquatic animal husbandry and disease management strategies that will reduce the risk of harm to marine ecosystems.

DETAILED RECOMMENDATIONS

12. Establish and maintain a database on diseases and parasites in marine waters. Baseline information should be collected to identify pathogens and parasites that infect the species to be cultivated in areas that are targeted for aquaculture production. The Fish and Wildlife Service conducts a National Wild Fish Health Survey to collect information on the distribution of pathogens and parasites in freshwater and—to a lesser extent—estuaries, but little focus has been placed on marine waters.

12.1. The National Wild Fish Health Survey should be expanded (or a similar program established) to develop diagnostics and proactively identify the presence and distribution of pathogens in areas and species targeted for marine aquaculture.

12.2. NOAA or the lead state permitting agency should use information from the database to inform permitting decisions, especially in regards to species and site selection.

13. Use siting whenever possible to eliminate or reduce the likelihood and ecological impact of diseases and parasites.

13.1. NOAA or the lead state permitting agency should develop siting criteria to eliminate or reduce the likelihood and ecological impact of diseases and parasites. Criteria should include:

- Avoiding areas with dense populations or seasonal aggregations of wild fish or other marine wildlife that may be susceptible to diseases or parasites that may be found in aquaculture facilities. For example, farms sited along migratory paths of wild fish populations may make the wild populations vulnerable to diseases or parasites transferred from the farm or vice versa.
- Avoiding habitat for endangered or threatened species that may be vulnerable to diseases or parasites that may be found in aquaculture facilities.

14. Establish management practices for diseases and parasites that minimize the occurrence of outbreaks and that minimize the use of drugs. NOAA, in coordination with USDA APHIS and other federal and state agencies should develop guidelines for the prevention and treatment of diseases in farmed aquatic organisms to minimize impacts on the marine ecosystem. The National Aquatic Animal Health Plan, which was commissioned by the Joint Subcommittee on Aquaculture and is expected to be completed in 2007, may provide useful guidance to agencies in formulating regulations in this regard.

14.1. Guidelines, which will vary based on species, production system, site variables, and the disease, parasite, or pest of concern, should include:

- Measures to be taken to minimize the risk of disease outbreaks on farms, including husbandry practices, stocking density, water quality, and other living conditions.
- Measures to ensure biosecurity and prevent the spread of diseases, parasites, and pests between neighboring farms or between stocks or year classes on the same farm. Measures to achieve this might include stocking farms with certified disease-free animals and the use of single year class stocks.

- Restrictions on the use of products or materials from outside the geographic region of the farm that may carry diseases, parasites, or pests.
    - The use of unprocessed feeds (including raw fish or fish parts, either fresh or frozen) obtained from outside the geographic area of the farm should be prohibited.
- Measures for the safe and efficient use of drugs, vaccines, and other products used to prevent and treat disease and parasites, including—
    - In cases where vaccines have been developed, they should be used to maintain fish health and prevent outbreaks of disease.
    - When needed to treat disease, drugs should be used under the supervision of a veterinarian. Drugs should not be used in the absence of a clinical sign of disease.
    - The impacts of drugs on the marine ecosystem should be evaluated before their use and drugs with the least impacts selected.
    - Extra-label use of drugs for aquatic animals in net pens or similar structures should be prohibited, unless the drug was specifically approved for use in fish grown in a similar ocean environment.

14.2. Compliance with the guidelines should be a condition of any permit issued. Eligibility for government assistance, including indemnification, should be contingent on adherence to the guidelines.

15. Support research and development of aquatic animal husbandry and disease management strategies that will reduce the risk of harm to marine ecosystems.

15.1. NOAA should coordinate and support research on:

- **Vaccines and diagnostics,**
- **Disease prevention measures, and**
- **Biosecurity protocols.**

CHAPTER 6

WATER POLLUTION

Introduction

The dramatic expansion of salmon and shrimp farming in recent decades has heightened concerns about pollution from marine aquaculture. As with any concentrated animal rearing operations, aquaculture facilities produce a variety of wastes that are potentially harmful to the environment. Unlike terrestrial livestock operations, however, marine aquaculture facilities discharge their untreated wastes directly into coastal and ocean waters. In the United States, aquaculture discharges are currently small compared to other sources of water pollution, but little is known about the assimilative capacity of the marine environment for these pollutants. Additionally, marine aquaculture operations tend to cluster geographically, raising the potential for cumulative impacts. Wastes from marine aquaculture generally include dissolved (inorganic) nutrients, particulate (organic) wastes (feces, uneaten food and animal carcasses), and chemicals.

The extent to which the environment is affected by pollution from aquaculture depends on a variety of factors, including the species being cultured, the culture method and practices, and oceanographic characteristics of the culture site. The farming of finfish in cages or net pens, for example, requires large inputs of food and can result in the discharge of substantial amounts of wastes. Farming of filter-feeding mollusks, on the other hand, in which no feed is added to the system, promotes the recycling of nutrients within the coastal ecosystem.

Numerous studies and reports (NRC 2000, Howarth et al. 2000, Boesch et al. 2001, U.S. Commission on Ocean Policy 2004) have documented the harmful effects of nutrient pollution in estuarine and coastal waters. Aquaculture discharges of inorganic nutrients are currently small relative to other waste loads, such as terrestrial agriculture and sanitary sewerage, but because marine aquaculture wastes are discharged untreated into coastal and ocean waters, they can be significant contributors of nutrients in relatively pristine or poorly flushed sites. The effect of organic enrichment of the sediments beneath net pens and sea cages has been extensively documented, although these effects also appear currently to be local and temporary.

If U.S. marine aquaculture expands dramatically, as called for by the Department of Commerce and others, pollution from a greatly expanded industry could have significant effects locally and regionally. On the other hand, increased culture of filter-feeding mollusks—for commercial purposes and for wild stock restoration programs—has been proposed as a way to mitigate the harmful effects of eutrophication (NRC 2004).

Although net pen or sea cage aquaculture facilities are point sources of pollution that are relatively easy to monitor, there is a wide variety of interpretations regarding the severity of environmental impacts, both locally and regionally. One perspective is that the effects of the aquaculture industry, even if greatly expanded, would be small, especially when one considers that aquaculture wastes make up a small fraction of the pollutants entering coastal waters. Others have argued

In the United States, aquaculture discharges are currently small compared to other sources of water pollution, but little is known about the assimilative capacity of the marine environment for these pollutants.

that on a local scale, pollution from aquaculture can be significant and does in fact pose a serious threat to marine ecosystems.

Considering that clean marine waters are a prerequisite for economic success for the aquaculture industry and are highly valued by the public, it is in the interest of the industry as well as society at large to minimize pollution from aquaculture facilities. If the U.S. industry expands considerably, the choices made regarding the species and methods of culture, as well as the location and concentration of facilities, will determine whether pollution effects from marine aquaculture will be substantial or minor. Below we examine studies on pollution from marine aquaculture and its effects on the marine environment. Through this review, as well as through the Task Force's extensive discussion with marine scientists, aquaculturists, government regulators, and interested members of the public, we attempt to reach some conclusions regarding the nature and severity of such pollution, and the best approaches to control it.

Waste Discharges and their Effects on the Marine Environment

A number of reports have attempted to quantify the nutrient outputs from marine fish farming. Unfortunately the various reports do not use a common measure. Some authors estimate discharges per ton of fish produced, others estimate discharges per day at various size farms, and others attempt to compare discharges from fish farms to human waste equivalents. Where possible, these figures have been converted to kg nutrient per ton of fish produced and are summarized in Table 6-1.

An early review by Folke et al. (1994) examined the issue of eutrophication from salmon farming in Nordic countries and concluded that salmon farms produced and released large amounts of nitrogen and phosphorus. Using estimates current at that time of nutrient discharge of 78 kg of nitrogen and 9.5 kg of phosphorus per metric ton of fish produced (Ackefors and Enell 1994), it was estimated that a salmon farm producing 100 tons of salmon in cages releases the equivalent nitrogen and phosphorus of a settlement of 1,950 and 850 people, respectively. Folke et al. (1994) concluded that if the human equivalent discharges of nitrogen and phosphorus are extrapolated to account for the entire salmon farming industry in the Scandinavia, then a substantial amount of nutrients are released, possibly as much as large cities or even small countries.

Using calculations based on production figures, feed inputs, and feed conversions, Enell (1995) found that large amounts of nitrogen (13,750 tons) and phosphorus (1,200 tons) were discharged from large-scale salmon farming operations into the Baltic Sea. Enell (1995) determined that in 1994 about 55 kg of nitrogen and 4.8 kg of phosphorus were discharged for every ton of fish produced, and noted this is considerably less than per ton discharges in the early days of the industry. Nonetheless, the total amount of nutrients discharged increased dramatically because of a large expansion of the industry. The author concluded that nutrient loads from fish farms can have an impact on specific areas and should be considered in environmental assessments. The overall pollution load from fish farming compared to other sources in the region, however, was deemed insignificant.

In another review, Wu (1995) suggested that about 85 percent of phosphorus, 80 to 88 percent of carbon, and 52 to 95 percent of nitrogen input into marine fish farming systems may be lost to the environment through feed wastage, fish excretion, feces, and respiration. Wu (1995) suggested that a large amount of the pollution accumulates in the bottom sediments under farms. Impacts of wastes on the benthos include high sediment oxygen demand, anoxic sediments, production of toxic gases, and a

TABLE 6-1.

Estimates of nitrogen and phosphorus (kg per metric ton of fish produced) released from various types of cage aquaculture. *(Adapted from Islam 2005)*

Nitrogen	Phosphorus	Species cultured	Feed type	Source
78	9.5	Atlantic salmon	Pellet	Ackefors and Enell 1994
55	4.8	Atlantic salmon	Pellet	Enell 1995
35	7.0	Atlantic salmon	Pellet	ICES 1996
104	18	Gilthead seabream	Pellet	Lupatsch and Kissil 1998
321	—-	Areolated grouper	"Trash fish"	Leung et al. 1999
47-71	8-15	Rainbow trout	Various pellets	Bureau et al. 2003
20-30	6.7	Atlantic salmon	Pellet	Brooks and Mahnken 2003
76	8	Barramundi snapper	Pellet	Dept. of Fisheries, Western Australia 2003*
160	35	Mandarin, bream, & Channel catfish	Forage fish & formulated diet	Guo and Li 2003
133-463	25-80	Various marine spp.	Various	Islam 2005**

*Cited by Islam 2005

**Based on the results of two models meant to represent the breadth of species and methods of cultivation in sea cage culture worldwide.

decrease in benthic biodiversity, though significant impacts are believed to be limited to the general vicinity of the farm. Water column impacts around farms generally include decreased oxygen content, increased biological oxygen demand, and increased nutrients. The amount of pollution and wastes and their impact, however, was dependant on species, farming practices, and site variables. For example, Wu reported extensive water column and benthic effects from Asian fish farms feeding "trash fish" to the cultured species. This was likely due to increased wastage of food and poor feed conversion efficiency when using relatively unprocessed fish as feed.

Hardy (2000) calculated the amount of wastes produced by a single average salmon farm and compared it with the dissolved nutrients in human waste. It was estimated that a salmon farm producing 200,000 five kg fish discharges about 396 kg of nitrogen per day, or the equivalent of about 20,000 people; 40kg of phosphorus per day, or the equivalent of about 27,000; and 2,500 kg of fecal solids, or the equivalent of about 62,500 people.

Islam (2005) provides a review of the issues associated with effluent discharge from coastal aquaculture facilities in Asia and estimates the total discharge into the environment of nitrogen and phosphorus from marine aquaculture. Islam (2005) concludes that the nutrient impact from fish farming is a function of feed conversion and wastage, feed composition, and metabolic processes in the fish. Based on one set of model calculations, the author estimates that for each ton of marine fish produced, about 132.5 kg of nitrogen and 25 kg of phosphorus are discharged into coastal waters. Using another model, the author estimates these figures could be as high as 462.5 kg of nitrogen and 80 kg of phosphorus discharged for each ton of fish produced. These calculations are significantly higher than the figures produced by Enell (1995). However, Enell (1995) only considered the highly developed salmon farming industry, in which there has been considerable effort to refine diet formulations and improve feed conversions. The calculations by Islam (2005) are very general in nature and are meant to include

…the impacts from aquaculture wastes, though likely small in relation to other sources such as biological nitrogen fixation, are of greatest concern when facilities are clustered geographically and when sited in moderately flushed areas.

the global cage aquaculture industry, which includes a wide variety of technologies and species at various stages of aquaculture development.

Goldburg and Naylor (2005), in a review of issues associated with the development of marine aquaculture, provide some estimates for the amount of nutrient pollution that could be released by an expanded industry. Using estimates from Brooks and Mahnken (2003) for the amount of nitrogen released per kilogram of farmed salmon produced, they estimate the amount of nitrogen released by the salmon farming industry in British Columbia. Extrapolating from the known economic value of the British Columbia salmon farming industry and their estimate of nitrogen production by that industry, the authors then estimate nitrogen output from a $5 billion U.S. marine aquaculture industry if it had similar rates of nitrogen production as salmon farming. They conclude that nitrogen discharges from a marine aquaculture industry of this size could amount to 108,000 to 158,000 mt per year. The authors note that this is equivalent to the nitrogen in the untreated sewage from about 17.1 million people or in wastes from the North Carolina hog industry. According to the authors, the impacts from aquaculture wastes, though likely small in relation to other sources such as biological nitrogen fixation, are of greatest concern when facilities are clustered geographically and when sited in moderately flushed areas.

Several recent studies have observed damage to the benthos as a result of fish farming activities. Loya et al. (2004) reported on the effect of sea cage aquaculture on corals in the Red Sea. Coral reproduction was impaired at a site close to cage fish farms compared to a reference site farther away. High levels of nutrients released from the fish cages were believed to cause eutrophication that reduced the ability of the corals to successfully produce larvae, thus contributing to the degradation of reefs. Corals at the eutrophic site also had lower lipid levels during the reproductive season, possibly signaling poor nutrition.

Boyra et al. (2004) studied the effect of cage farms on benthic communities in the Canary Islands by comparing the composition and coverage of the macrobenthic assemblages near two sea cage farms with control locations. They found that pollution from the farms impacted benthic communities in terms of species composition and coverage. At two sites near fish farms examined in the study, the presence of pollution tolerant species and filter-feeding species was observed and appeared to indicate an impact caused by wastes from fish farming activities.

Several studies correlated the presence of seabass and seabream cage farming operations in the Mediterranean Sea with the decline of seagrass meadows around the fish farms (Pergent et al. 1999, Ruiz et al. 2001). Impacts on seagrass meadows are of concern because of their importance in the structure and functioning of coastal ecosystems. In the areas around the fish farms, the authors observed an increase in turbidity in the water column and enrichment of the sediments with organic matter and nutrients. In some cases, directly below farms there was complete loss of seagrass and in nearby areas there were declines in shoot biomass and leaf growth. The authors concluded that the declines in seagrass observed in the studies could be explained by the discharges from the nearby fish farms.

Another study reported on the long-term effects of fish farming on seagrass meadows in the Mediterranean and showed that even after cessation of fish farming, environmental impacts can continue and the environment can be slow to recover. Delgado et al. (1999) examined a range of sites, from a disturbed area close to a former fish farm site to undisturbed areas. Although the fish farm had stopped operating several years earlier, effects on seagrass were still observed. Water quality had recovered so the authors proposed that the persistent impact on the seagrass—

including reduced shoot density, biomass, and photosynthetic capacity—was a result of the persistence in the sediment of excess organic matter discharged by the fish farm.

Brooks and Mahnken (2003) review the effects caused by the release of wastes from salmon farming into the water column and onto the benthos in the Pacific Northwest. The authors reach several conclusions about the environmental impact of salmon farms. First, based on monitoring of both poorly and well-flushed sites, they find little potential for significant enhancement of phytoplankton populations and little risk from reduced concentrations of dissolved oxygen associated with salmon farming in the region. Second, biodeposits from salmon farms can affect sediment chemistry and macrobenthic communities. The effects of such changes can be correlated with the depth and current speed at each farm site. Finally, chemical and biological remediation of the benthos occurs naturally when salmon farming is stopped. Remediation can occur very quickly or can take several years, depending on the site's oceanographic characteristics. Natural remediation occurs in a series of successional stages in which opportunistic and pollution tolerant species are gradually replaced by fauna increasingly indicative of conditions prior to the onset of fish farming.

Experimental aquaculture operations in the U.S. and the Bahamas have produced insights on the nature and fates of discharges from sea cages in oceanic or near-oceanic conditions. Alston et al. (2005), in an unpublished project report, provided results from the culture of mutton snapper and cobia at relatively low densities (approximately 1.3 and 4 fish/m3, respectively) in sea cages moored ½ mile off Puerto Rico where ocean depth averaged 28 meters and current averaged 8.4 cm/second. These authors report no significant difference between the experimental and control sites in dissolved phosphate and nitrogen, organic matter in sediments, and organic nitrogen in sediments. They also found no evidence of anaerobic sediments beneath the sea cages. There was a significant increase in benthic macroinvertebrates beneath the cages. The lack of a significant increase in dissolved and organic nutrient concentrations near the sea cages was attributed to the tremendous dilution effect of the currents continuously "flushing" the sea cages.

The effect of one 3000 m^3 sea cage moored off Eleuthra Bahamas was reported by Benetti et al. (2005) in an unpublished project report. The cage was stocked with 14,000 cobia fingerlings, which grew to over 3 kg in less than one year, for an estimated economic feed conversion ratio of 2:1.[8] This ratio is greater than that currently reported for most commercial salmon operations, but is considerably less than that reported for some other marine species. The authors note that increased microalgal biomass is likely to be a better indicator of eutrophication than increased dissolved nutrient concentration in subtropical marine ecosystems. This is based on the assumption that ambient nutrient concentration would only be expected to increase significantly in such nutrient-starved ecosystems if the assimilative capacity of the phytoplankton for nutrients had been exhausted. Accordingly, clean fouling plates were placed up- and down-current from the sea cage. Over the one-year period of monitoring, no significant increase in microalgal biomass was observed, nor were significant increases in dissolved oxygen, total nitrogen, and total phosphorus found.

Results from a demonstration project ½ mile off the Isles of Shoals, New Hampshire, show similar results. Atlantic halibut, haddock and cod have been cultured at various

[8] The feed conversion ratio is the weight of feed used to live farmed fish harvested. It provides a relative measure of the economic efficiency of aquaculture species and practices. Details of the computation and interpretation of feed conversion ratios is discussed in chapter 7.

Concerns about chemical pollution from fish farming center around medications or other treatments used to keep farmed fish disease and parasite free.

times at low densities in up to four sea cages at a site with 55 meters water depth. The largest number of fish raised in the facility is 30,000 cod, which were stocked as 3 g fingerlings in 2003 and kept at the site for nearly two years. In an unpublished environmental monitoring report for the project (Ward et al. 2005), researchers found no significant change in sediment organic matter content and grain size. The benthic fauna showed no significant trends in density, biomass or diversity. Pollution intolerant taxa were in the majority at experimental and control sites. Monthly water quality monitoring showed no significant trends in total suspended solids, particulate organic content, chlorophyll and dissolved oxygen among sampling sites up-current, down-current and adjacent to the fish pens. Water samples were not tested for inorganic nutrient content.

In contrast to other studies done on pilot-scale operations, a study of the benthic effects of sea cage fish culture offshore Oahu, Hawaii, at a commercial scale showed significant impacts (Lee et al. 2006). During the study period, Cates International operated three 3000 m^3 sea cages 2 km offshore Ewa Beach, Oahu. The water depth averages 30 meters but the cages were submerged approximately 10 meters off the bottom. Up to 130,000 Pacific threadfin, known locally as moi, could be enclosed in each cage.[9] Although previous unpublished benthic and water quality monitoring data indicated no significant effects, the benthic fauna showed considerable changes during the course of this study, indicating the effects of organic enrichment of the sediments under and near the sea cages. Replicate benthic core samples were taken on 12 sampling dates spanning three years.

These authors found anaerobic conditions under the sea cages and reduced redox potential at a site 80 meters away from the cages, indicating hypoxic conditions in the sediments there. The benthic fauna showed decreased diversity and predominance of opportunistic species under and near the cages relative to up-current and down-current control sites. Further, benthic diversity at the impacted sites decreased over the course of the study, with the sampling site 80 meters from the sea cages initially more closely matching control sites, but later more closely resembling the site under the cages in terms of species abundance and diversity. One species that typified control sites disappeared altogether from the impacted sites 1½ years into the study. The authors conclude that the changes in benthic infauna over the course of the study follows a typical pattern for organic enrichment of sediments, as the site under the sea cages evolved into a highly polluted site and the site 80 meters down-current followed, indicating that the benthic effects had spread well beyond the physical footprint of the sea cages. In this case, notwithstanding the "open water" location of sea cages and robust longshore current, substantial alteration of the benthic environment resulted from commercial marine aquaculture operations.

