POLICY FORUM: ECOLOGY

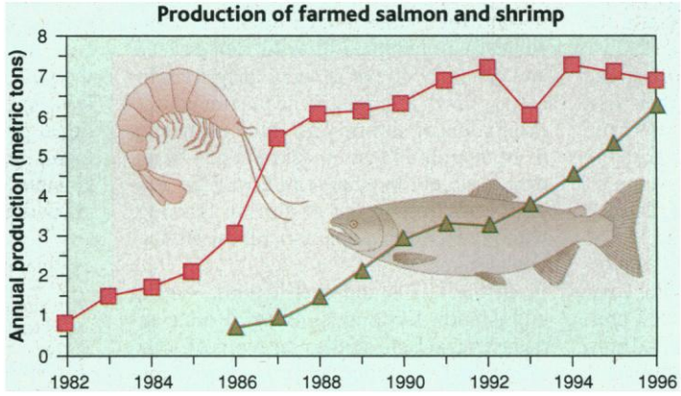
Nature's Subsidies to Shrimp and Salmon Farming

Rosamond L. Naylor, Rebecca J. Goldburg, Harold Mooney, Malcolm Beveridge, Jason Clay, Carl Folke, Nils Kautsky, Jane Lubchenco, Jurgenne Primavera, Meryl Williams

Seafood production is undergoing a dramatic transition. While many fisheries stocks worldwide have declined precipitously, fish farming (or aquaculture) has boomed. Global aquaculture production more than doubled in weight and value between 1986 and 1996, and it currently accounts for over one-quarter of all fish consumed by humans (*1*).

Here we focus on the environmental impact of two of the most lucrative and widely traded aquaculture products: shrimp and salmon. Globally, these crops make up only 5% of farmed fish by weight but almost one-fifth by value (*2*). Both shrimp and salmon farming have expanded and intensified rapidly as a result of technological changes in production and strong demand in industrialized countries {see the figure [created with data from (*2*, *3*)]}. Fish farming is becoming the dominant production method for salmon, and it accounts for 25% of world shrimp production—a 10-fold increase from the mid-1970s (*1*, *3*).

It is commonly assumed that aquaculture relieves pressure on wild fisheries and adds to the world's food supply. For herbivorous species, this assumption is generally valid (*4*). For species raised as carnivores, however, the opposite may be true. Farmed species such as shrimp and salmon are fed nutrient-rich diets containing large amounts of fishmeal and fish oil extracted from wild-caught fish. The input of fish products is two to four times the volume of fish outputs for these crops (*5*). Because of their dependence on wild-caught fish, shrimp and salmon aquaculture deplete rather than augment fisheries resources (*5*, *6*).



The increasing scale of these enterprises is now having unforeseen ecological consequences. The conversion of coastal ecosystems to aquaculture ponds destroys nursery areas that support ocean fisheries. Fish farming degrades coastal waters through discharge of nutrients and chemicals, and it disrupts coastal ecosystems by the introduction of exotic species. The ocean's capacity to assimilate wastes and maintain viable fish populations is being challenged by aquaculture's continued growth. Yet producers and consumers remain unaware of—and do not pay for—many of the environmental and social costs of shrimp and salmon aquaculture.

Shrimp Farming

Asian farmers have long raised shrimp, but in small quantities; only recently has shrimp farming become a large industry. From the early 1980s to the mid-1990s, shrimp aquaculture production has grown by a factor of 7. The explosive growth of shrimp farming has been supported by national governments, private investors, and international development agencies motivated to generate foreign exchange, private profits, and employment. Farmed shrimp is produced mainly in developing countries for markets in industrialized nations, at a global value exceeding $6 billion annually (*2*, *3*).

In shrimp aquaculture, young shrimp, primarily tiger shrimp (*Penaeus monodon*) and Pacific white shrimp (*P. vannamei*), are reared to marketable size in ponds of varied stocking densities. Higher stocking densities are typically supported by increased pumping and aeration of water and greater input of commercial feed and chemicals. Shrimp feed contains about 30% fishmeal and 3% fish oil, and intensive shrimp farming actually results in a net loss of fish protein (*5*).

The rapid growth of shrimp aquaculture has masked the industry's erratic production on a regional scale. The record-breaking 1986 shrimp crop in Taiwan was followed by a spectacular collapse in yields the next year. This boom-and-bust pattern has been repeated in China, Thailand, and Indonesia. Diseases and poor soil and water quality are the main causes of these shrimp mortalities, especially in intensive systems. In many cases, the ponds do not recover productivity.

Crop failures appear to result largely from poor environmental management of shrimp farms. Chemical and biological pollution by shrimp farms results from disposal in coastal waters of pond effluents and sludge; salinization of soil and water; misuse of antibiotics and other chemicals; and introduction of exotic shrimp species and diseases (*7*, *8*). The result is not just habitat degradation near ponds, but also pollution within ponds, which are often densely sited along coastlines.

