POLICY FORUM: ECOLOGY

Aquaculture—A Gateway for Exotic Species

Rosamond L. Naylor*, Susan L. Williams, Donald R. Strong

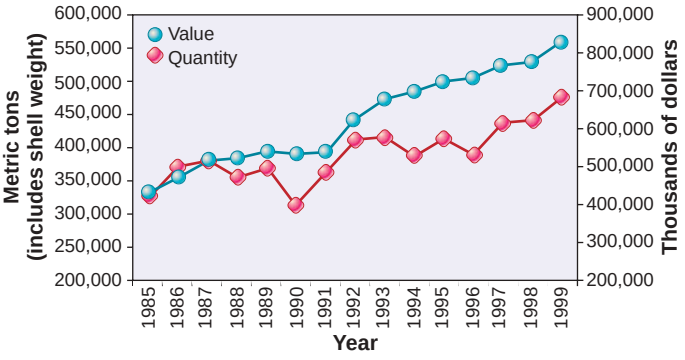
Aquaculture—the farming of fish, shellfish, and aquatic plants—is among the fastest-growing segments of the world food economy. Global aquaculture production more than doubled in volume and value during the past decade and now supplies one-third of seafood consumed worldwide. Growth in U.S. production parallels the global trend (see figure, this page). Spread across all 50 states in the United States, farms collectively raise over 100 different species of aquatic plants and animals (*1*). Plans are under way for a fivefold increase in domestic aquaculture output by 2025 with more lenient regulatory oversight in accordance with the National Aquaculture Act (*1*, *2*).

In the United States and abroad, aquaculture has led to introductions of unwanted seaweeds, fish, invertebrates, parasites, and pathogens and without special care, the rapid expansion of this sector will result in the spread of even more pests. Aquaculture has become a leading vector of aquatic invasive species worldwide (*3*, *4*). Although the problem is global, much can be learned from recent U.S. experience.

Most major aquatic species cultured in the United States are not native to their farm sites (*1*). Accidental escapes and even purposeful releases create "biological pollution" with irreversible and unpredictable ecological impacts. Surprisingly little federal oversight exists even for deliberate aquaculture introductions in the United States (*5*). For example, no restrictions existed to prevent the escape of seaweed species introduced in 1973 to Hawaii; they have since spread rapidly across the state's coral reefs (*6*). Likewise, bighead and silver carps, imported from Asia for confined food culture and biological control in the 1970s, have become established in rivers throughout the Mississippi Basin and compete with native fish (*7*). Local and state regulations are inadequate, particularly because once species escape, they often move across state boundaries.

Mollusk-Related Introductions

Farming oysters, clams, scallops, and other mollusks is an important industry in the United States worth more than $100 million annually (*8*). Ecological impacts of mollusk farming are small, relative to other forms of aquaculture (*9*); the industry relies on clean water and advocates environmental protection. Nonetheless, mollusk farming is responsible for many invasions of exotic species. The widely cultured Japanese or Pacific oyster is established on almost all Northern Hemisphere coasts (*10*). Industry safeguards to prevent establishment of exotic mollusks, e.g., use of sterile triploids and culture in environments unsuitable for reproduction, are not foolproof (*10*). Concern about these safeguards led Maryland to protest the recent introduction to Virginia of a new Southeast Asian oyster, *Crassostrea ariakenesis*, intended to restore the Chesapeake Bay oyster economy.



U.S. aquaculture production. [Source (*8*)]

Alien mollusks and species hitchhiking with them become competitors, predators, pathogens, and parasites of wild species and can harm molluscan aquaculture itself. *Terebrasabella heterouncinata*, a parasitic worm introduced into California with South African abalone in the 1980s, deforms shells of cultured abalone (*11*). It has reduced market prices for infested animals by half and caused closure of several abalone farms. Other major pests transferred through molluscan aquaculture include the Japanese oyster drill (*10*), turbellarian flatworm (*10*), Asian eelgrass (*12*), and highly invasive seaweeds (*13*). One of these seaweeds, *Codium fragile*, is known as the "oyster thief" because it overgrows and smothers oyster beds (*13*).

Introduced Carp for Biological Control

Channel catfish (*Ictalurus punctatus*) are the most widely farmed fish in the United States, accounting for more than 70% of domestic aquacultural production by meat weight (*1*). Asian black carp (*Mylopharyngodon piceus*) provides the cheapest means of controlling trematodes in catfish ponds (*14*, *15*). However, they eat mollusks, posing a special ecological risk in the Mississippi Basin. Freshwater mollusks are the most endangered group of animals in North America, and 90% of native mussel species designated as endangered, threatened or of special concern are found in the Southeast where the catfish industry is concentrated. Black carp have escaped and colonized open water in all other countries where they have been introduced (*16*).

Black carp are currently held in eight Southern states, mainly in sterile triploid form (*16*). Despite the strong ecological rationale for using triploids, Mississippi permitted the transport and use of fertile diploids in 1999 in response to a major outbreak of trematodes. In February 2000, fishing and conservation groups petitioned to list black carp as an "injurious" species under the federal Lacey Act (*14*). The U.S. Fish and Wildlife Service (USFWS), responsible for enforcing the Lacey Act, has not yet reached a decision on the petition.