Chemicals

Concerns about chemical pollution from fish farming center around medications or other treatments used to keep farmed fish disease and parasite free. One of the largest concerns is with pesticides used to control parasites—technically known as parasiticides—because these substances are directly discharged into the marine environment, either through in situ bath treatments or

[9] Cates International reports harvesting moi at ¾-1 lb. If we assume that the average weight of fish over the course of growout is ½ lb. and no mortality, that translates into a potential average stock density in the cages of about 10 kg/m^3. For comparative purposes, commercial salmon farms report stock densities in the range of 15-40 kg/m^3 and organic standards for net pen culture of fish adopted by the Organic Food Federation require maintaining a density of 10 kg/m^3 or less for salmon and 15 kg/m^3 for cod.

after passing through fish when they are administered in feeds. Though some chemicals appear to be very effective treatments, there is very little known about the lethal and sublethal effects of the chemicals on nontarget marine organisms. Some studies have found pesticides to be toxic to marine organisms in laboratory settings or under particular conditions. Others have hypothesized that in the natural environment, currents and dilution limit the extent to which the chemicals can cause toxic effects.

The most studied parasite treatments are those used to control sea lice on farmed salmon. Sea lice are parasitic copepods that can increase mortality in juvenile fish and substantially reduce growth of farmed fish if not treated. Several scientific studies from the mid- to late 1990s focused on a particular chemical, ivermectin, which was beginning to be used in the industry. Ivermectin acts as a neurotoxin on sea lice and is delivered to fish in feed, but it is poorly absorbed by the fish so a large percentage of the dosage is excreted in feces (Davies and Rodger 2000). Several studies have shown that ivermectin is toxic to marine life. In laboratory experiments, Thain et al. (1997) demonstrated that ivermectin is toxic to the lugworm, even at low concentrations in the sediment. Additionally, sublethal effects on feeding activity were observed. In another laboratory experiment, Collier and Pinn (1998) studied the effect of ivermectin on benthic communities. The researchers concluded that ivermectin may pose a significant risk to benthic fauna, but that the level of contamination and the duration of exposure are important variables in determining the extent of any impact. Davies et al. (1998) cautioned that there may be significant risks to polychaetes in sediments below and around salmon farms when ivermectin is used. Davies et al. (1998) also observed that the half-life of ivermectin is greater than 100 days in marine sediments.

More recent studies of other neurotoxins used to control sea lice in salmon farming have resulted in mixed conclusions. Ernst et al. (2001) studied the potential impact on coastal ecosystems from two pesticides, azamethipos and cypermethrin. Of the two, the authors conclude that azamethipos posed a much lower risk, while cypermethrin was found to be highly toxic to marine organisms. These authors also studied the dispersion of the pesticides into the marine environment after their use as sea lice treatments. Pesticide treatments were simulated, with a dye added to the pesticide treatment so that dispersion could be monitored. The dispersion experiment took place in the Bay of Fundy, a salmon farming area with high tidal flows. After studying the dispersion of the pesticides it was concluded that treatment with cypermethrin creates the potential for "lethal plumes," which can cover up to a square kilometer from the treatment of a single cage. The dye was detected up to 3000 meters away from the release point at the farm and is believed to be closely correlated to the dispersion of the pesticide. Another important observation of the research was that the dye, and therefore the pesticide, was found to move into the intertidal zone—an area rich in benthic organisms that could be harmed by the chemicals.

Other studies have focused on the potential effect of pesticides on lobsters, a species of great commercial importance in areas of coastal Maine and maritime Canada with extensive salmon farming. Burridge et al. (2000a) examined the effects of cypermethrin on the American lobster. Cypermethrin has been used by

Farmed oysters in Puget Sound, Washington. Bivalve mollusks feed by filtering plankton out of surrounding waters. As a result, shellfish farming can help to clean coastal waters with excessive plankton production caused by nutrient pollution.

Photo: Bill Dewey

Antibiotic use in net pen or sea cage culture is a concern because the treatments are discharged to the environment through fish feces or through uneaten food, where they can contribute to the development of resistant strains of bacteria.

salmon farmers in Maine to control sea lice. The study found that cypermethrin is lethal to larval stages of lobsters and that the lethal concentrations of the pesticide are much lower (1.2 to 3.6 percent) than the recommended sea lice treatment concentration. Using mathematical modeling, however, the authors determined that in an operational setting, organisms such as lobsters may not be exposed to lethal concentrations for enough time to experience adverse effects. In an attempt to more accurately model a real world situation in which pesticides are used and released to the environment, Burridge et al. (2000b) conducted a laboratory experiment in which lobsters were intermittently exposed to sea lice treatments. The researchers found that although stage IV larval lobsters were not affected by the sea lice treatments, repeated exposure to high concentrations of the pesticides azamethipos and cypermethrin harmed adult lobsters. In another study, Waddy et al. (2002) report on the effects of emamectin benzoate, another sea lice treatment, on the molting behavior of the American lobster. This laboratory study demonstrated that emamectin benzoate disrupts the endocrine system in lobsters. The authors found that the chemical interferes with a molting hormone, leading to premature shedding of the shell.

Antibiotics are another class of drugs used in aquaculture that may have substantial environmental effects. Antibiotic use in net pen or sea cage culture is a concern because the treatments are discharged to the environment through fish feces or through uneaten food, where they can contribute to the development of resistant strains of bacteria. Very little is known about the effects of antibiotic use on the marine environment, or for that matter, the extent of antibiotic use in aquaculture. However, there are indications that antibiotic use is relatively high when new segments of the industry develop, but as advancements are made—such as vaccines, breeding for disease resistance, and improved understanding of culture practices—the dependence on antibiotics in the industry sector lessens. For example, annual antibiotic use by salmon farmers in Norway declined from a high of nearly 50 tons in the late 1980s to current levels below 1 ton (Norwegian Directorate of Fisheries 2001).

Several researchers have reported on the environmental effects of antibiotic use at fish farms. Ervik et al. (1994) examined the level of antibiotic resistant bacteria living in blue mussels and in the guts of wild fish, as well as antibiotic residues in the muscle tissue of wild fish living near Norwegian salmon farms at a time when antibiotic use was relatively high. They found large increases in both resistant bacteria in mussels and wild fish, and in antibiotic residues in wild fish after the antibiotics oxytetracycline and oxolinic acid were administered on the farms.

Capone et al. (1996) conducted field sampling for antibiotics in sediments and aquatic organisms under and around salmon farms in Puget Sound, Washington. Detection of antibiotic residues in sediments at the farms varied widely and was generally limited to the area under the farm. Antibacterial residues were not present in oysters and only trace residues were present in Dungeness crabs collected from the area around the farms. However, high levels of antibacterial residues were found in the edible meat from red rock crabs collected from around the farm. In fact, residual antibiotic concentrations were well above the U.S. Food and Drug Administration limits and they persisted in red rock crabs for at least two weeks.

Chelossi et al. (2003) sampled areas around a Mediterranean fish farm for levels of bacteria, types of bacteria, and their resistance to antibiotics. Observations were made in the area of the farm as well as at a control location 200 meters away. The researchers found high levels of bacteria in sediments under the fish farm and they reported that many of the bacteria (96 percent) in the farm and control locations were resistant to antibiotics, suggesting widespread antibiotic resistance in areas surrounding fish farms. A high number of antibiotic resistant gram-negative bacteria were isolated from sediments under the fish farm, which the authors attribute to adaptation in the bacterial community as a result of common use of ampicillin by the fish farm. In another recent study from the Mediterranean region, Rigos et al. (2004) estimated the release of two antibiotics, oxolinic acid and oxytetracycline, into the environment from Greek sea bream farming operations. Rigos et al. (2004) collected data on antibiotic absorption and fecal excretion in sea bream held in a laboratory then, using data on sea bream production and antibiotic use in Greece, they estimated the annual release of antibiotics from fish farms. The absorption data indicated that 60 to 73 percent of the oxytetracycline and 8 to 12 percent of the oxolinic acid administered to sea bream is lost in feces. Results from the calculations of annual antibiotic discharges indicate that more than 1,900 kg of oxytetracycline and 50 kg of oxolinic acid are released from Greek sea bream farming to the environment.

The Regulatory Environment for Marine Water Quality

Background

The Clean Water Act (33 U.S.C. 1251 et seq.) is one of the major federal statutes regulating marine aquaculture in the United States. Enacted by Congress in 1972 as the Federal Water Pollution Control Act, and subsequently amended to its current form, the Clean Water Act (CWA) is the fundamental federal law controlling pollution of fresh and marine waters. Although the purpose of the Clean Water Act is to reduce or eliminate pollution as an outcome, as a practical matter the Act controls the discharge of pollutants as an action. The CWA's primary mechanism of operation is its requirement that anyone discharging pollutants from a point source into the waters of the United States may only do so in compliance with the terms of a permit under the National Pollutant Discharge Elimination System (NPDES).

NPDES permits form the backbone of Clean Water Act pollution control. The CWA allows the Environmental Protection Agency (EPA) to delegate federal authority to control water pollution to any state that applies to manage its own program, and demonstrates to the satisfaction of EPA that the state program is at least as stringent as the federal program and that the state has sufficient legal authority to carry out the program. Most states now manage their own NPDES permit programs, but EPA still administers a few programs in state waters—Massachusetts and New Hampshire, for example. EPA nonetheless retains the right to enforce the Clean Water Act in state waters, although it generally gives considerable deference to the state government.

EPA retains permitting authority for federal marine waters (generally beginning three nautical miles offshore). In addition to obtaining and complying with an NPDES permit, facilities—such as an oil and gas rig or ocean outfall sewage pipe—discharging directly into ocean waters must satisfy special ocean discharge criteria designed to protect against unreasonable degradation of the marine environment.

Marine Aquaculture and the Clean Water Act

Salmon farming along the coast of Maine began in earnest in the 1980s, and growth was rapid in the 1990s. By the end of the decade there were over 40 finfish aquaculture leases in coastal waters. Although the EPA indicated as early as 1988 that net pen aquaculture facilities might require NPDES permits, it did not issue permits for any such facility (Firestone and Barber 2003).

In July 2000, the U.S. Public Interest Research Group (USPIRG) and other citizens' groups filed suit under the Clean Water Act against three Maine finfish aquaculture operators[10], alleging violations of the Act for operating without an NPDES permit (DEP 2002). In early 2002, the District Court of Maine found for the plaintiffs in all three cases. In these cases, the court found that the net pen salmon farms operated by the defendants were, in fact, point sources of pollution that had added various pollutants to the navigable waters of the United States (Firestone and Barber 2003).

Interestingly, the court determined that escaped fish of nonnative strains of Atlantic salmon raised in these farms were pollutants within the meaning of the Clean Water Act, in addition to the more conventional pollutants such as feces, fish excretions, uneaten food, and drugs and therapeutic chemicals used to control disease and parasites. In a settlement of one of the cases lodged in July 2002, the court required, among other remedies, that the salmon farm operator culture only "North American" strains of Atlantic salmon and take measures to ensure cultured fish do not escape.

In early 2002, EPA issued an NPDES permit to Acadia Aquaculture to discharge pollutants from a salmon net pen facility in Blue Hill Bay, Maine (EPA 2002a). Clearly influenced by the ongoing litigation, the permit:

- Limited total annual feed use for the facility;
- Imposed minimum dissolved oxygen concentration thresholds for waters in and near the pens;
- Prohibited the culture of transgenic or non-North American strains of salmon;
- Required marking of cultured fish so that escapes could be identified;
- Established indicators and thresholds for anoxia in sediments underlying and adjacent to the pens;
- Restricted the use of drugs and pesticides; and
- Required extensive benthic and water column monitoring.

Although the permittee never constructed the salmon farm for which the Blue Hill permit was issued, this permit formed the basis for the State of Maine's general permit for marine finfish aquaculture when Maine took over NPDES permitting for such facilities in late 2002. Although Maine's general permit included many features from the Blue Hill permit, it removed the restriction on total feed use, and relaxed restrictions on drug and chemical use and other requirements.

A case decided in 2002 in Washington state provides a counterpoint to the USPIRG cases. Taylor Resources, Inc., grows mussels on lines suspended from rafts in Puget Sound. The mussels are not actively fed—they live off plankton filtered from the surrounding water. Taylor does not treat the mussels with drugs or therapeutic chemicals. Although the species of mussels cultured—*Mytilus galloprovincialis*—is not native, there are now self-sustaining wild populations in Puget Sound. Taylor applied to the State of Washington for an NPDES permit for these operations, but was told the state would not even accept its application, much less issue the permit. The Association to Protect Hammersley, Eld & Totten Inlets (APHETI) subsequently filed a CWA citizen suit against Taylor for discharging pollutants into Puget Sound without a permit.

Although the court in *APHETI* (as in the USPIRG cases) held that the failure of the competent agency to issue a permit was not a defense against a violation of the CWA, the District Court nonetheless granted summary judgment to Taylor. The court found that Taylor's rafts were not point sources under EPA's regulatory definition. Further, because Taylor neither fed its shellfish nor put chemicals or drugs in the water to treat them, the

[10] The Clean Water Act allows citizens with standing to file suit directly against alleged violators of the Act. The "citizen suit" provision of the Act puts a powerful enforcement tool in the hands of the public in cases where the state or federal government have not acted promptly or prudently.

court found that Taylor did not "discharge a pollutant." In affirming the decision of the lower court, the Ninth Circuit Court of Appeals reasoned that "biological materials" released into the water should not be considered pollutants unless they are the product of a "human or industrial process." The court appeared to reason that because the same species of mussels are producing the same kinds of waste products in the wild nearby, the cultured mussels, while certainly introduced by human hands, do not pass a threshold test of substantial human transformation for generic biological materials to qualify as pollutants.

By contrast, in *National Wildlife Federation v. Consumers Power Company* (862 F. 2d 580, 583 (6th Cir. 1988)), native fish killed by power turbines were found to be pollutants because these "biological materials" would not have been discharged in the form and quantity they were but for the operation of a dam. Citing this and other precedents, the Ninth Circuit opined in *APHETI* that substantial transformation of natural materials—for example wastes from processing these same shellfish—could result in their being considered pollutants.

A second key question considered in *APHETI* was whether Taylor's rafts were "point sources" within the meaning of the CWA. The NPDES system requires permits only for point sources. Notwithstanding the environmental effects of alleged discharges of pollutants, if Taylor's fixtures were not determined to be point sources, there was no requirement for a permit. In deciding this question, the court relied on technical reasoning related to the specific language of EPA regulations defining a "concentrated aquatic animal production facility" (CAAPF) as a type of point source. The court found that Taylor's rafts met the structural requirements to be a CAAPF as well as meeting the production threshold (20,000 pounds per year for "cold water species"). However, EPA's regulations exclude facilities that "feed less than [approximately 5,000 pounds] of food during the calendar month of maximum feeding." Because Taylor does not add feed to these facilities at any point, the court determined its facilities do not qualify as a CAAPF, and hence are not considered a point source.

EPA's Effluent Guidelines

The CWA requires EPA to develop technology-based effluent limitation guidelines for different categories of pollution sources, such as industrial, commercial and public sources. Such guidelines provide minimum pollution control technology to be deployed by dischargers, and may also include numeric and narrative limitations on discharges, required best management practices, and monitoring and reporting requirements (EPA 2004). Effluent guidelines are implemented when they are incorporated into NPDES permits by EPA or state water quality agency permit writers.

To settle a lawsuit brought by the Natural Resources Defense Council in the early 1990s, EPA agreed to develop effluent limitation guidelines for, among other things, aquaculture facilities. In June 2004, EPA issued final effluent guidelines for CAAPFs (EPA 2004). The effluent guidelines apply to commercial and noncommercial operations that produce or contain 100,000 pounds or more of aquatic animals per year and discharge at least 30 days per year. The rule specifically excludes:

- Closed pond systems, which are assumed only to discharge during brief periods of excess runoff;
- Molluscan shellfish operations; and
- Facilities rearing native species for periods of no more than four months for purposes of stock enhancement.

Facilities meeting the criteria for exclusion may still be required to implement management measures if they are judged to be a "significant contributor of pollution to the waters of the United States." Given the

The exclusive reliance by EPA on process-based controls (i.e., BMPs) instead of outcome-based controls (e.g., numerical effluent limitations) means that there is little possibility to measure either the contribution of aquaculture operations to pollution of U.S. waters or the success of management measures.

threshold and exclusions, facilities falling under the rule are fairly large land-based hatcheries and commercial production facilities using flow-through or recirculating systems, as well as net pen finfish farming operations. Although the rule would only apply to about five percent of the more than 4,000 aquaculture facilities in the U.S., it would likely apply to any commercial-scale marine finfish cage culture operation. In justifying its choice of threshold, EPA explains that one typical net pen contains 100,000 pounds of aquatic animals or more.

Although its draft rule proposed numeric limitations on only one pollutant, total suspended solids (TSS), the final rule reduced this control to "qualitative" limits on TSS through a requirement to implement best management practices (BMPs), including:

- Minimizing waste of feed;
- Proper storage of drugs, pesticides and feed;
- Routine inspection and maintenance of the production and wastewater treatment systems;
- Training of personnel; and
- Appropriate recordkeeping.

EPA's final rule also included narrative limitations on spilled materials (drugs, pesticides and feed), fish carcasses, viscera and other waste, excess feed, feed bags, packaging material, and netting. Compliance with the rule must be documented in a BMP plan describing how the facility is minimizing discharges. Development of specific BMPs are the responsibility of the facility operator and plans are not required to be submitted to or approved by EPA.

Because EPA found no available technology to directly control effluents from net pen systems in open water, it did not impose specific requirements to reduce concentrations of pollutants in the "effluent" from net pens. However, in the effluent guidelines EPA also backed away from direct limits on total feed use, such as it had imposed in the Blue Hill permit, instead relying on feed management and monitoring to reduce excess feed use.

The exclusive reliance by EPA on process-based controls (i.e., BMPs) instead of outcome-based controls (e.g., numerical effluent limitations) means that there is little possibility to measure either the contribution of aquaculture operations to pollution of U.S. waters or the success of management measures. In taking this tack on legally mandated effluent guidelines, EPA appears to be judging that aquaculture facilities are a relatively minor contribution to water pollution in the U.S. There also appears to be little anticipation of future growth in aquaculture in the U.S., since the nonquantitative approach taken by EPA allows neither meaningful assessment nor mitigation of cumulative impacts from aquaculture operations.

Given the substantial amount of litigation that had occurred during the time these guidelines were being developed and EPA's own acknowledgement of fish as potential pollutants through its permit writing, it is noteworthy that the final guidelines do not include measures to reduce escapes of nonnative species or genotypes. Draft guidelines proposed in September 2002 would have required operators of some net pen systems to implement BMPs to minimize escape of nonnative species (EPA 2002b). But the final guidelines make no mention of cultured species as potential pollutants, nor do they propose any measures to minimize escapes.

Water Quality Standards and Ocean Discharge Criteria

As discussed above, NPDES permits are the chief method that states and the federal government use to implement effluent limitations, and attain and maintain water quality standards. For many years after the Clean Water Act was amended to its modern form in 1972, the focus of the EPA and state water quality agencies was on improving water quality in lakes, streams and rivers. More recently, attention has turned to addressing growing problems with estuarine and coastal marine water quality, particularly eutrophication and other problems associated with municipal stormwater, combined sewer overflows, and non-point source pollution.

Because it both requires good water quality and can itself contribute to water pollution, marine aquaculture faces many challenges in the coastal environment. As a result, many experts are looking increasingly to the offshore environment, where water quality is relatively high and where pollutants will presumably be quickly dissipated and/or assimilated in the open ocean. With growing interest in the ocean environment for aquaculture and other uses, such as wind energy production, there is concern that no water quality standards exist for federal ocean waters. While the assimilative capacity of the ocean for pollution from marine aquaculture and other sources is presumably great, little research has been done to test that assumption. Further, the current reliance on management practices (instead of numeric or narrative limitations or standards) under EPA's effluent limitations guidelines does not address concerns about cumulative and secondary impacts from pollution if the offshore aquaculture industry grows substantially, as proposed by the Department of Commerce.

In addition to effluent limitation guidelines and water quality standards, the Clean Water Act offers another potentially powerful tool for controlling marine pollution. Section 403 of the Clean Water Act prohibits EPA or a state from issuing an NPDES permit for a discharge into ocean waters unless the discharge satisfies guidelines intended to prevent the degradation of those waters. NPDES permit regulations require state and federal permits to comply with section 403 and prohibit issuance of a permit if insufficient information exists to make a "reasonable judgment" whether the discharge complies with criteria for ocean environmental quality established under section 403 (40 CFR 122.4).