When shrimp yields decline, ponds are often abandoned; the life-span of intensive shrimp ponds in Asia rarely exceeds 5 to 10 years (*7*, *8*). Conversion of extremely degraded pond areas to other agricultural uses is often not economically feasible. The rapid expansion of shrimp farms has caused socioeconomic problems, such as dislocation of poor coastal communities, and has degraded wide coastal areas, including mangrove forests and other wetlands (*7*, *8*). These areas provide critical habitat for biodiversity, including marine finfish and the wild shrimp used to stock

R. L. Naylor is in the Institute for International Studies, Stanford University, Stanford, CA 94305–6055, USA. E-mail: roz@leland.stanford.edu. R. J. Goldburg is with the Environmental Defense Fund, 257 Park Avenue South, New York, NY 10010, USA. E-mail: Becky_Goldburg@edf.org. H. Mooney is in the Department of Biology, Stanford University, Stanford, CA 94305–5020, USA. E-mail: hmooney@leland.stanford.edu. M. Beveridge is in the Institute of Aquaculture, University of Stirling, Stirling, Scotland FK9 4LA, UK. E-mail: mcmb1@stir.ac.uk. J. Clay is with the World Wildlife Fund, 1250 24th Street NW, Washington, DC 20037, USA. E-mail: Jason.Clay@wwfus.org. C. Folke and N. Kautsky are with the Department of Systems Ecology, Stockholm University, S-106 91 Stockholm, Sweden. E-mail: calle@system.ecology.su.se and nils@system.ecology.su.se. J. Lubchenco is in the Department of Zoology, Oregon State University, Corvallis, OR 97331–2914, USA. E-mail: lubchenj@bcc.orst.edu. J. Primavera is in the SEAFDEC Aquaculture Department, Tigbauan, Iloilo, Philippines 5021. E-mail: nykjprim@iloilo.net. M. Williams is with the International Center for Living Aquatic Resources Management (ICLARM), MC P.O. Box 2631, 0718 Makati, Metro Manila, Philippines. E-mail: M.J.Williams@cgnet.com

farms. With roughly 50% of the world's mangrove ecosystems already transformed or destroyed by humans, the incremental cost of mangrove conversion to shrimp ponds is high (*9*).

Salmon Farming

Salmon farming, too, has boomed in the past several decades. Initiated in Norway in the 1960s, salmon farming increased steadily in the late 1970s because of technological breakthroughs, high profits, and support from government agencies promoting economic development. Worldwide production has grown rapidly, to 644,000 metric tons in 1997, and is worth more than $2 billion annually (*2*). Salmon are grown and consumed primarily in industrialized countries. Top producers include Norway, the United Kingdom, Canada, the United States, and Chile.

Atlantic salmon (*Salmo salar*), the dominant farmed species, spend their first year in freshwater ponds. Fish are then transferred to floating netpens anchored in coastal bays for another 1 to 2 years of growth. Carnivorous in the wild, farmed salmon currently depend on a diet that is 45% fishmeal and 25% fish oil (*5*). Research is leading to reductions in fishmeal content of feeds and improved conversion efficiencies of feed to salmon flesh. Nevertheless, in 1997, about 1.8 million tons of wild fish for feed were required to produce 644,000 metric tons of Atlantic salmon—a 2.8:1 ratio. The European salmon farming industry requires a marine support area for feed estimated at 40,000 to 50,000 times the surface area of cultivation and equivalent to about 90% of the primary production of the fishing area of the North Sea (*6*). Consequently, it depends heavily on fishmeal imported from South America.

Salmon farming uses a "dilution" approach to water pollution. Salmon netpens allow feces and uneaten feed to flow directly into coastal waters, resulting in substantial discharges of nutrients. The Nordic salmon farming industry discharges quantities of nitrogen and phosphorous equivalent to the amounts in untreated sewage from a population of 3.9 and 1.7 million people, respectively (*10*). Poor water quality and high stocking densities have facilitated outbreaks of salmon diseases and parasites that have caused large losses to salmon farms (*6*). These problems have led salmon farmers to use antibiotics and pesticides, which also end up in coastal waters, although European researchers have reduced antibiotic usage by developing salmon vaccines (*11*).

The extent of biological pollution by escaped farmed salmon is hotly debated. Interbreeding with escaped farmed salmon may lead to genetic degradation of wild salmon populations—especially since wild populations have genetic characteristics specific to the rivers where they spawn. Atlantic salmon escaped from farms have become so common that they sometimes dominate catches in Norway, and they are frequently caught in Pacific waters in North and South America (*12*). Since 1994, over 9000 Atlantic salmon have been recovered from coastal waters between Washington and Alaska.

Opportunities and Constraints

Rapid growth in shrimp and salmon farming has clearly caused environmental degradation while contributing little to world food security. These industries provide food mainly for industrialized countries, consume vast quantities of wild fish as feed, and generally do not generate long-term income growth in impoverished communities. Promotion of shrimp and salmon farming in both rich and poor countries is being driven largely by short-run economic motives and, in the case of shrimp farming, without regard to collapses of local production systems.