A listing of "injurious" would prohibit importation and interstate transfer of black carp but would not bar proliferation and dissemination of the species within states where it already exists (*2*). At issue is state sovereignty over federal authority, even when potential damage clearly transcends state boundaries. All other species of Asian carp introduced in the United States, even those under the theoretical control of genetic triploidy, have escaped, have reproduced in the wild, and have spread throughout the Mississippi Basin (*4*, *7*). Missouri adopted a policy in 2000 to hold all black carp for certified triploid production and sale through the Department of

R. L. Naylor is at the Center for Environmental Science and Policy, Stanford University, Stanford, CA 94305–6055, USA. S. L. Williams is director, Bodega Marine Laboratory, and professor of Environmental Science and Policy, University of California at Davis, Bodega Bay, CA 94923, USA. D. R. Strong is at Bodega Marine Laboratory, and professor of Evolution and Ecology, University of California at Davis, Davis, CA 95616, USA.

*To whom correspondence should be addressed. E-mail: roz@stanford.edu

Conservation for 5 years before banning the fish altogether (*17*). Such an approach may strike an acceptable balance between industry and conservation objectives.

Farmed Salmon

The introduction and frequent escape of farmed salmon along Atlantic and Pacific coastlines pose an equally challenging problem. In the United States, farming of Atlantic salmon (*Salmo salar*) is now valued at about $100 million annually (*1*). This fish has been selectively bred for aquaculture and differs genetically from wild Atlantic and Pacific salmon species with which it competes, and in some cases interbreeds, after escape (*18*, *19*). In addition, intensive culture elevates the risk of disease and parasite transfers. Infectious salmon anemia and sea lice—widespread problems in European salmon aquaculture—have recently appeared in North American farms and could spread to wild salmon (*1*).

Up to 40% of Atlantic salmon caught in the North Atlantic and more than 90% caught in the Baltic Sea are of farmed origin (*20*). More than a half-million Atlantic salmon escaped on the West Coast of North America between 1987 and 1997 (*21*); they have been found in 77 British Columbian rivers and are spawning in some locations (*1*, *22*). In the New Brunswick–Maine region, farmed escapees vastly outnumber wild salmon in some spawning rivers (*1*). The establishment of farmed salmon in the wild increases pressure on endangered native salmon populations. Even more pressure could arise if transgenic salmon containing added growth-hormone genes are approved for commercial net-pen culture.

Regulatory Quagmire

The case of Atlantic salmon in Maine illustrates the regulatory quagmire in which the aquaculture industry and conservation agencies operate. The National Marine Fisheries Service (NMFS) opposes introductions of fertile non–North American strains of Atlantic salmon and is working with the USFWS and the Army Corps of Engineers (which provides net-pen permits) to enforce a ban. The state of Maine prohibits the use of live non–North American salmon, but allows the use of foreign genetic material (milt). Until November 2000 when wild salmon in Maine were listed under the Endangered Species Act (ESA), state sovereignty ruled on this issue. Now state and federal agencies must comply with the ESA. More generally, the regulatory structure for controlling exotic introductions is diffuse and uncoordinated among state and federal agencies. Federal authority is based only on the Lacey Act (1900), the Plant Protection Act (2000), and the National Invasive Species Act (1996) that focuses on ballast water introductions; none have been effective in aquaculture (*4*, *5*).

The National Research Council (*23*) has ranked invasive species and overexploitation as the most serious threats to native marine biodiversity. Nonetheless, marine and freshwater species received the smallest allocation (<1%) of the federal FY2000 budget for invasive species management, whereas more than 90% went to agriculture (*24*). The Federal Aquatic Nuisance Species Task Force, a multiagency body legislated by the Aquatic Nuisance Prevention and Control Act (1990) to assume federal management leadership, has received no appreciable budget to support research and control programs. Moreover, the new Invasive Species Management Plan (2001) focuses primarily on terrestrial species and largely ignores aquaculture introductions (*24*).

Improved Oversight

A clear policy on exotic introductions is needed as aquaculture expands—one that includes scientific risk assessment for all nonnative introductions and single-agency oversight for the prevention, containment, and monitoring of potentially harmful exotics. New Zealand's Hazardous Substances and New Organisms Act (1996) provides a model that the United States and other countries should follow. The New Zealand approach regulates exotic introductions comprehensively in a single legislative act with clear oversight. Importers of nonnative species must apply to an independent regulatory authority accountable to the Environment Ministry and Parliament for public approval. All species are considered potentially invasive and therefore prohibited unless proven otherwise.

International transfers of nonnative species for aquaculture pose high ecological risks given the absence of strong policies in most countries. The World Conservation Union (IUCN) has identified at least 46 international quasi-legal instruments that address exotic species invasions; however, there is no binding agreement apart from the Convention on Biological Diversity (CBD) that deals comprehensively with introductions, control, and eradication of exotic species (*25*). The CBD (convened by the IUCN and ratified in 1992 by 170 countries excluding the United States) holds signatory members accountable for conducting scientific risk assessments for introductions and advocates use of native species in aquaculture. Persuading the United States and nonsignatory countries to abide by this process remains a worthy challenge.

In many cases, the aquaculture industry itself has an economic stake in preventing introductions of exotic species that harm their products. In other cases, the costs of exotic species introduced by aquaculture are external to the industry and even to the state or country where the industry operates. Comprehensive guidelines for preventing introductions of invasive species exist through the IUCN (*25*) and ICES (International Council for the Exploration of the Sea) (*26*) and have been implemented by New Zealand as a working model. Widespread adoption of these policies is urgently needed in the United States and abroad to stem the rising tide of aquatic invasions.

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