Section 403(c) requires EPA to develop guidelines for determining degradation of ocean waters, including effects of proposed discharges on marine life, such as:

- The transfer, concentration and dispersal of pollutants through biological, physical or chemical processes;
- Changes in marine ecosystem diversity, productivity and stability; and
- The persistence and permanence of the effects of pollutants.

EPA last revised the regulations implementing section 403 of the Clean Water Act in 1980 (45 FR 65942-65954). These regulations require that an assessment of the impact of proposed ocean discharges on the biological community in and surrounding the discharge be made prior to issuing an NPDES permit. The regulations also prohibit a permitted discharge from causing "unreasonable degradation" of the marine environment. Lastly, if there is insufficient information to determine that no unreasonable degradation will occur, no permit may be issued unless the permit applicant satisfies two conditions:

1. The proposed discharge will not result in significant impacts that will not be reversed or eliminated after cessation of the discharge; and
2. There are no reasonable alternatives to the onsite disposal of the pollutants proposed to be discharged.

Since 1980, EPA and the states have gained considerable experience in protecting water quality, including aquatic ecosystem structure and function, with its regulatory tools. To make better use of that experience and those tools, in January 2001, EPA proposed to revise the ocean discharge criteria and to begin the process of establishing water quality standards for ocean waters under federal jurisdiction. In its proposal (Fox 2006), EPA suggested two ways of improving the

> In light of current proposals to significantly expand marine aquaculture… revision of ocean discharge criteria and establishment of ocean water quality standards offer proactive means of protecting marine water quality.

implementation of section 403 of the Clean Water Act. First, EPA would establish numeric and narrative water quality standards for ocean waters under federal jurisdiction. Second, EPA would establish a process to delineate areas of the ocean having outstanding ecological value, for which new or significant expansion of existing discharges would be prohibited. In this way, EPA was attempting to establish a more objective and comprehensive regime for protecting ocean environmental quality than was possible through the highly subjective tests under the 1980 ocean discharge guidelines.

Although EPA's proposed changes to the ocean discharge guidelines were ready for publication in the Federal Register, they were not published prior to President Bush's inauguration in 2001, and the current administration has not submitted them for publication. In light of current proposals to significantly expand marine aquaculture, as well as growing pressure on the oceans from other industrial uses, revision of ocean discharge criteria and establishment of ocean water quality standards offer proactive means of protecting marine water quality.

Progress in Addressing Water Quality Issues

Norwegian Salmon Farming

For culture of aquatic species requiring feeds, the feed is the ultimate source of nutrients and biological oxygen demand that can cause water quality problems. If aquaculture is going to take place in net pens or sea cages immersed in and open to the sea, treatment of "effluents" is not a viable option. Reducing feed use becomes the only practicable method of reducing discharges of dissolved nutrients, uneaten feed, and chemical additives. Since feed is also the largest single cost for such aquaculture operations, producers have a dual incentive for reducing feed inputs—reducing environmental impacts and improving profits.

Norway is the largest producer of farmed salmon, producing 577 million tons of salmon and rainbow trout (nearly 40 percent of the global total) valued at $1.39 billion in 2003. According to the Norwegian Bellona Foundation, the Norwegian salmon farming industry reduced discharges of nitrogen from 56.2 kg to 45.1 kg per ton of fish from 1992 to 1999 (Bellona 2003). Per ton discharges of phosphorus decreased from 11.1 kg to 9.8 kg per ton over the same period. These improvements have resulted from better understanding of salmonid nutritional requirements, which in turn resulted in increased efficiency of feed conversion into salmon flesh (Gatlin and Hardy 2002). Also, improved monitoring to reduce overfeeding and other management measures have reduced wastage.

These improvements have not been enough to reduce total nutrient discharges from salmon farming in Norway, however. Per ton reductions in discharges have been more than offset by growth in the industry. Aquaculture is estimated to be responsible for 60 percent of phosphorus discharges and 25 percent of nitrogen discharges in northern Norway, according to the Norwegian Institute for Water Resources. Bellona concludes that pollution impacts from fish farming are largely local and reversible. Sediments rendered anoxic due to deposition of large quantities of organic matter from salmon farms can recover to a nearly natural state if left fallow for three to five years. Nutrients in the water column go into the Norwegian Sea and ultimately the Barents Sea, where their contribution to the total nitrogen load is insignificant.

Because water pollution effects have been found to be largely localized, recent work in Norway has focused on establishing local carrying capacity for nutrients and other pollutants, and maintaining cumulative salmon farming in a region within these limits. The carrying capacity for dissolved nutrients and particulate organic matter is dependent on depth, current speed, seafloor conditions and policy decisions about acceptable environmental impacts. A study by Aure and Ervik (2002, cited in the Bellona report but not listed in the bibliography) concluded that standing stock in a fish farm could be increased from 60 to 250 tons if the water depth under the farm is increased from 30 to 80 meters. Aure et al. (2002) found that local carrying capacity for farmed salmon increased from approximately 100 tons to 300 tons if freestanding cages were used instead of a compact design with a number of cages lined up on either side of a central walkway. It is not known what metric was used to establish carrying capacity in that study.

Integrated Aquaculture

Intensive net pen or sea cage aquaculture systems rely on dilution to disperse pollutants. Environmental effects resulting from this approach may be acceptable on a small scale with a widely dispersed industry, but become increasingly problematic if the industry expands. In Asia various forms of polyculture—or integrated aquaculture, wherein the wastes produced by one agricultural activity are turned into the inputs for another—have been practiced for centuries. In modern integrated aquaculture, the inorganic and organic wastes from a fish farm become primary inputs into co-culture of, respectively, seaweeds and filter-feeding mollusks. Conceptually, changing what are currently viewed in industrial aquaculture as wastes to be disposed of into valuable commodities to be captured and channeled into useful products may be a key to improving the sustainability of marine aquaculture.

Chopin et al. (2001) review biological and economic aspects of integrated aquaculture, and analyze the potential for these practices to be used to reduce pollution from intensive "fed" marine aquaculture. They note that developed countries tend to focus on "high value and high production monoculture" in both terrestrial agriculture and aquaculture. As short-term economic success in a region leads to a rush of new entrants, environmental degradation can result. This can harm the industry itself because fish health is dependent on good environmental quality and because disease outbreaks are facilitated by geographic clustering of fish farms.

Cultivating nori (*Porphyra* spp.) in proximity to a salmon farm resulted in improved production and product quality (Chopin et al. 1999) due to the constant supply of nutrients to the algae. While complete utilization of nutrients from a fish farm may be impractical because of light and space requirements of macroalgae, early studies suggest promising bioremediation results from fish-algae co-culture and also offer an opportunity for diversification of marine aquaculture operations away from single-species production.

Discussion and Conclusions

Clearly, discharges from aquaculture can harm marine water quality. A substantial body of research shows that conventional fed aquaculture—culture operations, such as for finfish, that require external inputs of food—introduces tens of kilograms of dissolved nitrogen, and several times that amount of particulate organic matter, for every ton of fish produced. Relying on dilution to address nutrient discharges from fed aquaculture operations only works for small, widely dispersed culture operations. Discharges of pollutants to the marine environment are unlikely to be benign if the U.S. industry approaches $5 billion in annual production, mostly through increases in marine finfish production, as suggested by the Department of Commerce. If such an expansion takes place, a variety of measures—including proper siting, adherence to best management practices, improved feed formulations and integrated aquaculture—will be crucial to ensure minimal impact to water quality.

…changing what are currently viewed in industrial aquaculture as wastes to be disposed of into valuable commodities to be captured and channeled into useful products may be a key to improving the sustainability of marine aquaculture.

Benthic impacts are well documented under finfish net pens. Anoxia and significant changes in the abundance and diversity of benthic fauna have been demonstrated in cage culture of salmon, sea bream, sea bass and other species. Even some aquaculture in more oceanic conditions has been shown to have benthic impacts if the cages are moored close to the bottom. Open water demonstration projects for marine species in the U.S. have been quite small, of short duration, or used relatively low stocking densities, making their results of little value in predicting the effects of commercial-scale operations.

Research in Norway has shown that benthic effects decline rapidly with increasing depth of water under salmon nets, but situating farms as close to shore as possible may be a prerequisite for economic viability of the industry. Fallowing periods of several years have been found necessary in Norway to allow benthic recovery. Research on benthic impacts from salmon farms in the Pacific Northwest indicates that benthic recovery may be quicker under some conditions. We are not aware of any research documenting benthic effects that may result from repeated cycles of fish farming and fallowing. Some of the lessons learned regarding appropriate siting of nearshore salmon net pens may be applicable to deep water facilities.

In the United States, most commercial-scale net pen fish farms are considered point sources of pollution under the Clean Water Act. As such, they must operate under a permit specifying the amounts and types of pollution they are allowed to discharge. In addition, point source discharges into ocean waters must also comply with special restrictions designed to protect marine waters from degradation. But by their very nature, it is difficult if not impossible for discharges from net pens or sea cages to be "treated" in any traditional water quality sense. Unless and until integrated aquaculture systems are commercially proven, there is little possibility of controlling what comes out of cages. As a result, if marine aquaculture is going to be allowed in cages immersed in marine waters, controlling pollution will likely require controlling what is put into the pen. Such controls could occur on a per-farm basis, through limitations on stocking density and feed and chemical inputs, or on a regional basis by limiting the number of farms allowed based on a determination of the environmental carrying capacity for pollutants.

Perhaps viewing discharges from marine aquaculture to be a minor source of pollutants, the EPA has not required fed aquaculture facilities to directly reduce discharges, instead relying on management of inputs to minimize pollution. If this course continues to be followed, the only way to address the cumulative impacts of marine aquaculture is by ensuring that ambient water quality standards are established and maintained to protect the health of marine ecosystems.

Currently there are no water quality standards for federal marine waters. Most states have marine water quality standards, but it is not known whether these standards are sufficient to protect marine environmental health. Most water quality standards were at least initially designed with only human health in mind and concern about coastal environmental quality is a relatively recent development. The Clean Water Act's ocean discharge criteria offer a related, but distinct, tool for protecting marine water quality. Much has been learned since these criteria were last revised in 1980 about the relationship of water quality to the health of aquatic ecosystems. Again, if little can or will be done to abate pollution from individual facilities, ensuring mechanisms are in place to protect ambient marine water quality becomes all the more essential. Such mechanisms should be in place before significant expansion of the marine aquaculture industry occurs.

Summary of Recommendations

- Existing effluent limitations for aquaculture should be reviewed and revised if necessary to ensure that concerns particular to the proposed expansion of aquaculture into federal marine waters are addressed.
- EPA should ensure that all coastal states have water quality standards for marine waters, and that those standards protect the health of marine ecosystems.
- EPA should establish water quality standards for federal marine waters or revise guidelines for determining degradation of ocean waters to achieve the same level of protection.
- Regulations for implementing water quality standards and ocean discharge criteria should be clarified to ensure that pollution discharge permits for marine aquaculture facilities address, inter alia, cumulative and secondary impacts at the local and regional level from expansion of the industry.
- EPA and the states should coordinate with NOAA so that management practices and other measures required in pollution discharge permits are integrated, to the extent possible, into operating plans for marine aquaculture facilities called for in the governance recommendations.

16. Use existing authority under the Clean Water Act to ensure that development of marine aquaculture does not degrade marine water quality or the health of marine ecosystems. The Clean Water Act provides a variety of tools to ensure that marine environmental quality is not degraded by discharges of pollutants, which may include live organisms and their gametes, from marine aquaculture facilities. Mechanisms for regulating discharges include effluent limitations guidelines, which specify limits on pollutants in effluents (based on the performance of the best available technology and management practices designed to achieve such limitations), and water quality standards, which specify narrative and numeric standards for water quality to maintain designated uses (such as fishing and swimming) in receiving waters. In addition, discharges to marine waters under both federal and state jurisdiction must comply with guidelines designed to prevent degradation of the environmental quality of marine waters. These ocean discharge criteria have not been revised since 1980, despite considerable progress since that time in understanding the structure and function of marine ecosystems.

16.1. To ensure that water quality and the health of marine ecosystems are not degraded by marine aquaculture, the Environmental Protection Agency should:

- **Review effluent limitations guidelines (ELGs) for concentrated aquatic animal production facilities (CAAPFs) to ensure they address concerns related to aquaculture in marine waters under federal jurisdiction;**
- **Ensure water quality standards are in place for marine waters under state jurisdiction; and**
- **Promulgate water quality standards for marine waters under federal jurisdiction or revise guidelines for determining degradation of ocean waters required by section 403(c) of the Clean Water Act.**

17. EPA and the states should include enforceable conditions in new and revised NPDES permits for CAAPFs to ensure compliance with ELGs, water quality standards and/or ocean discharge guidelines.

18. Regulations implementing water quality standards and guidelines for determining degradation of ocean waters should specifically:

18.1. Authorize NPDES permit writers to limit discharges of uneaten feed, animal wastes, drugs and chemicals by CAAPs if required to achieve water quality standards and/or comply with ocean discharge criteria;

- **Establish size thresholds for large CAAPFs above which the inclusion in permits of such controls would be mandatory.**

18.2. Require CAAPFs, as a condition of their NPDES permits, to—

- **Periodically report the number and species of aquatic animals held in the permitted facility, and the amount and type of feeds, drugs and other chemicals used at a CAAPF;**
- **Promptly report failures of nets, cages or other containment structures; and**
- **Submit plans detailing best management practices (BMPs) for approval by the NPDES permitting authority and comply with those plans.**

18.3. If legislation is enacted authorizing NOAA to issue site and operating permits for offshore aquaculture, BMP plans required under the Clean Water Act could be integrated into the broader operating plans we recommend NOAA require as a condition of operating permits issued by that agency.

CHAPTER 7

AQUACULTURE FEEDS AND FEEDING

Introduction

The U.S. Department of Commerce has called for a fivefold increase in the value of domestic aquaculture. This growth is anticipated to occur in the offshore area and largely through raising marine finfish species, which command a higher price at the market. Marine finfish also require a diet rich in protein and energy. The main source of the protein and energy in feeds for marine fish is wild fish caught by reduction fisheries.

Aquaculture is the largest consumer of the global supply of fishmeal and fish oil. It currently uses nearly half of the fishmeal produced and more than three quarters of the fish oil produced worldwide. As aquaculture of carnivorous species grows, so too will the need for protein- and energy-rich aquafeeds. However, fishmeal and fish oil are finite resources. These feed ingredients are typically made from small pelagic fish such as sardines and anchovies, which are caught for this purpose.

Most of the reduction fisheries that produce fishmeal and fish oil have reached, or in some cases exceeded, sustainable harvest levels. While global landings from reduction fisheries have remained relatively stable over the past few decades, an increased demand for the product could result in fishing above sustainable levels unless those fisheries are carefully managed. Moreover, marine scientists have begun to question whether current guidelines for sustainable harvest levels are indeed ecologically sustainable. While management policies for reduction fisheries aim to sustain harvest over time, very few protect the critical ecological role that these fish play in marine ecosystems, often as important food for marine predators.

Aquaculture is seen as a supplement to global seafood supplies as capture fisheries, which are already fully exploited, plateau and the world appetite for seafood increases. However, aquaculture of carnivorous species, such as salmon and cod, may increase pressure on wild fisheries if the energy and protein demands of such species continue to be met with fishmeal and oil. Scientific feed formulation and high-tech feeding practices have resulted in substantial improvements of feeding practices on the farm. But efficient fish farming methods may remain linked to inefficient use of natural resources through their dependency on wild fish for meal and oil.

A seemingly simple solution is the promotion of aquaculture of herbivorous finfish or shellfish species that do not require inputs of fishmeal and fish oil. Currently, the American taste for seafood generally favors carnivorous[11] species. Market forces are driving the production of species high in demand. However, public tastes can change over time. Few people ate, or even knew what calamari or tilapia were 20 years ago. Promotional programs can introduce the public to seafood products that are inherently more sustainable.

There is a growing realization that if aquaculture of carnivorous species is to expand, alternative sources of protein, most likely plant-based, are necessary. Alternative feed ingredients are under various stages of

There is a growing realization that if aquaculture of carnivorous species is to expand, alternative sources of protein, most likely plant-based, are necessary.

[11] Carnivorous fish are more technically referred to as piscivorous, meaning they eat other fish.

development and use, from the use of fishery byproducts, terrestrial and marine plants, to poultry and livestock processing byproducts. As research in this area continues, it will be a major challenge for the industry to continue to grow while reducing its dependence on wild fish for feeds. To do this, marine aquaculture in the United States must focus on the development of feed alternatives that are economical and meet the dietary requirements of fish, as well as encouraging the use of more sustainable feed ingredients.

As long as it is dependent on fishmeal and oil for feeds, marine aquaculture faces challenges to its sustainability. Long-term solutions to this problem lie in changes in the management of reduction fisheries, the development of sustainable alternative aquafeed ingredients, and in changes in consumer preference for aquaculture products.

The Use of Feeds in Aquaculture

Aquaculture is a form of agriculture. Just as livestock depend on farmers to supply food, most fish and crustaceans raised on farms in the United States require feed. A wide variety of aquatic species is currently farmed in the U.S., and those species have varying requirements for feed. On one end of the spectrum are filter-feeding mollusks such as oysters, clams, and mussels that do not require any feed inputs. In the middle are omnivorous species such as catfish and tilapia that are typically given feed, but have more flexibility in the specific ingredients needed in their diet. On the other end of the spectrum are carnivorous species such as salmon and marine finfish that require a high-energy, high-protein diet—needs that are met with substantial quantities of fishmeal and fish oil.

Estimated global aquafeed production in 2003 was 19.5 million tons (Tacon 2005). It is not surprising at a global level that carp—the largest volume aquaculture product—consume 45 percent of aquafeeds produced, while marine finfish (including salmonids) and shrimp together account for 31 percent. While carp species require little or no fishmeal and fish oil in their diet, the sheer volume of their production combined with the increasing use of commercially formulated feeds to achieve faster growth, results in carp consuming the most aquafeed.

Global aquafeed production is small in comparison to global industrial feed production for agriculture. Feed for aquaculture accounted for just 3 percent of the 620 million tons of estimated feed production in 2004 for the major farmed animal species, while poultry led with 38 percent, pigs at 32 percent and cattle at 24 percent (Gill 2005).

Dependency on Fishmeal and Fish Oil

Despite being the smallest sector for major farmed animal feeds, aquaculture is the largest consumer of two common ingredients in many animal feeds: fishmeal and fish oil. They provide an excellent source of animal protein, essential amino acids, omega-3 fatty acids, vitamins and minerals, and energy (Hertrampf & Piedad-Pascual 2000). Fishmeal and oil have moved beyond feed supplements to become the major components of feeds for these species.

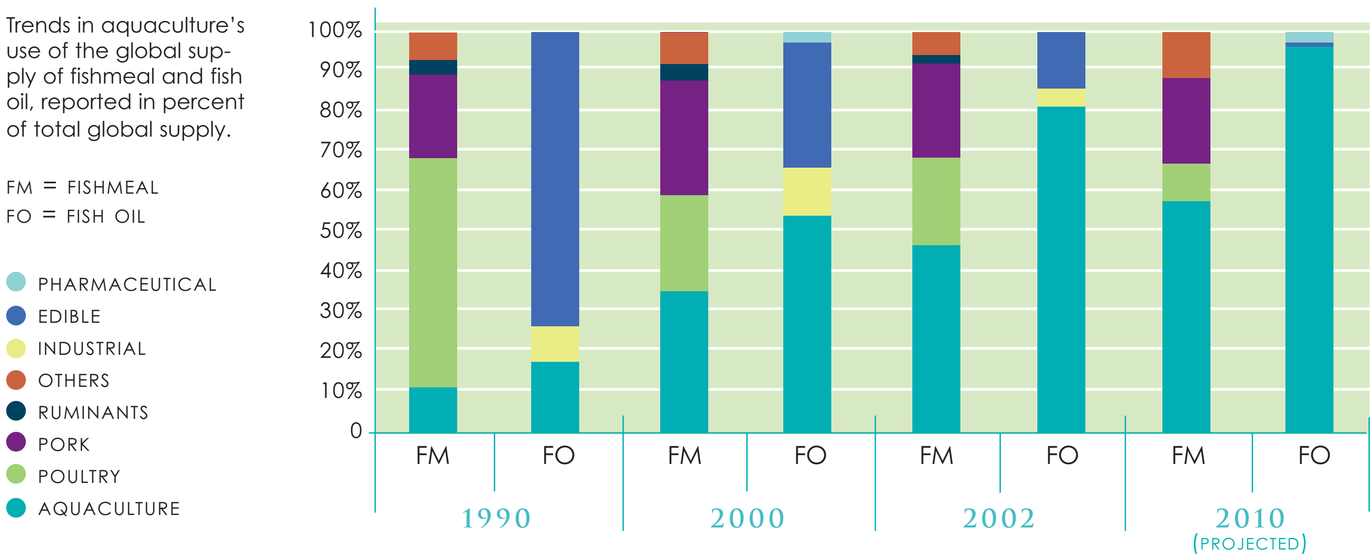
The International Fishmeal and Fish Oil Organization (IFFO) reports that aquaculture was the largest consumer of fishmeal and oil in 2002 (the most recent estimate), using about 46 percent of the global fishmeal supply and 81 percent of the global fish oil supply (Figure 7-1). These percentages were anticipated to increase in 2003 to 53 percent and 87 percent, respectively (Tacon 2005). The poultry and pork industries each used nearly a quarter of the available fishmeal in 2002. Industrial uses and human consumption accounted for nearly 20 percent of the available fish oil in 2002 (Pike 2005).