In the 1970s and early 1980s, shrimp and salmon farming were small-scale industries that appeared to be more of a solution than a problem for protection of marine resources. The increasingly large scale of these industries, combined with other human activities, now places substantial demands on ocean ecosystems, which in turn result in the demise of fisheries and biological diversity. These ecological impacts are not reflected in either local or international prices for aquaculture inputs or outputs. So long as the full environmental costs of feed and stock inputs, effluent assimilation, and coastal land conversion are not recognized in the market, ocean resources—including fisheries—will deteriorate further.

Incentives provided through regulation, pollution taxes, or reduction of financial subsidies are urgently needed to improve the efficiency and reduce the environmental impacts of shrimp and salmon farming. Industrialized salmon-farming countries have the regulatory institutions in place to restrict environmental damages from aquaculture. In developing countries, where most farmed shrimp is produced, regulatory institutions are much weaker. Strong, transparent, and enforceable environmental regulations are needed in both types of countries. Pollution taxes may be difficult politically to implement; however, existing financial subsidies for production could be reduced more easily. Moreover, countries could encourage production of fish other than shrimp and salmon that are fed diets containing little or no fishmeal.

A more comprehensive avenue for improving production practices is through international trade. If the World Trade Organization (WTO) permitted restrictions on the process of production, and not just on the quality of products, it would then be possible to restrict demand to fish originating from environmentally sound aquaculture systems. This measure would require a fundamental change in world trading rules and would be possible only if a future round of the WTO took on environmental sustainability as a major objective, just as the Uruguay Round (1986–1994) focused on agriculture and intellectual property rights. Under current WTO rules, the best hope for restricting trade of aquaculture products is through food safety issues, such as antibiotic residues. Changing the global trading system is a tall order, at least in the short run. But reorienting national policies immediately toward an ecologically, socially, and economically sustainable view of aquaculture is both feasible and necessary.

References and Notes

1. M. B. New, *World Aquacult.* **28**, 11 (1997).
2. Food and Agriculture Organization (FAO) of the United Nations, *Aquaculture Production Statistics* (FAO, Rome, 1998).
3. B. Rosenberry, *World Shrimp Farming* (Shrimp News International, San Diego, CA, 1994 and 1996).
4. M. J. Williams, in *Sustainable Aquaculture*, J. E. Bardach, Ed. (Wiley, New York, 1997), pp. 15–51; R. J. Goldburg and T. Triplett, *Murky Waters: Environmental Effects of Aquaculture in the United States* (Environmental Defense Fund, New York, 1997). For example, carp is the most commonly farmed fish worldwide (*2*); increased farming of carp and other largely herbivorous freshwater fish in China and India has contributed importantly to food security without threatening ocean fisheries and coastal ecosystems.
5. A. G. J. Tacon, *International Aquafeed Directory and Buyers' Guide 1997/98* (Turret RAI, Middlesex, UK, 1997); A. G. J. Tacon, *World Aquacult.* **27**, 20 (1996).
6. Recalculated from C. Folke and N. Kautsky, *Ambio* **18**, 234 (1989).
7. J. H. Primavera, in *Tropical Mariculture*, S. de Silva, Ed. (Academic Press, London, 1998), pp. 257–289; J. H. Primavera, *Rev. Fish. Sci.* **1**, 151 (1993); G. W. Chamberlain, in *Global Trends: Fisheries Management*, E. K. Pikitch, D. D. Huppert, M. P. Sissenwine, Eds. (American Fisheries Society Symposium 20, Bethesda, MD, 1997).
8. C. E. Boyd and J. W. Clay, *Sci. Am.* **June**, 58 (1998).
9. World Resources Institute, *World Resources 1996–1997* (Oxford Univ. Press, New York, 1996).
10. C. Folke, N. Kautsky, M. Troell, *J. Environ. Mngt.* **40**, 173 (1994).
11. M. C. M. Beveridge, L. G. Ross, L. A. Kelly, *Ambio* **23**, 497 (1994); M. C. M. Beveridge, L. G. Ross, J. A. Stewart, in *Marine Biodiversity*, R. F. G. Ormond, J. D. Gage, M. V. Angel, Eds. (Cambridge Univ. Press, Cambridge, 1996), pp. 372–393.
12. D. Gausen and V. Moen, *J. Fish Aquat. Sci.* **48**, 426 (1991); D. Soto, paper presented at the joint meeting of the American Society for Limnology and Oceanography and the Ecological Society of America, St. Louis, MO, 7 to 12 June 1998; S. McKinnell *et al.*, *Aquacult. Res.* **28**, 145 (1997).

13. We thank W. Falcon, D. Kennedy, V. Spruill, M. Drew, and B. Goodman for helpful comments and assistance and the David and Lucile Packard Foundation for funding.