The total amount of fishmeal and fish oil used in aquaculture feeds has grown in the last decade. Between 1994 and 2003, fishmeal use in aquaculture feeds expanded from

FIGURE 7-1

Trends in aquaculture's use of the global supply of fishmeal and fish oil, reported in percent of total global supply.

FM = FISHMEAL
FO = FISH OIL



963,000 to 2,936,000 tons and fish oil use expanded from 234,000 to 803,000 tons (Tacon 2005). Some sectors saw very rapid increases in fishmeal and oil consumption, especially marine aquaculture sectors. For example, marine finfish aquaculture's use of fishmeal and fish oil more than tripled, while catfish remained stable (Figure 7-2).

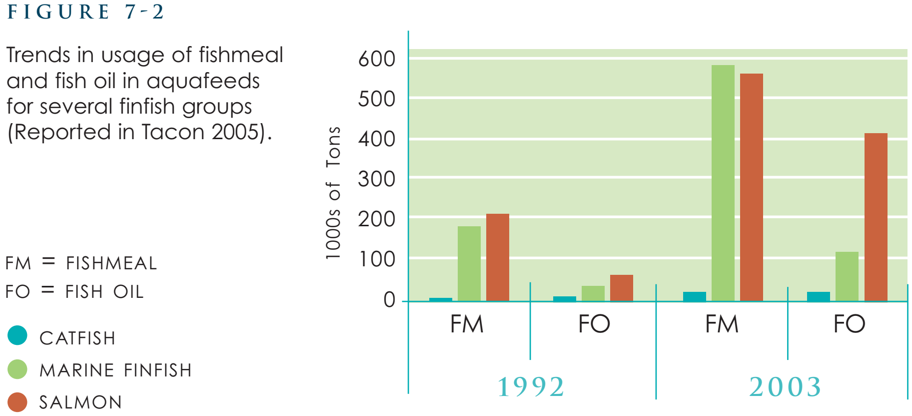
Two related trends are driving the increased use of fishmeal and fish oil. First, growth in the aquaculture industry overall requires more feed and therefore more fishmeal and fish oil as ingredients in feed. Second, the amount of fishmeal and fish oil included in aquafeeds, as a percentage by weight, have changed, especially for carnivores.

Over the past two decades there have been substantial changes in the level of fishmeal and oil included in the feeds. This is especially true for farmed salmon, where fishmeal usage tripled and fish oil usage increased by a factor of six (Figure 7-2). These increases are due to greater inclusion rates in feeds combined with growth in production. Fishmeal inclusion has been declining from an average of about 60 percent in 1985 to 45 percent in 1995, to a current average of about 35

FIGURE 7-2

Trends in usage of fishmeal and fish oil in aquafeeds for several finfish groups (Reported in Tacon 2005).

FM = FISHMEAL
FO = FISH OIL



percent. On the other hand, fish oil inclusion has been increasing from about 10 percent in 1985 to current levels that can reach 35 percent, but average about 25 percent (Tacon 2005).

Carnivorous species have specific dietary requirements for essential fatty acids, trace minerals, and high level of protein. These dietary requirements are readily available in fishmeal and fish oil, leading to the apparent higher dependency of aquaculture for carnivorous species on these ingredients (Hardy et al. 2001). Marine species represent about 25 percent of global aquaculture production yet they consume more than 75 percent of the fishmeal and fish oil used in aquaculture. Omnivorous and scavenging fish species, such as catfish, are dependent on fishmeal and fish oil to a lesser extent (Tacon 2004). Although carnivorous fish have certain requirements for protein, energy, fatty acids, and micronutrients, as do all organisms, they are not physiologically dependent on fishmeal and oil in a farm situation. Dietary requirements can be met by other sources.

The advances in feed formulation come with some trade-offs. Increased oil content has improved feed assimilation, resulting in less discharge of pollutants per ton of fish raised. But this comes at a cost of increased use of fish oil, which requires more wild fish to be rendered per unit weight than fishmeal.

Feed Conversion Ratios and Converting Fish to Fish

When comparing the efficiency of different aquaculture production practices and species there are several useful indices. The feed conversion ratio (FCR) expresses the efficiency of feed use on the farm. The simplest way to express it is as the ratio of the total amount of feed provided to farm animals to the live wet weight of animals harvested. When calculated in this way it is known as the economic or gross feed conversion ratio. A typical catfish farm has an economic FCR of 2.0 (Boyd et al. 2005). This means that 2000 kg of feed are required to produce 1000 kg of catfish (2000/1000=2.0). Typical FCRs reported for salmon and marine finfish farming are 1.3 and 2.2, respectively (Tacon 2005, FIN 2006). This ratio is important to farmers who want to compare efficiency of different feeds, growing conditions, or species. It is primarily an economic index, although it plays a role in calculating indices of ecological efficiency.

To measure ecological efficiency, analytical techniques such as ecological footprint, life cycle, and energy analysis have all been used to provide important insights (Brown and Herendeen 1996, Wackernagel and Rees 1996, Mattsson and Sonesson 2003). When applied to aquaculture, or any agricultural or industrial activity, these approaches attempt to quantify the many biological and energetic inputs and outputs to gauge performance with ecologically relevant parameters. The results of these analyses can identify areas where improvements in ecological efficiency (and thus sustainability) can be made.

A less exhaustive metric, called feed conversion efficiency or fish conversion efficiency (FCE), is also useful. FCE, sometimes referred to as the "wild fish to farmed fish ratio", estimates the amount of wild fish needed as feed input to produce a unit of farm-raised fish. Unlike FCR, FCE accounts for the fact that fishmeal and fish oil are often included in different amounts in the feeds that are the staring point for FCR. It therefore can be used to describe the quantity of wild fish required to produce a given mass of farmed fish. Determining this ratio is a multistep yet relatively straightforward calculation (See Box 7-1 for an explanation). FCE essentially shows the degree to which a particular aquaculture system (growing a particular species) depends on wild fish for feed ingredients. A large number indicates a high level of dependence, while a low number indicates less dependence. An FCE of less than one indicates that more fish is produced than is consumed in a particular production system for farmed species.

BOX 7-1.

Calculating the "Wild Fish to Farmed Fish Ratio" or FCE

1000 kg wild fish

YIELDS

240 kg fish meal and 50 kg fish oil

MAKES

Catfish feed
8000 kg (when 3% fishmeal is used)
5000 kg (when 1% fish oil is used)

Salmon feed
686 kg (35% fishmeal)
200 kg (25% fish oil)

Marine fish feed
480 kg feed (50% fishmeal)
333 kg feed (15% fish oil)

One thousand kg of wild fish yields about 240 kg of fishmeal and 50 kg of fish oil, based on global average yield rates of 24% and 5% for fishmeal and fish oil, respectively.

At typical inclusion rates of these ingredients in catfish feed, salmon feed, and marine finfish feed, the amount of feed shown at left can be produced for each taxon.* Since meal and oil are produced in different amounts, one ingredient (meal or oil) will limit production of feed for a particular taxon depending on the inclusion rates in the feed. The limiting nutrient and the amount yielded for each taxon are shown in bold.

5000 kg feed | 200 kg feed | 333 kg feed

YIELDS

2500 kg catfish (FCR 2.0) | **154 kg salmon** (FCR 1.3) | **151 kg marine fish** (FCR 2.2)

The weight of feed used is divided by the weight of fish harvested under real world growing conditions to get the gross or economic feed conversion ratio (FCR). This ratio is a measure of the efficiency with which a particular aquaculture system (species raised plus culture conditions) converts compound feed into fish. Using typical FCR values reported for our three example industry sectors*, the yield of farmed fish resulting from the feed derived from 1000 kg of wild fish is calculated by dividing the amount of feed for each aquaculture system by the FCR. The yield of farmed fish resulting from 1000 kg of wild fish is shown in bold at left.

FCE = input of wild fish/output of farmed fish

Catfish = 1000/2500 = **0.4** kg of wild fish used for each kg of catfish produced

Salmon = 1000/154 = **6.5** kg of wild fish used for each kg of salmon produced

Marine fish = 1000/151 = **6.6** kg of wild fish are used for each kg of marine fish produced

Once the yield of farmed fish is known, calculating the FCE is straightforward.

Calculating FCE separately for meal and oil usage and taking the larger of the two provides an ecologically conservative estimate of the dependence of aquaculture on wild fish stocks because it measures the amount of wild fish that must be processed to supply the scarcer ingredient in the feed used. Because the figures for FCRs, fishmeal and oil yield rates, and fishmeal and oil inclusion rates in feeds are global averages, the resulting FCEs are indicative of broad trends and do not necessarily reflect results achieved at a particular farm.

*The calculations above assume: catfish FCR=2.0 (Boyd et al. 2005), fish meal inclusion in feed=3% and fish oil inclusion=1% (Robinson et al. 2001); salmon FCR=1.3. fishmeal inclusion in feed=35% and fish oil inclusion=25% (Tacon 2005); marine fish FCR=2.2, fishmeal inclusion in feed=50% and fish oil inclusion=15% (FIN 2006). Additionally, the calculations assume global average yield rates from reduction fisheries of 24% for fishmeal and 5% for fish oil (FAO 1986, Hardy and Tacon 2002, Pike 2005, IFFO 2006).

TABLE 7-1.

Total estimated fishmeal and fish oil use and species production in 2003, based on FAO data. Values given in thousands of tons. (from Tacon 2005).

Species	Fishmeal	Fish Oil	FM+FO	Production	FCE[1]
Salmon	573.0	409.0	982.0	1,259.0	3.1-3.9
Marine shrimp	670.0	58.3	728.3	1,805.0	1.6-2.0
Marine fish	590.0	110.6	700.6	1,101.0	2.5-3.2
Feeding carp	438.0	43.8	481.8	10,179.0	0.19-0.24
Trout	216.0	126.0	342.0	554.0	2.5-3.1
Marine eels	171.0	11.4	182.4	232.0	3.1-3.9
Fw. Crustaceans	139.0	13.9	152.9	688.0	0.9-1.1
Tilapia	79.0	15.8	94.8	1,678.0	0.23-0.28
Milkfish	36.0	5.2	41.2	552.0	0.30-0.37
Catfish	24.0	8.0	32.0	569.0	0.22-0.28

FCE[1]—Pelagic equivalent inputs (wet weight basis) per unit of farmed fish output

The feed conversion efficiency of aquaculture systems has sometimes been compared to the trophic transfer efficiency of marine ecosystems. However, such comparisons neglect the large amounts of energy used to produce fish for human consumption through farming and fishing.

Trophic transfer efficiency, which is often assumed to be about 10 percent in most aquatic ecosystems (Pauly and Cristensen 1998), represents the efficiency of energy transfer between trophic (or feeding) levels in an ecosystem. The feed conversion efficiency of aquaculture systems has sometimes been compared to the trophic transfer efficiency of marine ecosystems. However, such comparisons neglect the large amounts of energy used to produce fish for human consumption through farming and fishing. In the case of FCE, this ratio does not account for the large industrial energy inputs required to harvest and process reduction fisheries, to produce compound feeds, and to manufacture and supply aquaculture systems. In addition, fish harvested for meal and oil are not necessarily of the same species or trophic level as organisms eaten by the wild cousins of farmed fish, further complicating direct comparisons of energy transfer.

Using a different method than that described in Box 7-1, Tacon (2005) calculated FCEs for a variety of farmed aquatic species (Figure 7-3).[12] Assuming a substantial reduction in inclusion rates of fishmeal and fish oil in aquafeeds through the use of nutritionally equivalent substitutes, Tacon (2004) estimated that by 2010, FCEs could be in the range of 1.2-1.5 for salmon and 1.5-1.9 for marine fish.

Currently, freshwater fish such as catfish, tilapia and carp require less than one unit of wild fish for every unit of farmed fish production. And shellfish require no feed inputs from the farmer, instead they filter plankton from the surrounding water. In other words, the farming of these fish and shellfish produces more animal protein than it consumes in production.

Dietary Requirements of Farmed Fish

Farmed fish have a dietary requirement for about 40 essential nutrients. They do not have a dietary requirement specifically for fishmeal and fish oil. Fishmeal and fish oil tend to be the most accessible, most cost-effective, and most easily digestible mechanism to deliver essential nutrients. Finding substitutes that meet the dietary requirements of farmed species will be critical in reducing aquaculture's dependency on fishmeal and fish oil.

[12] This method adds the amount of fish meal and fish oil in the feed used to produce a given amount of farmed fish, multiplies the combined total by a "fish live-weight conversion factor", and then divides the result by the weight of farmed fish produced. The live-weight conversion factor ranges from 4 to 5—equivalent to fish yielding 25-20% of meal plus oil after reduction, the remainder (75-80%) being water. This method provides a good estimate of FCE when the meal and fish oil in a specific feed are derived from similar amounts of whole fish.

Plant-based substitutes are able to provide the required nutrients. Ingredients to replace fishmeal and oil in aquafeed that are at various stages of research, development, and use include: canola meal, pea protein concentrate, soybean meal, canola (rapeseed) oil, corn gluten meal, wheat gluten meal, soybean protein concentrate, poultry by-product meal, and poultry oil. A high degree of variation exists in the amount and types of materials that are substituted for fishmeal and oil, depending on the protein, energy, and nutrient requirements of the species. Successful substitution will require that the resulting products contain essential nutrients, plus they must taste good to the fish and not contain "antinutrients." These are compounds that reduce the nutritional quality of a diet (Halver and Hardy 2002). For example, there are compounds that bind up minerals making them unavailable to the animal.

In searching for alternative feed ingredients, researchers must consider factors such as palatability, quality, digestibility, availability and cost (Hardy 1996). Researchers have had success identifying substitutes that can completely replace fishmeal in aquafeeds. However, there are currently no commercial alternatives to completely replace fish oil, which is a highly digestible source of energy for the fish and an important factor in the nutritional value of the final product (Tacon 2005). The main challenge in replacing fish oil is finding alternative sources of the long chain omega-3 fatty acids, DHA and EPA. Algal sources of these fatty acids are already being produced for human consumption. For example, the company Martek supplies algal supplement for infant formula approved by FDA. If production of algal fatty acids is scaled up and prices reduced, they may become economically viable for use in aquaculture feeds.

Reduction Fisheries: Main Source of Fishmeal and Fish Oil

Few people might guess that only two of the five largest capture fisheries produce seafood destined for your dinner plate[13] (FAO 2004). The other three produce fishmeal and fish oil for agricultural feeds and other uses.

The reduction fisheries—those that harvest wild fish to produce fishmeal and fish oil—target small pelagic species, such as anchovy, herring, mackerel, and menhaden. While most of the species targeted by reduction fisheries are eaten to varying degrees by human beings, the vast majority of these fish are harvested for reduction, a process in which boats haul the fish back to a processing plant where they are cooked, then the oil is pressed out and the rest is dried to make fishmeal.

Between 1950 and 2003, the amount of fish and shellfish landed by capture fisheries destined for reduction into meals, oils, and other nonfood purposes increased from 3 million tons to 21.4 million tons. In 1950 reduction fisheries made up 16 percent of total capture fishery landings, while reduction fisheries accounted for about 23 percent of total worldwide capture fishery landings in 2003. Reduction fisheries landings have fluctuated between 20 and 30 million metric tons annually over the last 30 years (Figure 7-2).

The largest reduction fisheries are in South America (37 percent of global landings), with the Far East (27 percent) and Southeast

Between 1950 and 2003, the amount of fish and shellfish landed by capture fisheries destined for reduction into meals, oils and other nonfood purposes increased from 3 million tons to 21.4 million tons.

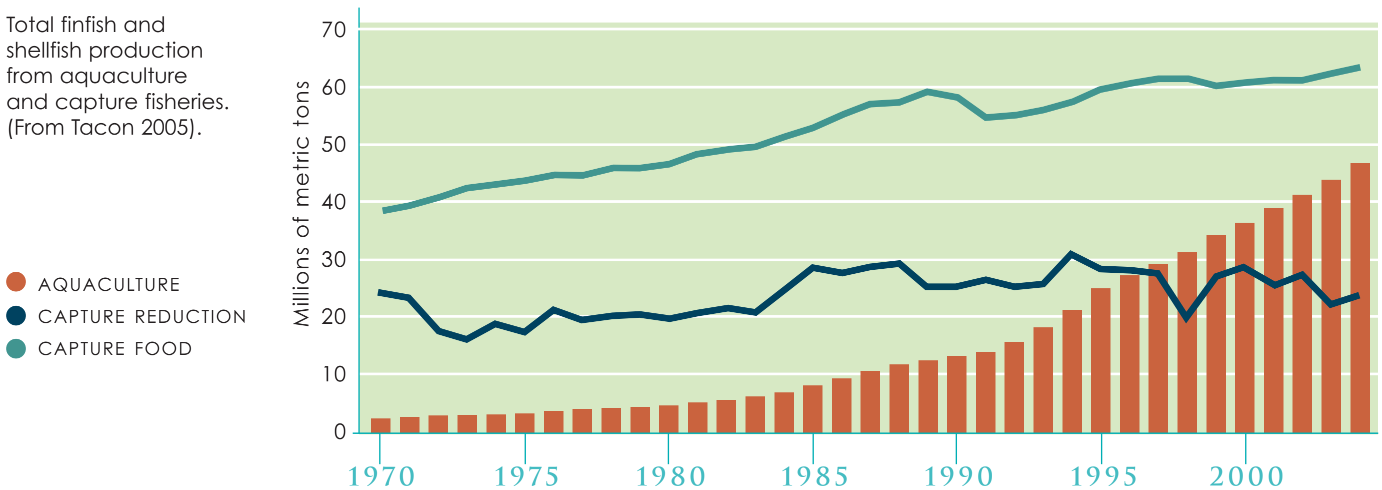
Small pelagic fish, from which fishmeal and fish oil are derived, are key food species for nonhuman consumers in marine ecosystems. Ecosystem-based management of reduction fisheries, combined with increased use of alternatives to wild ingredients in feeds, will improve the sustainability of aquaculture.

Photo: Getty Images

[13] The top five species in 2002 are: anchoveta, Alaskan pollock, skipjack tuna, capelin, and Atlantic herring. Of these, only Alaskan pollock and skipjack tuna are processed substantially for human consumption.

FIGURE 7-2.

Total finfish and shellfish production from aquaculture and capture fisheries. (From Tacon 2005).



Disposition of total global fish & shellfish catch in 2003: 63.23 million tonnes (69.1%) for direct human consumption, 21.27 million tonnes (23.4%) for reduction into fish meals and oils, and 6.6 million tonnes (7.5%) other miscellaneous purposes.

Asia (12 percent) also supporting major fisheries (Huntington et al. 2004). FAO reports that most reduction fisheries are currently fully exploited and some are considered overexploited. In fisheries management parlance, fully exploited fisheries are already producing catches at or near the maximum sustainable level, and overexploited fisheries risk depletion of stocks if catches are not reduced.

In the United States, the largest reduction fishery—menhaden—ranks second in total pounds landed nationwide (NMFS 2006). A recent decision by the Atlantic States Marine Fisheries Commission to cap menhaden harvest in Chesapeake Bay highlights the growing concern about reduction fisheries. While the Atlantic menhaden fishery is considered healthy on a coast-wide basis, most of the harvest occurs in Chesapeake Bay. Because menhaden play a unique and vital role in coastal ecosystems as both a filter feeder and forage species, managers implemented a precautionary cap to protect the stock. At the same time, additional research is being conducted to evaluate the ecological role menhaden play and to consider management strategies that will protect menhaden's ecological role (ASMFC 2005).

The menhaden fishery is not unique in raising ecosystem considerations for reduction fisheries. Most other reduction fisheries target forage fish that play important roles in marine ecosystems. Fishery managers traditionally manage catch on a species-by-species basis to ensure the population of the target species is maintained within agreed biological limits. However, these policies typically do not consider the broader ecosystem impacts of the fishery, such as predator-prey relationships, unintended bycatch, and habitat disturbance (Huntington et al. 2004). These are critical considerations to ensure the ecological sustainability of reduction fisheries and their products: fishmeal and fish oil.

A related issue to the sustainability of fishmeal and fish oil production is the ability to track the origin of those products. Currently, no system is in place that allows feed buyers to identify the species of fish used to make fishmeal and oil, nor the region or country from which the fish are harvested. According to FAO, 82 percent of total global fishmeal and 55 percent of fish oil production is not reported at the single species level (Tacon 2005). A key mechanism to evaluate the sustainability of fishmeal and fish oil is to identify the source of the product. If the sources of fishmeal and fish oil are known, then information can be gathered on the health of the fishery, compliance with regulations, and the health of the surrounding ecosystem. This information will help buyers determine the sustainability of fishmeal and fish oil, as well as fish produced from it. A traceability system would greatly enhance the domestic and international tracking of fishmeal and fish oil.

In addition to traditional reduction fisheries, alternative sources of fishmeal and fish oil are increasing in the supply chain. These sources do not depend on directed harvest of small pelagic fish for the purpose of reduction, but rather utilize wasted fish products from other fisheries. Seafood processing produces a large volume of "waste"—including heads, offal and scraps—that can be processed into fishmeal and fish oil. For example, Canada prohibits the harvesting of fish for the sole purpose of reduction. Therefore all fishmeal and fish oil produced in Canada come from processing waste. It is often cheaper for fish processing facilities to sell or give their fish waste away to a reduction facility rather than pay for the disposal of the waste. Therefore, economics provides the incentive to transform processing waste into fishmeal and fish oil (Tyedmers 2006).

Unavoidable bycatch is another source of fishmeal and fish oil. Bycatch is the accidental capture or mortality of sea life as a result of a direct encounter with fishing gear. Although the methodology to calculate worldwide bycatch and the estimates produced vary widely, scientists agree that a significant portion of global catch is unutilized (Alverson 1998, Kelleher 2005). This fishery by-product could be reduced into fishmeal and fish oil. However, minimizing bycatch has been a national and international priority over the last decade and remains a central challenge to fishery management. Use of bycatch for aquafeeds should be structured so as not to interfere with efforts to reduce bycatch.

Cost of Aquafeeds

Aquafeed is usually the highest cost of operating a fish farm that feeds its stock. For example, salmon feeds and feeding represent 60 to 70 percent of total farm production costs. Since fishmeal and fish oil can make up 50 to 75 percent of feed, any increases in the price of these finite commodities will lead to increased cost to the farm and therefore decreased profitability (Tacon 2005).

Fishmeal and fish oil are commodities traded on a global market. The cost of this product depends on the quality and quantity of the product as well as the cost and availability of similar products, such as soybean meal and plant-based oils (Tacon 2005). If low-cost and nutritionally equivalent substitutes for fishmeal and fish oil are found, economics will drive the aquaculture industry toward alternative feeds.

On the other hand, reducing aquaculture's demand for fishmeal and fish oil would not necessarily result in a reduction in forage fish catch. As a globally traded commodity, the fishmeal and fish oil prices might drop and/or the products would go to other uses. However, if the goal is to improve the sustainability of aquaculture itself, then reducing fishmeal and oil use is still desirable.

Human health issues

Recent studies have shown farm-raised salmon have higher contaminant levels than wild salmon (Hites et al. 2004, Huang et al. 2005). The greatest concern for contaminant accumulation in farmed fish is with persistent organic pollutants, such as polychlorinated biphenyls (PCBs), dioxin, flame

If low-cost and nutritionally equivalent substitutes for fishmeal and fish oil are found, economics will drive the aquaculture industry toward alternative feeds.

retardants, and pesticides. These contaminants are fat soluble and accumulate in the fatty tissues of animals, including the pelagic fish used for reduction to fishmeal and oil. Also, fishmeal and fish oil made from fish processing waste may also contain higher concentrations of contaminants, as processing waste often includes organs and fatty tissue.

Evidence points to some regional variation in the levels of contaminants, with fish from the South Pacific Ocean having the lowest levels and fish from the more industrialized northeast Atlantic region having the highest levels. Potential solutions to the problem of contaminants in feeds include sourcing ingredients from the least contaminated areas, stripping contaminants from fishmeal and oil, and replacing potentially contaminated ingredients with alternative ingredients. As new sources of fishmeal and fish oil become more prominent, care must be taken to monitor for contaminants and prevent use of products with harmful levels.

These studies raise serious health concerns. Their conclusions have been challenged by some in the seafood industry and others who believe benefits from eating seafood outweigh the risks. Although human health considerations are outside the scope of the Task Force's work, it must be recognized that perceptions about the health benefits and risks of eating seafood play a major role in consumer purchasing decisions.

The Regulatory Environment

In the United States, animal feeds—including aquafeeds—are primarily regulated at the point of distribution by the states. Regulation of feeds covers areas such as best management practices, labeling requirements, and ingredient definitions. There are currently no regulations on the use of fishmeal or fish oil in animal feeds.

States look to the American Association of Feed Control Officials (AAFCO) for guidance on model feed legislation. AAFCO is a nonprofit organization made up of state and federal feed control officials who develop model laws and regulations, feed ingredient definitions, and feed-labeling requirements. AAFCO works to promulgate consistent feed regulations across states. For example, AAFCO developed model regulations for organic standards for pet foods.

At the federal level, FDA's Center for Veterinary Medicine (CVM) has regulatory authority for both animal feed and animal drugs under the Federal Food, Drug, and Cosmetic Act (21 U.S.C. 301 et seq.). In addition to research and approval of the use of drugs in aquaculture, CVM has regulatory authority over nondrug feed additives and conducts biological and chemical research to support the food safety of new animal feeds.

Progress on Feeds

Advances in feed formulation, feed manufacturing technology, and feed management at the farm level have led to increased fish growth, reduced production costs, and reduced feed conversion ratios. For example, FCR for salmon farming decreased from over 2.0 to 1.3 from the early 1980s to today (Tacon 2005).

Research is underway to develop alternative feed ingredients for fishmeal and fish oil. While progress has been made in identifying substitutes for fishmeal, there is no commercially available product that can completely substitute for fish oil. Canada and Norway lead the way on dietary substitutes for fishmeal at 55 percent and fish oil at 50 percent (Tacon 2005). An independent group of researchers, including scientists from academic institutions and federal agencies as well as industry, is working to advance plant-based feeds with a particular focus on enhancing their use in the culture of carnivorous marine species (Bellis 2006). Great potential exists in research and development of feed alternatives to reduce aquaculture's dependency on fishmeal and fish oil.

BOX 7-2.

Country of Origin Labeling: A Model for Tracing Fishmeal and Fish Oil

Pelagic fish used to produce fishmeal and oil play important roles in marine ecosystems as consumers of plankton and prey for larger fish and other marine life. As a result, the use of fishmeal and fish oil in compound aquafeeds is a key factor affecting the sustainability of aquaculture. A hurdle to determining the sustainability of fishmeal and fish oil is identifying the source of these products. The United States recently adopted labeling requirements for seafood, which provides a model to encourage the production and use of sustainable aquafeeds.

The Farm Security and Rural Investment Act of 2002, also known as the 2002 Farm Bill, requires country of origin (COOL) labeling for all fish and shellfish products, as well as method of production (e.g., wild caught or farm raised). USDA implemented a labeling program for seafood to carry out the legislation in 2005. The labeling is required at the point of sale, or retail level, in supermarkets, however the food service industry is specifically exempted. While this program does not cover aquafeeds, similar labeling requirements for aquafeeds and their ingredients would identify the origin of fishmeal and fish oil. Combined with information on the management of reduction fisheries and feed production practices, such labeling could assist aquaculturists and certifying entities in determining the sustainability of feeds.

The ecosystem effects of reduction fisheries are beginning to receive more attention. Although it is only a first step, the recent decision by the Atlantic States Marine Fisheries Commission to set the first catch limits on Atlantic menhaden is encouraging in this regard (ASMFC 2005). Improvements to the sustainability of reduction fisheries will improve the sustainability of aquaculture practices that rely on fishmeal and fish oil.

Discussion and Conclusions

As aquaculture, and particularly carnivorous marine finfish culture, continues to grow, so too will the need for aquafeeds. Fishmeal and fish oil are a core ingredient in aquafeeds because of their protein, energetic and nutrient content. However, fishmeal and fish oil are finite resources derived from marine fisheries that have reached and in some cases exceeded sustainable harvest levels. Aquaculture currently consumes half of the fishmeal produced globally and three quarters of the fish oil.

If aquaculture is truly to increase global seafood supplies, then it must produce more animal protein than it consumes. To do this, the industry must reduce its use of fishmeal and, especially, fish oil derived from capture fisheries. Alternatives for fishmeal and fish oil are necessary to meet the demands of a growing aquaculture industry and to contribute to a net increase in seafood supplies. In addition to regulation, research and development, a certification program can provide market-based incentives to encourage the use of sustainable aquafeeds. Market-based approaches will be discussed in detail in Chapter 8.

Summary of Recommendations

- Support research and development for alternative feed ingredients.
- Substitute sustainable feed ingredients for unsustainable ingredients.
- Adopt ecosystem-based management approaches for reduction fisheries.
- Develop a traceability system for fishmeal and fish oil.
- Promote sustainable aquafeeds internationally.

If aquaculture is truly to increase global seafood supplies, then it must produce more animal protein than it consumes. To do this, the industry must reduce its use of fishmeal and, especially, fish oil derived from capture fisheries.

19. Substitute sustainable feed ingredients for unsustainable feed ingredients. Fishmeal and fish oil, which make up the bulk of the ingredients in diets for farmed carnivorous fish, are obtained from finite sources that are fully exploited or in some cases overfished. Recommendation 20 will help ensure that the supply from these sources becomes more sustainable. However, the finite nature of the resources highlights the need for feed alternatives and greater efficiency.

19.1. Congress should direct NOAA, in collaboration with the Department of Agriculture, to expand current activities or develop new activities that reduce the dependency of marine aquaculture on reduction fisheries for feeds. Acting through the Joint Subcommittee on Aquaculture, activities should be carried out in collaboration with industry, research institutions, and other stakeholders, including:

- Research and development on alternative, sustainable, and cost-effective feed ingredients consistent with sustainability standards called for in the governance recommendations; and
- Development of guidance and best management practices to maximize the substitution of alternative feed ingredients for fish meal and oil derived from directed reduction fisheries, including—
  - Seafood processing wastes and unavoidable fisheries bycatch,
  - Cultured marine algae and other microbial sources of omega-3 fatty acids,
  - Crop plants and other terrestrial protein sources, and
  - Other products produced in an environmentally sustainable manner.

19.2. As alternative and cost-effective ingredients for aquaculture feed become available, NOAA should require the use of the most sustainable ingredients by establishing milestones and a process for transition. Even as sustainable, ecosystem-based management of reduction fisheries is promoted, as called for in recommendation 20, there is a need to reduce the dependency of marine finfish aquaculture on finite supplies of fish meal and oil. As research and development produce viable alternative feed ingredients and more sustainable feeds, NOAA should establish goals and a process for transitioning to these new products.

- NOAA should establish a process for transition to alternative, sustainable feeds and create milestones for the use of such feeds within two years of the commencement of an enhanced research program. A mechanism to implement this transition could include specifying minimum levels of the most sustainable ingredients available in feeds with provisions for progressively increasing the minimum required levels to 100 percent as new sources, information, and technologies become available. The plan should be adaptive as new research and technology become available.
- NOAA should ensure that the milestones for feed are reflected in operating permits for marine aquaculture within five years of the commencement of an enhanced research program called for in recommendation 19.1. The type of feed used by an aquaculture facility must be consistent with the lead agency's milestones for aquafeeds as a condition of the permit.

- During the transition to alternative and sustainable feed ingredients, provide incentives for the use of more sustainable feeds. Incentives may include preference in permitting or economic incentives such as reduced fees.

20. **Source feed ingredients from capture fisheries (reduction fisheries) that are healthy and employ ecosystem-based fishery management.**[14] Most of the reduction fisheries around the world are fully exploited. Current management of marine reduction fisheries is geared toward sustaining fish harvests, however it does not consider or protect against the impacts the fishery is having on the ecosystem. Therefore, sustainability from a traditional fishery management perspective is at best a crude indicator of ecosystem health. An ecosystem-based approach to fishery management can address impacts on the ecosystem. Sustainable aquaculture of carnivorous fish requires that feed ingredients come from ecologically sustainable sources. For fishmeal and fish oil, this means that fisheries which they are derived from are neither overfished nor is overfishing occurring on those stocks, and the definition of overfishing used in their management protects both the fish stock and ecosystem structure and function.

    20.1. **Ensure capture fisheries that supply fishmeal and fish oil to the U.S. marine aquaculture industry (and other industries) are managed in an ecologically sustainable manner.** This should include both domestic and international sources of fishmeal and fish oil.

    - **Congress should direct NOAA, in cooperation with the states, to develop standards for ecologically sustainable reduction fisheries and adopt a new definition of overfishing based on the standards.** NOAA should ensure that domestic reduction fisheries are managed in an ecologically sustainable manner. The largest reduction fishery in the United States is the menhaden fishery along the Atlantic coast and Gulf of Mexico. It is managed in a traditional, single species approach, with the goal of sustaining the fishery over time. However this management approach does not ensure that the fishery is sustainable from an ecosystem perspective. NOAA, working with the states, should build on current initiatives to pursue ecosystem-based fishery management, by developing standards and new overfishing definitions for ecologically sustainable reduction fisheries.

21. **Develop and implement a traceability system for distinguishing, identifying, and sourcing fishmeal and fish oil so that ecologically sustainable feeds are available and distinguishable to fish farmers.** Currently, there is no way to track the source of fishmeal and fish oil, including the country where the fish were harvested or the species used to make the products. These are critical pieces of information that must be tracked to ensure the use of sustainable products in aquaculture, and to facilitate identification of any possible contaminants in the fishmeal and fish oil.

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[14] Sustainable feeds include both alternative feed ingredients that meet a sustainability standard as well as feeds produced with fishmeal and fish oil derived from fisheries managed for ecological sustainability.

21.1 In the United States, the U.S. Department of Agriculture should develop chain of custody procedures through which feed producers and fish farmers can verify the source and content of feed ingredients.

- Require country of origin labeling for aquafeed ingredients as well as aquafeed products.
- To the extent practicable, require additional labeling to help determine products are consistent with a sustainability standard. For example, include information on the species used to produce fishmeal and oil, the region[15] of the fishery, and whether the products are from bycatch or a directed fishery.

22. Provide leadership in the international arena to promote sustainable aquaculture and sustainable aquafeed production. To promote this agenda, the United States should:

22.1. Urge FAO to adopt a protocol to the Code of Conduct for Responsible Fisheries elaborating the need for, and ways to achieve, net seafood production from marine aquaculture;

22.2. Work to ensure that international fisheries agreements recognize the importance of forage fish in marine ecosystem dynamics and fishery management that maintains the structure and function of marine food webs;

22.3 Use its bilateral economic and scientific relationships to encourage countries to manage their domestic stocks of forage fish on an ecosystem basis; and

22.4 Lead an international effort for the development of a traceability system for distinguishing, identifying, and sourcing fishmeal and fish oil so that ecologically sustainable feeds are available and distinguishable to fish farmers. All elements of recommendation 21 should also apply to any international traceability system.

[15] Fishery management actions that conserve the structure and function of marine ecosystems, in addition to conserving the fishery resource.

CHAPTER 8

WORKING WITHIN THE MARKETPLACE: PRIVATE SECTOR INITIATIVES, CERTIFICATION, AND ECO-LABELING

One need not look further than the emergence of organic products to understand the power of consumer choice. The growth of the organic food sector in the U.S. has quickly outpaced other agriculture sectors, growing in the U.S. at a rate of 20 percent per year in recent years, to become an $11 billion market (NOAWG 2005). The organic label conveys information to the consumer about the method and practices by which the food was produced. The result has been the adoption of organic production practices by a growing number of farms.

Most of this report focuses on legal and regulatory ways to improve the sustainability of marine aquaculture. Demand-side programs, employing certification systems, corporate purchasing policies, and similar tools use market-based approaches to achieve the same goal. These programs generally establish standards for production practices that address environmental, social, or health considerations. This chapter will explore a variety of private sector initiatives, certification, and labeling programs to provide insight on how new market incentives for environmentally preferable aquaculture systems might be established.

Product Choices

On a typical trip to the supermarket or hardware store, consumers face a variety of labels. These may be the result of government regulation, such as the dolphin-safe label on canned tuna, or country of origin labeling at supermarket seafood counters. They may also be the result of an independent, third-party organization such as the Forest Stewardship Council, which certifies the sustainability of wood and paper products based on social and environmental standards. Many examples of labeling programs exist and some of their features may be adapted for an eco-labeling program for sustainable aquaculture.

Although individuals have an important and well-recognized marketplace role, corporate purchasers and other business buyers are the gatekeepers for many food selections. Company buyers choose the sources of food sold or served at restaurants, food service outlets, supermarkets, and other retailers. Individual consumers may then have an opportunity to choose among these foods.

Eco-labels are seals of approval given to products that are deemed to have fewer impacts on the environment than other similar products (Wessells et al. 2001). The rationale for labeling is to connect products in the marketplace with production practices. Public outcry about the killing of dolphins by some tuna fishing pratices led to the development of a dolphin-safe definition and label for canned tuna. The label provides additional information to consumers about their choices in the marketplace.

Consumers are increasingly looking to product labels to assist them in making more informed purchases based on environmental and social concerns. A survey of 1,640 U.S. residents found that 70 percent preferred to purchase seafood that was labeled to indicate the fish came from sustainable sources (Wessells et al. 1999).

As the information age progresses, consumers are becoming better educated and

Although individuals have an important and well-recognized marketplace role, corporate purchasers and other business buyers are the gatekeepers for many food selections.

Labeling and other private sector programs can complement or strengthen conventional regulatory programs to achieve desired conservation and management outcomes.

more discriminating. Many want to know where their food comes from, how it was raised, and what additives or contaminants it may contain. Retailers and suppliers are getting smarter too, tapping into this trend by supplying products tailored to consumer preferences. Both individual consumers and businesses can thus create powerful incentives through the marketplace for more sustainable production practices. In the case of seafood, businesses play an especially dominant role. More than half of U.S. seafood sales (wholesale value) are at restaurants and food service outlets (Packard Foundation 2001). Consumers typically have less information about product sources at these outlets than they do at supermarkets and other retail markets, and thus to a large degree businesses choose the sources of seafood for consumers.

Both retailers and food-service companies are now making environmentally preferable seafood choices. In February 2006, Wal-Mart announced plans to only purchase wild-caught seafood that is certified by the Marine Stewardship Council (Wal-Mart 2006). Wegmans Food Markets and Bon Appétit, a food service company, adopted a new purchasing policy in 2006 for farm-raised salmon based on health and environmental standards (Bon Appétit and Wegmans 2006). Compass Group USA, the U.S. division of the world's largest food service company, announced it would no longer purchase Atlantic cod and species they determine to be unsustainably produced (Compass Group 2006). The New England Aquarium is working with supermarket owner Ahold USA on a program to help Ahold make environmentally preferable purchases of farmed and wild seafood (Ahold 2006).

Labeling and other private sector programs can complement or strengthen conventional regulatory programs to achieve desired conservation and management outcomes. An eco-label conveys information that may give a product a market advantage over other similar products, providing a financial reward for industrial and business practices that benefit the environment. The availability of credible eco-labeling is thus an incentive to producers to comply with or even exceed strong environmental standards, and perhaps seek even stronger regulations than currently in place.

Private sector initiatives increasingly provide a public relations advantage, which may create market advantage but is also related to "goodwill"—an intangible asset valued by business independent of financial rewards. Some companies, such as Ahold, choose not to directly label environmentally preferable products, but discuss their programs through websites, pamphlets, and other media.

Corporate purchasing policies and certification are becoming valuable tools for promoting sustainable fisheries and protecting healthy marine ecosystems. In this chapter, we first evaluate efforts to develop organic standards for seafood, then review a sustainability certification program for wild-caught fish. Finally, we review similar product differentiation efforts that are underway for marine aquaculture. Although it is not yet possible to evaluate the efficacy of such programs for aquaculture products, results from capture fisheries are encouraging. Common features of a workable, widely accepted, and environmentally beneficial certification methodology for aquaculture begin to emerge from this analysis.

Organic Standards for Seafood

Organic farming aims to improve the healthfulness of food products, reduce the environmental impact of agriculture, and maintain farm animals under hygienic and humane conditions. As a result, it operates under principles that support efforts to improve the ecological sustainability of agriculture. If organic standards are developed for aquaculture, they could bring the same benefits to this sector. Major tenets of organic farming include recycling nutrients within the farm, eliminating or minimizing the use of drugs and pesticides, and in general reducing environmental externalities from farm operations.

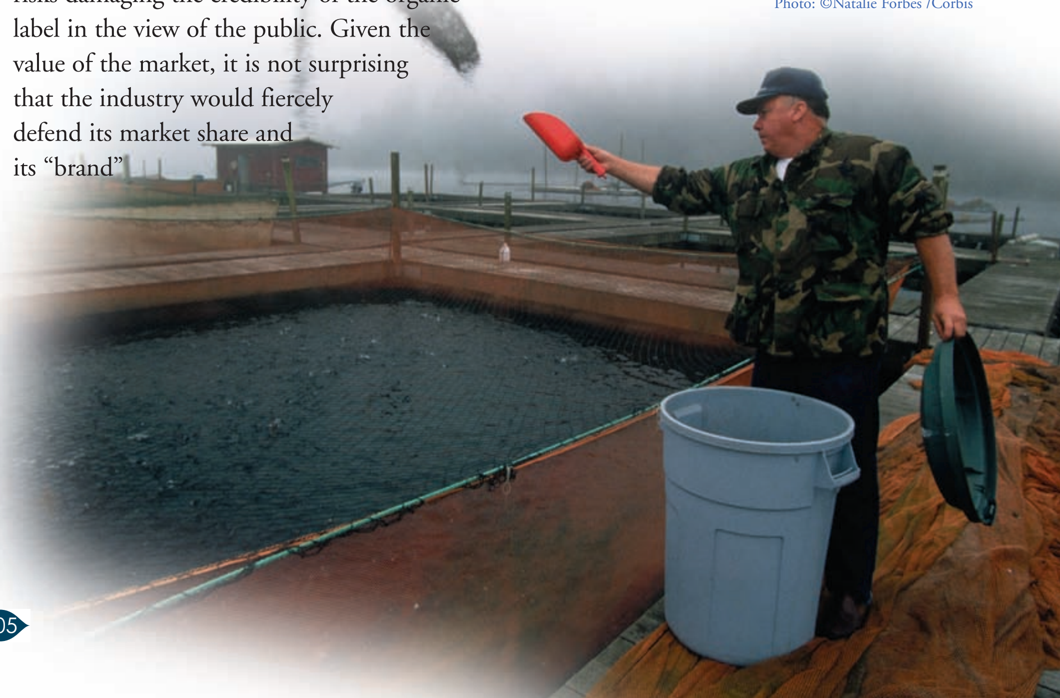
Formal standards have been established by the USDA that terrestrial crops and livestock must meet before they can be labeled “organic” in the United States. Aquaculture, however, does not fit neatly into the regime for organic agriculture established for terrestrial farms. Organic standards for aquaculture are under consideration by the USDA’s National Organic Standards Board. Draft aquaculture standards were made available in early 2006 for public comment by an aquaculture working group appointed by USDA (NOSB 2006). This draft is currently undergoing consideration and revision.

In Europe, a number of private certifiers have established their own organic standards for farmed seafood, and seafood meeting these standards is now in the marketplace. However, these standards are not necessarily consistent with U.S. requirements for organic agriculture. In 2005, the State of California banned the sale of seafood labeled “organic” in California to ensure consumers were not confused by organic seafood labeling in the absence of U.S. requirements.

A significant challenge for net pen and sea cage aquaculture is to implement the principle of organic agriculture requiring nutrient recycling. Fish wastes in the effluents from closed or contained flow-through aquaculture systems can be removed and recycled, but it is impractical to try to contain wastes from net pens or sea cages immersed in a water body. As discussed in Chapter 6, integrated aquaculture has been proposed as a way to use wastes from finfish production to produce seaweeds and/or bivalve mollusks while also reducing nutrient and organic pollution loading to the surrounding system. The USDA aquaculture working group’s draft standards “encourage” integrated aquaculture or other ways of reducing wastes, but only require such measures for net pens.

Feeds for aquatic animals have also posed a substantial challenge for those seeking organic certification for aquaculture products. Not surprisingly, feeds for organic livestock must also be organically produced. The USDA standards for terrestrial livestock reflect this principle, although they do allow nonorganic additives and supplements to make up a small percentage of the feed. For herbivorous or omnivorous fish such as tilapia, carp, and even catfish it is possible to obtain feeds made from organic plant ingredients, such as soy. For culture of carnivorous fish, however, meal and oil from wild-caught fish currently make up the bulk of compound feeds. In principle, wild fish cannot be organic in the agricultural sense because the provenance of wild-sourced ingredients precludes the control over inputs and growing conditions that would make such certification possible (USDA Aquatic Animal Task Force 2001).

However, a 2003 amendment to the (U.S.) Organic Food Production Act of 1990 allows wild seafood to be certified as organic if regulations are developed after public notice and comment. Although clearly intended to convey the benefits of the organic label on wild seafood, this legislation alarmed many in the organic food community because bending the rules to satisfy one political constituency or another risks damaging the credibility of the organic label in the view of the public. Given the value of the market, it is not surprising that the industry would fiercely defend its market share and its “brand”



Feeding time at a salmon farm in Washington. Private sector initiatives, such as purchasing agreements and environmental certification, can harness the power of the marketplace to improve feed production and utilization practices and other environmental aspects of aquaculture.

Photo: ©Natalie Forbes /Corbis

integrity. The practical difficulty in establishing criteria and processes for certifying wild seafood as organic, combined with deep skepticism of the whole concept within the organic farming community, has stalled the development of rules in this area.

The aquaculture working group acknowledged the dilemma of wild-sourced ingredients by including two options for feeds in its draft organic standards for aquaculture products. One option would allow the use of wild fish ingredients in feeds if they come from fisheries certified to be sustainably managed under internationally recognized certification organizations, are used in aquaculture systems that maintain no more than a one-to-one ratio of wild fish input to aquaculture animals cultured, and meet other criteria. The second option would require that aquatic animal ingredients in aquafeeds come from organically raised animals, except for small amounts as additives or supplements.

Shellfish farming has its own set of challenges for organic certification. In theory, bivalve mollusks and other aquatic grazers could be certified organic in much the same way that natural grass-fed beef can be organic. Although such livestock eat wild grasses, rangeland is typically managed and the fodder is thought to be sufficiently "natural" and free from additives to justify the organic label. A significant issue to be resolved is how to monitor for, and protect against, environmental contaminants that might enter the shellfish through the wild food chain. Shellfish growers have expressed concern that the draft proposed organic aquaculture standards did not create a pathway for organic certification of shellfish. Because of the unique nature of shellfish farming, such standards may have to be pursued on a separate track.

Given these challenges, the question is which forms of aquaculture can be accommodated under the rules for organic certification while maintaining the integrity of the organic label? For herbivorous species, including shellfish, it would seem possible to develop a set of organic standards—including for feeds—that adhere closely to organic principles. For marine carnivores, however, the dominance of wild feed ingredients and the lack of control over effluents are major deviations from organic farming principles that will have to be addressed. These concerns should be addressed in a way that maintains public confidence in the organic label. Ultimately, some segments of the aquaculture industry may find it more expedient and beneficial to pursue labeling for sustainability instead of organic status.

Sustainability Certification for Wild-Caught Seafood

The most prominent seafood certification program is the Marine Stewardship Council (MSC). MSC was founded jointly by Unilever, the world's largest buyer of seafood, and World Wildlife Fund, an international conservation organization, in 1997. Since 1999 it has operated independently. The MSC website clearly states its purpose: "In a bid to reverse the continued decline in the world's fisheries, the MSC is seeking to harness consumer purchasing power to generate change and promote environmentally responsible stewardship of the world's most important renewable food source" (MSC 2006).

MSC is a global, nonprofit organization. It has developed environmental principles and criteria for sustainable and well-managed fisheries to guide its certification process. A fishery must adhere to these principles in order to receive the MSC certification. The three principles are:

- Maintenance and re-establishment of healthy populations of targeted species;
- Maintenance of the integrity of ecosystems; and

• Development and maintenance of effective fisheries management systems, and compliance with relevant local and national laws and standards.

The certification program is voluntary. Any capture fishery may apply for certification, but they do not currently certify aquaculture products. MSC approves or accredits independent certifiers to carry out an assessment of how the fishery performs compared to the standards. During the process, a peer review of the assessment is conducted and stakeholder comment is accepted. If the fishery passes the assessment, it will be certified. Finally, a formal objections procedure is in place (MSC 2005).

To date, 19 fisheries have been certified by MSC and over 300 products carry the MSC label. Wal-Mart announced in early 2006 a commitment to purchase all of it wild-caught fresh and frozen seafood from MSC-certified fisheries (Wal-Mart 2006). Wal-Mart will begin buying MSC-labeled seafood in 2006 and transition over the next three to five years so that all of its wild-caught seafood products will eventually carry the MSC label. Forty-six percent of Unilever's seafood products sold in 2005 were certified by the MSC (Unilever 2006). Whole Foods, Trader Joe's, Shaw's, and Legal Seafoods have pledged to buy MSC-certified products and Royal Caribbean Cruise Lines has expressed interest in serving MSC-labeled products on its cruise ships. Clearly, the MSC label has gained a great deal of momentum in the marketplace.

However, the MSC process is not perfect. MSC has been criticized by conservation organizations for a number of reasons: the use of consultants who usually work for the industry to conduct the certification; the lack of adherence to its standards during the assessment and certification process; the key principle regarding the protection of marine ecosystems is routinely not met by fisheries receiving certification; and fisheries not in compliance with national laws have been certified (Highleyman et al. 2004). At the same time, most major conservation organizations continue to support market-based initiatives, and many have provided comments and recommendations to improve the MSC process.

Another model to consider is the FAO Guidelines for the Eco-Labeling of Fish and Fishery Products from Marine Capture Fisheries (FAO 2005). The guidelines are based on existing international agreements regarding fisheries.[16] They contain three substantive requirements (or standards) that FAO recommends be included, at a minimum, in the development of any eco-labeling system:

• The fishery is conducted under a management system that is based on good practices and operates in compliance with the local, national, and international laws and regulations.
• The stock under consideration is not overfished and is maintained at a level that promotes the objective of optimal utilization and maintains its availability for present and future generations.
• Adverse impacts of the fishery on the ecosystem should be appropriately assessed and effectively addressed.

In addition, the guidelines cover procedural and institutional matters that an eco-labeling program should encompass. This part of the guidelines draws heavily on guidelines developed by the International Standards Organization (ISO). There are three stages that must be considered: setting standards for sustainable fisheries, accreditation of certifiers, and certification of fisheries. Setting the standards is among the most critical tasks of an eco-labeling program, as it defines quantitative and qualitative

[16] In particular, the 1982 U.N. Convention on the Law of the Sea, the 1995 U.N. Fish Stock Agreement, the 1995 FAO Code of Conduct for Responsible Fisheries, and the 2001 Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem.

measures by which the sustainability of a fishery will be assessed. Accreditation assures certification bodies are competent to conduct assessments of a fishery's adherence to standards and chain of custody requirements. Finally, certification provides the necessary assurances, by a third party, that a fishery conforms to the relevant standards.

At each of these stages, the guidelines provide minimum requirements. In setting the standards, there are requirements for transparency, participation by interested parties, notification, keeping of records, and review and revision of standards. The guidelines note that it is important not to impose excessive burdens on participating producers, which can create incentives for noncompliance. The accreditation process has requirements for nondiscrimination, independence, impartiality, transparency, accountability, and resolution of complaints. The certification process contains some of the requirements already mentioned for the other stages, as well as requirements for maintaining certification, renewal of certification, and maintaining chain of custody information. To be effective, the criteria for certification must be "practicable, viable and verifiable." Finally, a resolution of complaints and appeals process should be clearly stated and available.

A well-recognized, widely accepted certification system does not yet exist for marine aquaculture products.

There is a great deal of overlap between the MSC example and the FAO guidelines. It is clear that certain elements of an eco-labeling program are critical to its success, based on the experience of existing programs and the thorough evaluation by FAO for the development of its guidelines. This includes clear articulation of standards that ensure sustainability of a product, and establishing a credible and accountable process for accreditation and certification. In addition, good standards alone are not sufficient; procedural and institutional aspects play a vital role in public acceptance and confidence in a certification program.

Current Initiatives for Differentiation and Certification of Aquaculture Products

A well-recognized, widely accepted certification system does not yet exist for marine aquaculture products. This is a concern shared by both producers and environmentalists as aquaculture's share of the market grows. As individual and corporate buyers become accustomed to environmental certification for wild-caught seafood products, they are starting to seek aquaculture products with comparable attributes. While this is a positive development, with no comparable programs yet available except for shrimp, aquaculture producers are concerned they may be excluded from markets. However, along with organic certification, several certification or related demand-side efforts underway in the United States may lead to more sustainable aquaculture practices and their recognition in the marketplace. Five such programs are reviewed briefly below.

Several U.S. conservation organizations have created websites and wallet-sized cards which provide guidance to consumers on choosing environmentally preferable seafood. The Monterey Bay Aquarium's Seafood Watch Program, which uses ecological criteria to rate various farmed and wild fish as green, yellow, or red (corresponding to best, intermediate, and worst) choices, is perhaps best known. About eight million "Seafood Watch Pocket Guides" have been distributed by the Monterey Bay Aquarium and other zoos and aquaria. Environmental Defense's Oceans Alive Program has a similar "Seafood Selector" card and website. The Monterey Bay Aquarium uses Environmental Defense's information concerning seafood contaminants in its Pocket Guides. The Blue Ocean Institute also has a well-regarded "Guide to Ocean-Friendly Seafood."

Wegmans Food Markets, a food retailer, and Bon Appétit Management Company, a food service company, adopted in March 2006 a purchasing policy that includes a number of production standards. These standards, developed in consultation with Environmental Defense, define strong environmental and health criteria that suppliers must meet in order to have Wegmans and Bon Appétit purchase their farm-raised salmon. The purchasing policy sets numerical limits for contaminants such as PCBs, and requires salmon producers to take steps to reduce impacts on wild fish populations and the marine environment. The criteria include: limiting the use of fishmeal and fish oil in feed; implementing measures to prevent escapes; minimizing or eliminating drug use; reducing incidents of disease and parasites; reducing water pollution; monitoring and reducing the impacts on the sea floor; and prohibiting the killing or harassment of marine wildlife. The types of standards outlined in this purchasing policy could also be used as the basis for standards in a certification program for production of farm-raised salmon or other species.

Compass Group USA, which owns about ten food service companies (including Bon Appétit), announced in February 2006 that it was adopting a new policy based largely on the Monterey Bay Aquarium's Seafood Watch Program (Compass 2006). The Seafood Watch Program classifies seafood into three categories, from "best choices" to "avoid," based on ecological criteria. Compass Group pledged to decrease its use of farmed shrimp and salmon, which are on the Aquarium's "avoid" list, unless they are farmed in a more sustainable manner. The company also said it would stop selling all other "avoid" species and increase its use of "best choices."

In 2001, Ahold USA, which owns Giant, Stop and Shop, and four other grocery chains along the East Coast, enlisted the New England Aquarium to help audit sources of both farmed and wild seafood for their environmental impact (Seafood Choices Alliance 2005, Ahold 2006). This initiative, called "Eco-Sound," led Ahold USA to incorporate environmental sustainability into its purchasing criteria for seafood. The company has now stopped selling Chilean sea bass and has reduced its sales of orange roughy by 75 percent. Both are long-lived wild fish that are highly vulnerable to depletion.

The World Wildlife Fund (WWF) began a new initiative in 2004 to develop a sustainable aquaculture certification program. The initiative is organized around "aquaculture dialogues" for five species groups: salmon, mollusks, tilapia, catfish, and shrimp. Each dialogue has engaged a multistakeholder working group to review impacts of aquaculture and identify issues that require additional research. The results of these dialogues, while likely a few years off, could inform the development of best management practices or the development of standards for a certification system.

Finally, the Global Aquaculture Alliance (GAA) is an industry trade association dedicated to promoting aquaculture. GAA established best aquaculture practices (BAPs) for shrimp farming that form the basis for a certification program through the Aquaculture Certification Council (ACC). Certification is available to shrimp processing plants, farms, and hatcheries. The certification targets wholesale buyers, with the BAP label applied to cartons of shrimp sold to seafood wholesalers, not on retail packages.

The BAPs were derived from two previous efforts of the GAA: Guiding Principles for Responsible Aquaculture and Codes of Practices for Responsible Shrimp Farming (GAA 2006). To receive certification, a facility must register with the ACC and pay a processing fee, submit an application form that contains a self-assessment audit, and contract with an ACC-accredited certifier to review the application and conduct a site inspection. The site inspection typically takes one day, or just a few hours for a small farm. If a facility is approved for certification, participants must pay an annual program fee and maintain records. Finally, a facility must be recertified every two years (AAC 2006).

Private sector initiatives, eco-labeling, and certification have the potential to significantly improve the sustainability of aquaculture production practices.

Discussion and Conclusions

Private sector initiatives, eco-labeling, and certification have the potential to significantly improve the sustainability of aquaculture production practices. In addition to regulatory approaches outlined in other parts of this report, such programs may lead to reduced environmental impacts from aquaculture. By harnessing the enormous power of the marketplace to reward good behavior with respect to the environment, demand-side programs provide incentives for environmental protection that governments cannot provide. These methods are not a substitute for good environmental regulation and management, but they can complement and enhance the effectiveness of such measures.

No one kind of demand-side program is a "silver bullet" for the marketplace. Corporate purchasing standards, such as those adopted by Wegmans and Ahold, provide a strong economic incentive for suppliers to improve their production practices. They can be established relatively quickly and can be tailored to suit the needs of particular buyers and suppliers. Nevertheless, the proliferation of numerous, disparate corporate purchasing programs could result in a difficult marketplace for some suppliers, who have to implement different production standards to meet the needs of different customers, as well as result in a confusing marketplace for consumers.

Establishing one or a small number of certification programs can create a more coherent marketplace. Moreover, many companies may find it advantageous to rely on a credible certification program that provides them with seafood produced in an environmentally responsible manner and does not involve a major investment of company time and resources in its development.

Certification systems for both organic and conventional aquaculture production are complementary. While growing rapidly, organic agriculture is unlikely to dominate the marketplace due to generally higher production costs. Major issues to be resolved for aquaculture include the degree to which organic standards are, or can be, credibly applied to various forms of aquaculture, and whether a widely accepted approach for certifying the sustainability of aquaculture feed ingredients can be developed.

Although all the examples provided in this chapter have their strengths and weaknesses, collectively they shed light on some basic principles for a good sustainability scheme for aquaculture. Keys to success include high standards for sustainability achieved through practical and viable measures, strong verification procedures and compliance with standards, transparency and accessibility of the process to interested parties, and achieving and maintaining high consumer confidence in the label.

That said, the process for developing strong, credible certification programs, with requirements for transparency and broad agreement on standards, can be quite lengthy. Companies that profit by differentiating their brand and their products may wish to retain their own production standards. If developed collaboratively with conservation organizations, such standards often achieve considerable credibility. Product differentiation can be beneficial for the environment as well as the bottom line. Companies that wish to truly distinguish themselves on the basis of their environmental stewardship may push for more stringent production standards than a consensus-based certification program can achieve. Individual private sector programs are nimble and can be "laboratories" for innovation.

In short, while the development of certification systems for aquaculture is highly desirable, other programs to differentiate environmentally preferable farmed seafood in the marketplace may prove valuable catalysts for better production practices. Different approaches can be bridged at least in part by encouraging representatives from individual private sector programs to bring their experiences to the development of broad certification programs.

Summary of Recommendations

- Encourage companies to adopt purchasing polices favoring environmentally preferable aquaculture products.
- Encourage the development of certification systems for aquafeeds and aquaculture products.
- Certification systems for aquaculture products should contain criteria that require the use of feed derived from sustainable sources.

DETAILED RECOMMENDATIONS

23. **Encourage corporate seafood buyers and smaller businesses to pursue purchasing programs that favor environmentally preferable aquaculture products.** The objective of these systems should be to create marketplace incentives for sustainable aquaculture and feed production practices, as well as to provide business benefits for purchasers.

    23.1. These buyers should also be encouraged to participate in the development of certification systems for aquaculture

24. **Encourage the development of certification systems that will distinguish aquafeed and aquaculture products to the consumer, thus providing a marketplace incentive for more sustainable products.** The objective of these systems should be to create marketplace incentives for sustainable aquaculture and feed production practices. Certification informs the consumer that certain aquaculture products are raised and harvested in accordance with broadly accepted criteria for sustainability.

    24.1. USDA should promulgate credible federal organic standards for aquaculture under the agency's National Organic Program.

    24.2. An independent, third party organization, working cooperatively with relevant stakeholders, should coordinate a certification process for nonorganic aquaculture.

    - The organization should have a clear governance system that defines the policy of the organization.
    - The organization should be governed by a board that represents the full spectrum of stakeholder interests in sustainable aquaculture.
    - The organization should have a transparent governance system, including the body's sources of funding.
    - The organization should have or develop international recognition.
    - The organization should commit to continuous review and improvement of the system.

    24.3. The organization should coordinate the development of standards and/or specific criteria for determining sustainability of aquaculture products.

    - The process should be transparent, with full disclosure of the standards development procedure.
    - The process should include and encourage broad public input with a clear forum for public participation.
    - The process should be science based.
    - To the extent possible, the standards should be performance based and thus allow producers flexibility in how they achieve standards.

24.4. The organization should clearly define procedures for certification. This should include the requirements and process for farms to achieve, maintain, and renew certification.

- Farms must provide adequate information in an initial application so that the organization can verify that farm practices meet the standards and/or criteria for certification through the evaluation process.
- The organization should conduct a technical review of the application.
- The organization should provide a mechanism for public input and comment during the certification process.
- The organization should create a mechanism to resolve disputes.
- Farms must submit an annual report to ensure compliance with certification criteria.
- Certification should be valid for five years, after which farms must renew their certification.

25. A sustainable aquaculture certification system should include criteria that require the use of sustainable feed products. Market-based incentives for aquaculture products are an effective tool for consumers to create a demand for sustainable aquaculture products. The Task Force encourages the use of certification systems in recommendation 24. Any certification system for sustainable aquaculture products should make a strong commitment to ensure the use of sustainable feed ingredients.

25.1. Certification criteria should require that if feeds containing ingredients derived from fishery resources are used to produce the aquaculture product being considered for certification, the fisheries those ingredients are derived from must be considered healthy and are under a management system that protects the structure and function of marine ecosystems.

25.2. Certification criteria should require that feed ingredients not derived from directed fishery resources are produced in accordance with sustainability standards for aquafeeds.

CHAPTER 9

CONCLUSION: A VISION FOR THE FUTURE

Throughout the Task Force's investigation, we have made a considerable effort to identify issues related to the sustainability of aquaculture. The Task Force has reviewed environmental, social and economic considerations related to the long-term contribution of marine aquaculture to the nation's welfare and to the health of its marine ecosystems. Sustainability itself is a slippery term, and leaves much to interpretation. At the end of the day, the Task Force has come to think of sustainability as a direction instead of a particular place or data point. Some practices are clearly unsustainable, at least from an environmental standpoint, but given the many inputs and outputs associated with aquaculture it is exceedingly difficult to establish objectively when "sustainability" has been achieved.

The responsible use of the planet's resources to meet the needs of society for healthful food is a goal universally supported by those across the spectrum of the aquaculture debate. Rather than getting bogged down in definitions, the Task Force has offered the recommendations in the preceding chapters in the hope of providing a blueprint to responsibly develop aquaculture in marine waters. As suggested in the introduction, aquaculture is neither inherently good nor inherently bad: the outcome for better or worse depends entirely on the application. In our investigation, we found no silver bullets. Reasonable people will continue to disagree as to the appropriate environmental thresholds and tolerances, but we hope this report provides a substantial starting point for a national dialogue on the promise of, and appropriate limitations to, the use of marine waters for aquaculture.

The Task Force was asked, in part, to determine whether aquaculture can proceed in marine waters without harm to marine ecosystems. We believe it can under certain conditions. In this report, we have attempted to discuss rationally the environmental concerns with marine aquaculture and to specify the conditions under which aquaculture could proceed in the marine environment while ensuring minimal harm to marine life.

All human activities have an effect on the environment, but in these early years of the 21st century, we are increasingly realizing that we have trod too heavily on the planet. Unsustainable consumption patterns, particularly in developed countries, are leading to global ecological disruption and rapid depletion of both renewable and nonrenewable resources. It is in this context that the future of aquaculture must be determined. Growing our own seafood through aquaculture can provide part of the solution to a major ecological catastrophe—overharvesting of the world's marine life—while contributing to the global supply of healthy seafood.

Fresh farmed tilapia for sale alongside local wild salmon in Bethel, Alaska. Aquaculture currently supplies nearly half of the seafood produced for human consumption and that proportion is expected to increase. Sustainable development of aquaculture will require careful management of its environmental, social, and economic impacts as the industry continues to expand.

Photo: Gunnar Knapp

Growing our own seafood through aquaculture can provide part of the solution to a major ecological catastrophe—overharvesting of the world's marine life—while contributing to the global supply of healthy seafood.

If aquaculture is to fulfill this great promise, however, governments and citizens alike must be vigilant. Short-term economic considerations will make it all too easy for marine aquaculture to slip into the ecologically harmful methods of large-scale, intensive livestock production increasingly adopted on land. Despite some recent improvements, experience to date with commercial salmon farming is not encouraging in this regard. The most popular farmed species among consumers in developed countries tend to be carnivores, creating an additional challenge to sustainability. Forms of aquaculture that consume more fish than they produce cannot assist society in addressing the global problem of wild fisheries depletion.

Marine aquaculture poses an additional challenge because, unlike most terrestrial farming, in most cases it occurs in the public domain. In the United States, the federal and state governments hold the vast majority of ocean space and resources in trust for the public. As a result, it is incumbent on our government to consider the full range of uses of that space and those resources. In granting access to public space and resources for the aquaculture industry to carry out its activities, it is legitimate for the government, on behalf of the public owners of the resource, to condition the aquaculture industry's tenure. In that sense, these decisions are more like those associated with private use of public forests and rangelands than they are about how to regulate practices on private agricultural land.

If most of the ocean is to remain wild and open, as we believe most Americans want, then there are limits on the scope and nature of aquaculture that should be allowed to take place directly in marine waters. In this report, we have tried to identify appropriate limits and conditions on marine aquaculture to ensure that our heritage of healthy, bountiful oceans can be passed on to future generations. Given its inherently "leaky" nature, in situ marine aquaculture could do substantial damage to marine ecosystems if managed poorly. Managed properly, marine aquaculture can contribute positively to the restoration of marine ecosystems and to the diet of Americans. We believe that is a sound basis for a marine aquaculture policy for the nation.

REFERENCES

Ackefors, H. and M. Enell. 1994. The release of nutrients and organic matter from aquaculture systems in Nordic countries. *Journal of Applied Ichthyology* 10:225-241.

Ahold. 2006. Eco-Sound: sustainable fisheries, ensuring the sustainability and traceability of Ahold's seafood products. http://www.ahold.com/page/694.aspx#XSLTheader134122120120

Alden, R. 1997. *Maine's Aquaculture Strategy*. Maine Department of Marine Resources.

Alston, D., A. Cabarcas, J. Capella, D. Benetti, S. Keene-Meltzoff, J. Bonilla, and R. Cortes. 2005. Environmental and social impacts of sustainable offshore cage culture production in Puerto Rican waters. Final Report to NOAA Federal Contract Number: NA16RG1611. www.lib.noaa.gov/docaqua/reports_noaaresearch/finaloffshorepuertorico.pdf

Alverson, D.L. 1998. Discarding Practices and Unobserved Fishing Mortality in Marine Fisheries: An Update, 1998. National Marine Fisheries Service, 29 April, 1998. Seattle: Sea Grant Washington. Sea Grant Publication WSG 98-06, 76pp.

Anderson, W. 2002. *East coast states shellfish seed interstate transport: A regulatory overview*. Eastern United States Interstate Shellfish Seed Transport Workshop. Charleston, S.C., 2002.

Aquaculture Certification Council (ACC). 2006. Certification standards found on organization website. http://199.238.130.190/index.html

Arnold, W., S. Walters, J. Fajans, S. Peters, and T. Bert. 2004. Influence of congeneric aquaculture on hard clam (*Mercenaria* spp.) population genetic structure. *Aquaculture International* 12:139-160.

Atlantic States Marine Fisheries Commission (ASMFC). 2005. Addendum II to Amendment 1 to the Interstate Fishery Management Plan for Atlantic Menhaden. www.asmfc.org

Baum, E.T. 2001. Interactions between farmed and wild Atlantic salmon in Maine rivers. In *Marine Aquaculture and the Environment: a meeting for stakeholders in the Northeast*, M. Tlusty, D. Bengston, H. Halvorsen, S. Otleay, J. Pearce, and R. Rheault, eds. Cape Cod Press, Falmouth, MA.

Behnke, R.J. 2002. *Trout and Salmon of North America*. The Free Press, New York, NY.

Bellis, Diane. 2006. Personal communication. Coordinator for the Plant-Based Feeds Initiative, AgSource, Inc.

Bellona Foundation. 2003. The Environmental Status of Norwegian Aquaculture. Bellona Report No. 7 (2003). http://www.bellona.org/reports/Norwegian_Aquaculture

Benetti, D., L. Brand, J. Collins, G. Brooks, R. Orhun, C. Maxey, A. Danylchuk, G. Walton, B.Freeman, J.Kenworthy, and J. Scheidt. 2005. Cape Eleuthera Offshore Aquaculture Project: Working document final report, summary of observations phase I.

Benetti, D., L. Brand, M. Collins, R. Orhun, A. Benetti, B. O'Hanlon, A. Danylchuk, D. Alston, J. Rivera, and A. Cabarcas. 2006. Can offshore aquaculture of carnivorous fish be sustainable? Case studies from the Caribbean. *World Aquaculture*, March 2006.

Benson, A. and D. Raikow. 2005. *Dreissena polymorpha*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. Revision Date: 12/9/2004. http://nas.er.usgs.gov/queries/FactSheet.asp?speciesID=5

Blazer, V.S., and S.E. LaPatra. 2002. Pathogens of cultured fishes: potential risks to wild fish populations. Pages 197-224 in *Aquaculture and the Environment in the United States,* J. Tomasso, ed. U.S. Aquaculture Society, a Chapter of the World Aquaculture Society, Baton Rouge, LA.

Boesch, D.F., R.H. Burroughs, J.E. Baker, R.P. Mason, C.L. Rowe, and R.L. Siefert. 2001. *Marine Pollution in the United States: Significant Accomplishments, Future Challenges*. Pew Oceans Commission. Arlington, VA.

Bon Appétit Management Company and Wegmans Food Markets. 2006. Farmed Salmon Purchasing Policy. http://www.environmentaldefense.org/documents/5117_FarmedSalmonPolicy2006.pdf

Boyd, C., A. McNevin, J. Clay and H. Johnson. 2005.Certification issues for some common aquaculture species. *Reviews in Fisheries Science* 13:231-279.

Boyra, A., F.J.A. Nascimento, F. Tuya, P. Sanchez-Jerez, and R.J. Haroun. 2004. Impact of sea-cage fish farms on intertidal macrobenthic assemblages. *Journal of the Marine Biological Association of the United Kingdom* 84:665-668.

Bridger, C., R. K. Booth, R. S. McKinley, and D. A. Scruton. 2001. Site fidelity and dispersal patterns of domestic triploid steelhead trout (*Oncorhynchus mykiss* Walbaum) released to the wild. *ICES Journal of Marine Science* 58:510–516.

Brodeur, R. and M. Busby. 1998. Occurrence of an Atlantic salmon *Salmo salar* in the Bering Sea. *Alaska Fishery Research Bulletin* 5:64-66.

Brooks, K.M. and C.V.W. Mahnken. 2003. Interactions of Atlantic salmon in the Pacific Northwest environment II. Organic wastes. *Fisheries Research* 62:255 293.

Brown, M.T., and R.A. Herendeen. 1996. Embodied energy analysis and EMERGY analysis: a comparative view. *Ecological Economics* 19:219-235.

Bureau, D., S. Gunther and C. Cho. 2003. Chemical composition and preliminary theoretical estimates of waste outputs of rainbow trout reared in cage culture operations in Ontario. *North American Journal of Aquaculture* 65:33-38.

Burridge, L.E., K. Haya, F.H. Page, S.L. Waddy, V. Zitko, and J. Wade. 2000a. The lethality of cypermethrin formulation Excis to larval and post-larval stages of the American lobster (*Homarus americanus*). *Aquaculture* 182:37-47.

Burridge, L.E., K. Haya, S.L. Waddy, and J. Wade. 2000b. The lethality of anti-sea lice formulations Salmosan (Azamethipos) and Excis (Cypermethrin) to stage IV and adult lobsters (*Homarus americanus*) during repeated short-term exposures. *Aquaculture* 182:27-35.

Butler, J.R. 2002. Wild salmonids and sea louse infestations on the west coast of Scotland: sources of infection and implications for the management of marine salmon farms. *Pest Management Science* 58:595-608.

Cabello, F. 2006. Heavy use of prophylactic antibiotics in aquaculture: a growing problem for human and animal health and for the environment. *Environmental Microbiology* 8(7):1-8.

Capone, D.G., D.P. Weston, V. Miller, and C. Shoemaker. 1996. Bacterial residues in marine sediments and invertebrates following chemotherapy in aquaculture. *Aquaculture* 145:55-75.

Carlton, J.T. 1992. Dispersal of living organisms into aquatic ecosystems as mediated by aquaculture and fisheries activities. Pp. 13-46 in *Dispersal of Living Organisms Into Aquatic Ecosystems*, A. Rosenfield and R. Mann, eds. Maryland Sea Grant College Program, College Park, MD.

Carlton, J.T. 2001. *Introduced Species in U.S. Coastal Waters: Environmental Impacts and Management Priorities*. Pew Oceans Commission, Arlington, VA.

Chelossi, E., L. Vezzulli, A. Milano, M. Branzoni, M. Fabiano, G. Riccardi, and I.M. Banat. 2003. Antibiotic resistance of benthic bacteria in fish-farm and control sediments of the Western Mediterranean. *Aquaculture* 219:83-97.

Chopin, T., C. Yarish, R. Wilkes, E. Belyea, S. Lu, and A. Mathieson. 1999. Developing *Porphyra*/salmon integrated aquaculture for bioremediation and diversification of the aquaculture industry. *Journal of Applied Phycology* 11:463-472.

Chopin, T., A. Buschmann, C. Halling, M. Troell, N. Kautsky, A. Neori, G. Kraemer, J. Zertuche-Gonzalez, C. Yarish, and C. Neefus. 2001. Integrating seaweeds into marine aquaculture systems: A key toward sustainability. *Journal of Phycology* 37:975-986.

Cicin-Sain, B., S. M. Bunsick, R. DeVoe, T. Eichenberg, J. Ewart, H. Halvorson, R.W. Knecht, and R. Rheault. 2001. *Development of a Policy Framework for Offshore Marine Aquaculture in the 3-200 Mile U.S. Ocean Zone*. Center for the Study of Marine Policy, University of Delaware.

Cicin-Sain, B., S.M. Bunsick, J. Corbin, M.R. DeVoe, T. Eichenberg, J. Ewart, J. Firestone, K. Fletcher, H. Halvorson, T. MacDonald, R. Rayburn, R. Rheault, and B. Thorne-Miller. 2005. *Recommendations for an Operational Framework for Offshore Aquaculture in U.S. Federal Waters*. Center for the Study of Marine Policy, University of Delaware.

Cohen, A.N. 2002. *The release of pest species by marine aquaculture: lessons from a South African parasite introduced into California waters*. San Francisco Estuary Institute, Oakland, CA.

Collier, L.M. and E.H. Pinn. 1998. An assessment of the acute impact of the sea lice treatment ivermectin on a benthic community. *Journal of Experimental Marine Biology and Ecology* 230:131-147.

Compass Group. 2006. Compass Group Announces Landmark Policy to Purchase Sustainable Seafood. 13 February 2006. http://www.cgnad.com/default.asp?action=article&ID=272

Davies, I.M., P.A. Gillibrand, J.G. McHenery, G.H. Rae. 1998. Environmental risk of ivermectin to sediment dwelling organisms. *Aquaculture* 163:29-46.

Davies, I.M., and G.K. Rodger. 2000. A review of the use of ivermectin as a treatment for sea lice (*Lepeophtheirus salmonis* Kroyer and *Caligus elongatus* Nordmann) infestation in farmed Atlantic salmon (*Salmo salar* L.). *Aquaculture Research* 31:869-883

Delgado, O., J. Ruiz, M. Perez, J. Romero, and E. Ballesteros. 1999. Effects of fish farming on seagrass (*Posidonia oceanica*) in a Mediterranean bay: seagrass decline after organic loading cessation. *Oceanologica* 22:109-l 17.

Department of Environmental Protection, Maine (DEP). 2002. Maine Pollution Discharge Elimination System Permit and Marine Waste Discharge License Fact Sheet: General Permit for Finfish Aquaculture.

Department of Marine Resources, Maine (DMR). 2003. Maine Aquaculture Review.

Department of Marine Resources, Maine (DMR). 2006. Marine Aquaculture website. 1 June 2006. http://www.maine.gov/dmr/aquaculture/index.htm>

Duff, J., T. Getchis, and P. Hoagland. 2003. A Review of Legal and Policy Constraints to Aquaculture in the U.S. Northeast. Aquaculture White Paper No. 5, NRAC Publication No. 03-005.

Enell, M. 1995. Environmental impact of nutrients from Nordic fish farming. *Water Science and Technology* 31:61-71.

Environmental Protection Agency (EPA). 2002a. Acadia Aquaculture NPDES Permit. http://www.epa.gov/region1/npdes/AcadiaFinalFeb21.pdf

Environmental Protection Agency (EPA). 2002b. Effluent limitations guidelines and new source performance standards for the concentrated aquatic animal production point source category; proposed rule. *Federal Register* 67(177):57872-57928

Environmental Protection Agency (EPA). 2004. 40 CFR Part 451: Effluent limitations guidelines and new source performance standards for the concentrated aquatic animal production point source category; final rule. *Federal Register* 69(162):51982-51930.

Ernst, W., P. Jackman, K. Doe, F. Page, G. Julien, K. Mackey, and T. Sutherland. 2001. Dispersion and toxicity to nontarget organisms of pesticides used to treat sea lice on salmon in net pen enclosures. *Marine Pollution Bulletin* 42:432-443.

Ervik, A., B. Thorsen, B.T. Lunestad and O.B. Samuelson. 1994. Impact of administering antibacterial agents on wild fish and blue mussels *Mytilus edulis* in the vicinity of fish farms. *Diseases of Aquatic Organisms* 18:45-51.

Farley, C. A. 1992. Mass mortalities and infectious lethal diseases in bivalve molluscs and associations with geographic transfers of populations. Pages 139-154 in *Dispersal of Living Organisms into Aquatic Ecosystems*, A. Rosenfield and R. Mann, eds. Maryland Sea Grant, College Park, MD.

Firestone, J., and R. Barber. 2003. Fish as pollutants: limitations of and crosscurrents in law, science, management and policy. *Washington Law Review*. 78:693-756.

Fishmeal Information Network (FIN). 2006. Fishmeal and fish oil facts and figures, May 2006 update. http://www.gafta.com/fin/finfacts.html

Fleming, I., K. Hindar, I. Mjolnerod, B. Jonsson, T. Balstad, and A. Lamberg. 2000. Lifetime success and interactions of farm salmon invading a native population. *Proceedings of the Royal Society of London, B.* 267:1517-1523.

Folke, C., N. Kautsky, and M. Troell. 1994. The costs of eutrophication from salmon farming: implications for policy. *Journal of Environmental Management* 40:173-182.

Food and Agriculture Organization of the United Nations (FAO). 1986. The production of fishmeal and oil. FAO Fisheries Technical Paper 142, FAO Fisheries Department, Rome.

Food and Agriculture Organization of the United Nations (FAO). 2000. *Small ponds make a big difference: integrating fish with crop and livestock farming.* Rome.

Food and Agriculture Organization of the United Nations (FAO). 2004. The State of World Fisheries and Aquaculture 2004. Rome.

Food and Agriculture Organization of the United Nations (FAO). 2005. Guidelines for the Eco-Labeling of Fish and Fishery Products from Marine Capture Fisheries. Rome. http://www.fao.org/docrep/008/a0116t/a0116t01.htm

Food and Agriculture Organization of the United Nations (FAO). 2006. State of world aguaculture: 2006. FAO Fisheries Technical Paper 500. FAO Fisheries Department, Rome.

Fox, J. Charles. 2006. Personal communication. Former Assistant Administrator for Water, U.S. Environmental Protection Agency.

Gatlin, D. and R. Hardy. 2002. Manipulations of diets and feeding to reduce losses of nutrients in intensive aquaculture. In *Aquaculture and the Environment in the United States*. U.S. Aquaculture Society, Baton Rouge, LA.

Gaughan, D. 2002. Disease translocation across geographic boundaries must be recognized as a risk even in the absence of disease identification: the case with Australian Sardinops. *Reviews in Fish Biology and Fisheries* 11:113–123.

Gill, C. 2005. World feed panorama: disease takes toll, but feed output bounces back. *Feed International*, 26(1):4-9.

Global Aquaculture Alliance (GAA). 2006. Guiding Principles for Responsible Aquaculture and Codes of Practice for Responsible Shrimp Farming. www.gaalliance.org

Goldburg, R. and R. Naylor. 2005. Future seascapes, fishing, and fish farming. *Frontiers in Ecology and the Environment* 3(1):21-28.

Gross, M.R. 1998. One species with two biologies: Atlantic salmon (Salmo salar) in the wild and in aquaculture. *Canadian Journal of Fisheries and Aquatic Sciences* 55(Suppl. 1):131–144.

Gulf of Mexico Fishery Management Council. 2005. Draft preliminary options paper to the generic amendment to Coral and Coral Reef FMP, Coastal and Migratory Pelagics FMP, Red Drum FMP, Reef Fish FMP, Shrimp FMP, Spiny Lobster FMP, and Stone Crab FMP to provide for regulation of offshore marine aquaculture. Gulf of Mexico Fishery Management Council, Tampa, FL.

Guo, L. and Z. Li. 2003. Effects of nitrogen and phosphorus from fish-cage culture on the communities of a shallow lake in the middle Yangtze River basin of China. *Aquaculture* 226: 201-212.

Hallerman, E.M. 2000. Genetically modified organism mariculture in the coastal zone. *Integrated Coastal Zone Management* 1:209-212.

Halver, J. and R. Hardy. 2002. *Fish Nutrition*. Academic Press, San Diego, CA.

Hardy, R.W. 1996. Alternate protein sources for salmon and trout diets. *Animal Feed Science Technology* 59:71-80.

Hardy, R.W. 2000. Fish feeds and nutrition: urban legends and fish nutrition. *Aquaculture Magazine* 26(6):47-50.

Hardy, R.W., D.A. Higgs, S.P. Lall, & A.G.J. Tacon. 2001. Alternative dietary protein and lipid sources for sustainable production of salmonids. Fisken og Havet. No. 8. Institute of Marine Research, Bergen, Norway. www.imr.no

Hardy, R.W. and A. Tacon. 2002. Fish meal: historical uses, production trends and future outlook for supplies. Pages 311-325 in *Responsible Marine Aquaculture*, Stickney, R. and J. McVey, eds. CABI Publishing, New York.

Harvell, D.R. Aronson, N. Baron, J. Connell, A. Dobson, S. Ellner, L. Gerber, K. Kim, A. Kuris, H. McCallum, K. Lafferty, B. McKay, J. Porter, M. Pascual, G. Smith, K. Sutherland, and J. Ward. 2004. The rising tide of ocean diseases: unsolved problems and research priorities. *Frontiers in Ecology and Environment* 2:375–382.

Haskell, S., K. Carberry-Goh, M. Payne, and S. Smith. 2004. Current status of aquatic species biologics. *Journal of American Veterinary Medical Association* 225:1541-1544.

Health Canada. 2003. Integrated pest management of sea lice in salmon aquaculture. Health Canada, Ottawa, Ontario.

Hedrick, P. 2001. Invasion of transgenes from salmon or other genetically modified organisms into natural populations. *Canadian Journal of Fisheries and Aquatic Sciences* 58:841–844.

Hertrampf, J.W. & Piedad-Pascual, F. 2000. Handbook on Ingredients for Aquaculture Feeds. Kluwer Academic Publishers, Dordrecht, Boston, London.

Highleyman, S., A. Mathews Amos, H. Cauley. 2004. An independent assessment of the Marine Stewardship Council. http://www.alaskaoceans.net/aboutus/documents/WildhavensMSC.pdf

Hites, R., J. Foran, D. Carpenter, M. Hamilton, B. Knuth, S. Schwager. 2004. Global assessment of organic contaminants in farmed salmon. *Science* 303:226-229.

Hopkins, D.D., R.J. Goldburg and A. Marston. 1997. An environmental critique of governmental regulations and policies for open ocean aquaculture. *Ocean and Coastal Law Journal* 2:235-260.

Howarth, R., D. Anderson, J. Cloern, C. Elfring, C. Hopkinson, B. Lapointe, T. Malone, N. Marcus, K. McGlathery, A. Sharpley and D. Walker. 2000. Nutrient pollution of coastal rivers, bays and seas. *Issues in Ecology* (7). Ecological Society of America. Washington, DC.

Huang, X., R. Hites, J. Foran, C. Hamilton, B. Knuth, S. Schwager, D. Carpenter. 2005. Consumption advisories for salmon based on risk of cancer and noncancer health effects. *Environmental Research* 101(2):263-274.

Huntington, T., C. Frid, R. Banks, C. Scott and O. Paramor. 2004. Assessment of the sustainability of industrial fisheries producing fishmeal and fish oil. Report to the Royal Society for the Protection of Birds (RSPB). Poseidon Aquatic Resource Management Ltd., Lymington, Hampshire, UK.

Hutchings, J. 1991. The threat of extinction to native populations experiencing spawning intrusions by cultured Atlantic salmon. *Aquaculture* 98:119-132.

ICES. 1996. Report of the working group on environmental interaction of mariculture. ICES C.M., Nantes.

International Fishmeal and Fish Oil Organization (IFFO). 2006. Industry Overview webpage. http://www.iffo.net/default.asp?fname=1&sWebIdiomas=1&url=253

Islam, M.S. 2005. Nitrogen and phosphorus budget in coastal and marine cage aquaculture and impacts of effluent loading on ecosystem: review and analysis towards model development. *Marine Pollution Bulletin* 50:48–61.

Johnson, H. 2003. U.S. Seafood Market in 2020: strong demand likely boon to aquaculture. *Global Aquaculture Advocate*, November 2003.

Joint Subcommittee on Aquaculture (JSA). 2004. Guide to Drug, Vaccine, and Pesticide Use in Aquaculture. Prepared by The Federal Joint Subcommittee on Aquaculture, Working Group on Quality Assurance in Aquaculture Production. http://www.aquanic.org/jsa/wgqaap/drugguide/drugguide.htm

Kelleher, K. 2005. Discards in the World's Marine Fisheries: An Update. FAO Fisheries Technical Paper. No. 470. FAO Fisheries Department, Rome.

Krkosek, M., M. Lewis, and J. Volpe. 2005. Transmission dynamics of parasitic sea lice from farm to wild salmon. *Proceedings of the Royal Society of London*, Series B 272:689-696.

Lee, C.S. 2003. Application of biosecurity in aquaculture production systems. Proceedings of the 32nd US-Japan Cooperative Program in Natural Resources (UJNR) Aquaculture Panel. *Aquaculture and Pathobiology of Crustacean and Other Species Symposium*, Davis and Santa Barbara, CA, 2003.

Lee, H.W., J.H. Bailey-Brock and M.M. Gurr. 2006. Temporal changes in the polychaete infaunal community surrounding a Hawaiian mariculture operation. *Marine Ecology Progress Series* 307:175-185.

Leung, K., J. Chu and R. Wu. 1999. Nitrogen budget for the areolated grouper *Epinephelus areolatus* cultured under laboratory conditions and in open-sea cages. *Marine Ecology Progress Series* 186:271-281.

Lightner, D.V., R. Redman, T. Bell, and R. Thurman. 1992. Geographic dispersion of the viruses IHHN, MBV, and HPV as a consequence of transfers and introductions of penaeid shrimp to new regions for aquaculture purposes. Pages 155-173 in *Dispersal of Living Organisms into Aquatic Ecosystems*, A. Rosenfield and R. Mann, eds. Maryland Sea Grant, College Park, MD.

Loya, Y., H. Lubinevsky, M. Rosenfeld, and E. Kramarsky-Winter. 2004. Nutrient enrichment caused by in situ fish farms at Eilat, Red Sea is detrimental to coral reproduction. *Marine Pollution Bulletin* 49:344–353.

Lupatsch, I. and G. Kissil. 1998. Predicting aquaculture wastes from gilthead seabream (*Sparus aurata*) culture using nutritional approach. *Aquatic Living Resources* 11(4):265-268.

Marine Stewardship Council (MSC). 2005. Guidance to clients: The MSC fishery assessment and certification process. http://www.msc.org/assets/docs/fishery_certification/Guidance_to_Clients_V1.pdf

Marine Stewardship Council (MSC). 2006. Marine Stewardship Council website. www.msc.org

Mattsson, B., and U. Sonesson. 2003. *Environmentally-friendly Food Processing*. Woodhead Publishing Limited, Cambridge, UK.

McGinnity, P. 2003. Fitness reduction and potential extinction of wild populations of Atlantic salmon, *Salmo salar*, as a result of interactions with escaped farm salmon. *Proceedings of the Royal Society B* 270:2443-2450.

McKinnell, S. and A. Thomson. 1997. Recent events concerning Atlantic salmon escapees in the Pacific. *ICES Journal of Marine Science* 54:1221–1225.

Meyer. F. 1991. Aquaculture disease and health management. *Journal of Animal Science* 69:4201-4208.

Morton,A., R. Routledge, C. Peet, and A. Ladwig. 2004. Sea lice (*Lepeophtheirus salmonis*) infection rates on juvenile pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) salmon in the nearshore marine environment of British Columbia, Canada. *Canadian Journal of Fisheries and Aquatic Sciences* 61:147–157.

Muir, W. and R. Howard. 1999. Possible ecological risks of transgenic organism release when transgenes affect mating success: sexual selection and the Trojan gene hypothesis. *Proceedings of the National Academy of Science* 96:13853–13856.

Myrick, C.A. 2002. Ecological impacts of escaped organisms. Pages 225-245 in *Aquaculture and the Environment in the United States,* J. Tomasso, ed. U.S. Aquaculture Society, a Chapter of the World Aquaculture Society, Baton Rouge, LA.

National Marine Fisheries Service (NMFS). 2005. Final Recovery Plan for the Gulf of Maine Distinct Population Segment of Atlantic Salmon (*Salmo salar*). Prepared by NOAA's National Marine Fisheries Service (NMFS), Silver Spring, Maryland and Northeastern Region U.S. Fish and Wildlife Service, Hadley, Massachusetts.

National Marine Fisheries Service (NMFS). 2005. Fisheries of the United States, 2004.

National Marine Fisheries Service (NMFS). 2006. Personal communication from the National Marine Fisheries Service, Fisheries Statistics Division, Silver Spring, MD.

National Oceanic and Atmospheric Administration (NOAA). 2003. Code of Conduct for Responsible Aquaculture Development in the U.S. Exclusive Economic Zone. http://www.nmfs.noaa.gov/trade/AQ/AQCode.pdf

National Organic Aquaculture Working Group (NOAWG). 2005. Proposed National Organic Standards for Farmed Aquatic Animals and Plants (Aquaculture) with Supporting Documentation and Information, a white paper. http://www.bee.cornell.edu/extension/aquaculture/documents/NOAWG White Paper 24 May 05 PDF.pdf

National Organic Standards Board (NOSB). 2006. Interim Final Report of the Aquaculture Working group. http://www.ams.usda.gov/nop/TaskForces/AATFInterimFinalReport.pdf

National Research Council (NRC). 1992. *Marine Aquaculture: Opportunities for Growth*. National Academy Press, Washington, DC.

National Research Council (NRC). 2000. *Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution*. National Academy Press, Washington, DC.

National Research Council (NRC). 2002. *Animal Biotechnology: Science Based Concerns*. National Academy Press, Washington, DC. http://www.nap.edu/catalog/10418.html

National Research Council (NRC). 2004a. *Atlantic Salmon in Maine*. National Academy Press, Washington, DC. http://fermat.nap.edu/books/0309091357/html

National Research Council (NRC). 2004b. *Nonnative Oysters in the Chesapeake Bay*. National Academy Press, Washington, DC.

Naylor, R., K. Hindar, I. Fleming, R. Goldburg, S. Williams, J. Volpe, F. Whoriskey, J. Eagle, D. Kelso, and M. Mangel. 2005. Fugitive salmon: assessing the risks of escaped fish from net-pen aquaculture. *Bioscience* 55:427-437.

Nickum, D. 1999. *Whirling Disease in the United States: A Summary of Progress in Research and Management*. Trout Unlimited, Arlington, VA.

Nico, L. 2005. *Oreochromis aureus*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. Revision date: 28 July 2004 http://nas.er.usgs.gov/queries/FactSheet.asp?speciesID=463

Nico, L. and E. Maynard. 2005. *Cyprinus carpio*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. Revision date: 23 August 2004 http://nas.er.usgs.gov/queries/FactSheet.asp?speciesID=4

Norwegian Directorate of Fisheries. 2001. Key figures from Norwegian Aquaculture Industry, 2000. Directorate of Fisheries, Department of Aquaculture. Bergen, Norway.

OIE. 2001. Aquatic Animals Commission brochure. Office International des Epizooties, Paris.

Packard Foundation. 2001. *Mapping Global Fisheries and Seafood Sectors*. David and Lucille Packard Foundation, Los Altos, CA.

Pauly, D. and V. Christensen. 1998. Fishing down marine foodwebs. *Science* 279:860-863.

Penston, M., M., McKibben, D. Hay, and P. Gillibrand. 2004. Observations on open-water densities of sea lice larvae in Loch Shieldaig, Western Scotland. *Aquaculture Research* 35:793-805.

Pergent, G., S. Mendez, C. Pergent-Martini, and V. Pasqualini. 1999. Preliminary data on the impact of fish farming facilities on *Posidonia oceanica* meadows in the Mediterranean. *Oceanologica* 22:95-107.

Perry, H. 2005. *Carcinus maenas*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. Revision Date: 14 February 2005. http://nas.er.usgs.gov/queries/FactSheet.asp?speciesID=190

Pew Oceans Commission. 2003. *America's Living Oceans: Charting a Course for Sea Change*. Pew Oceans Commission, Arlington, VA.

Pimentel, D., L. Lach, R. Zuniga, and D.Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. *BioScience* 50:53–65.

Pike, I. 2005. Ecoefficiency in aquaculture: global catch of wild fish used in aquaculture. *International Aquafeed* 8(1):38-40.

Power, A. and C. Mitchell. 2004. Pathogen spillover in disease epidemics. *The American Naturalist* 164:S79-S89.

RaLonde, R. 1993. Shellfish aquaculture in Alaska and the potential of interaction with wild species. In *Interactions Between Cultured Species and Naturally Occurring Species in the Environment*, M. Collie and J. McVey, eds. Proceedings of the Twenty-second US-Japan Aquaculture Panel Symposium. UJNR Technical Report No. 22.

Reisenbichler, R.R. and S.P. Rubin. 1999. Genetic changes from artificial propagation of Pacific salmon affect the productivity and viability of supplemented populations. *ICES Journal of Marine Science*, 56:459–466.

Rieser, A. 1996. Defining the federal role in offshore aquaculture: should it feature delegation to the states? *Ocean and Coastal Law Journal* 2:209-233.

Rigos, G., I. Nengas, M. Alexis, and G.M. Troisi. 2004. Potential drug (oxytetracycline and oxolinic acid) pollution from Mediterranean sparid fish farms. *Aquatic Toxicology* 69:281–288.

Robinson, E., M. Li, and B. Manning. 2001. A practical guide to nutrition, feeds, and feeding of catfish (second revision). Mississippi Agricultural and Forestry Experiment Station, Bulletin 1113, November 2001.

Ruiz, J.M., M. Perez, and J. Romero. 2001. Effects of fish farm loadings on seagrass (*Posidonia oceanica*) distribution, growth, and photosynthesis. *Marine Pollution Bulletin* 42:749-760.

Seafood Choices Alliance. 2005. Eco-friendly means business. *Afishianado*, Spring 2005. http://www.seafoodchoices.com/resources/newsletters.php

Simberloff, D., I. Parker, D. Windle. 2005. Introduced species policy, management, and future research needs. *Frontiers in Ecology and the Environment* 3:12-20.

Suryanata, K. and N. Umemoto. 2003. Tension at the nexus of global and local: Culture, property, and marine aquaculture in Hawai´i. *Environment and Planning A* 35: 199-213.

Tacon, A.G.J. 2004. Use of fishmeal and fish oil in aquaculture: a global perspective. *Aquatic Resources, Culture and Development* 1(1):3-14.

Tacon, A.G.J. 2005. State of information on salmon aquaculture feed and the environment. Prepared for the WWF Salmon Aquaculture Dialogue. http://www.worldwildlife.org/cci/dialogues/salmon.cfm

Thain, J. E., I.M. Davies, G.H. Rae, and Y. Allen. 1997. Acute toxicity of ivermectin of the lugworm *Arenicola marina. Aquaculture* 159:47-52.

Tyedmers, Peter. 2006. Personal communication. Assistant Professor, School for Resource and Environmental Studies, Dalhousie University.

Unilever. 2006. Our fish sustainability initiative. http://www.unilever.com/ourvalues/environmentandsociety/env_social_report/sustainability/fish/

U.S. Commission on Ocean Policy. 2004. *An Ocean Blueprint for the 21st Century*. U.S. Commission on Ocean Policy. Washington, D.C.

U.S. Department of Agriculture (USDA). 1998. Census of Aquaculture. http://www.nass.usda.gov/census/census97/aquaculture/aquaculture.htm

U.S. Department of Agriculture (USDA). 2000. Aquaculture Outlook. 13 March 2000. http://usda.mannlib.cornell.edu/usda/ers/LDP-AQS/2000s/2000/LDP-AQS-03-13-2000.pdf

U.S. Department of Agriculture (USDA). 2006. Census of Aquaculture (2005). http://www.nass.usda.gov/Census_of_Agriculture/2002/Aquaculture/AQUACEN.pdf

USDA Aquatic Animal Task Force. 2001. Recommendations on operations that produce aquatic animals. http://fwcb.cfans.umn.edu/isees/OrganicAquaculture/TskFrcRec5.01.doc

U.S. Department of Commerce (USDOC). 1999. Aquaculture Policy. http://www.nmfs.noaa.gov/trade/DOCAQpolicy.htm

U.S. Department of Commerce (USDOC). 2005. Imports and exports of fishery products: annual summary 2005. Current Fisheries Statistics No. 2005-2. http://www.st.nmfs.gov/st1/trade/documents/TRADE2005.pdf

Volpe, J.P., E.B. Taylor, D.W. Rimmer, B.W. Glickman. 2000. Natural reproduction of aquaculture escaped Atlantic salmon (*Salmo salar*) in a coastal British Columbia river. *Conservation Biology* 14:899-903.

Volpe, J., B. Anholt, B. Glickman. 2001. Competition among juvenile Atlantic salmon (*Salmo salar*) and steelhead (*Oncorhynchus mykiss*): relevance to invasion potential in British Columbia. *Canadian Journal of Fisheries and Aquatic Science* 58:197–207.

Wackernagel, M., and W. E. Rees. 1996. *Our Ecological Footprint*. New Society Publishers, Gabriola Island, BC, Canada.

Waddy, S. L., L.E. Burridge, M.N. Hamilton, S.M. Mercer, D.E. Aiken, and K. Haya. 2002. Emamectin benzoate induces molting in American lobster, *Homarus americanus. Canadian Journal of Fisheries and Aquatic Sciences* 59:1096-1099.

Waknitz , F.W., R. Iwamoto, and M. Strom. 2003. Interactions of Atlantic salmon in the Pacific Northwest IV: impact on the local ecosystems. *Fisheries Research* 62:307-328.

Wal-Mart. 2006. Wal-Mart Stores, Inc. introduces new label to distinguish sustainable seafood. http://www.walmartfacts.com/articles/4425.aspx

Ward, L.G., R.E. Grizzle and J.D. Irish. 2005. CINEMar/Open Ocean Aquaculture Annual Progress Report. University of New Hampshire Open Ocean Aquaculture Environmental Monitoring Report. http://ooa.unh.edu

Welcome, R.L. 1988. International introductions of inland aquatic species. FAO Fisheries Technical Paper 294. FAO Fisheries Department, Rome.

Wessells, C.R., R.J. Johnston, and H. Donath.1999. Assessing consumer preferences for eco-labeled seafood: the influence of species, certifier and household attributes. *American Journal of Agricultural Economics*, 81(1999):1084-1089.

Wessells, C.R., K. Cochrane, C. Deere. P. Wallis, R. Willmann. 2001. Product certification and eco-labeling for fisheries sustainability. FAO Fisheries Technical Paper No. 422. FAO Fisheries Department, Rome.

Wu, R.S.S. 1995. The environmental impact of marine fish culture: towards a sustainable future. *Marine Pollution Bulletin* 31:159-166.

Marine Aquaculture Task Force
6930 Carroll Avenue, Suite 400
Takoma, Park, MD 20912

www.whoi.edu/sites/marineaquataskforce

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