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Threats to Aquatic Environments: Is Aquaculture a Solution?

Rosamond Naylor
Julie Wrigley Senior Fellow
Center for Environmental Science and Policy, Stanford University

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Threats to Aquatic Environments: Is Aquaculture a Solution?

ROSAMOND NAYLOR*

Center for Environmental Science and Policy
Encina Hall 418E, Stanford University
Stanford, Ca. 94305-6055, USA
Email: roz@stanford.edu

Marine ecosystems and fisheries face serious threats from over-fishing, run-off of land-based pollutants, introductions and invasions of exotic species, coastal development and habitat alteration, unintended by-catch, and climate change. Annual global fish catches fluctuate between 80 and 90 million metric tonnes (MMT) and appear to be declining. As a result of limitations on wild capture, aquaculture has emerged as a major player in seafood production and marketing worldwide. During the past decade, global output of farmed finfish and shellfish almost tripled in weight and nearly doubled in value. This paper shows how aquaculture is both a contributing factor and a possible solution to the decline in world fisheries. The threats include overfishing of small pelagic fish (low on the marine food chain) to feed farmed fish, the transmission of diseases from farms to the wild, and genetic changes caused by the escape of farmed fish from netpens. The introduction of offshore aquaculture facilities and genetically modified farmed fish present further risks to wild fish populations. The paper discusses the benefits and risks of aquaculture for marine ecosystems and wild fish supplies, and presents ideas for a more sustainable future for fish production.

ROSAMOND NAYLOR is the Julie Wrigley Senior Fellow at the Center for Environmental Science and Policy (CESP) at Stanford University. Her research focuses on the environmental and equity dimensions of intensive food production. She has been involved in field-level research projects on aquaculture production, high-input agricultural development, biotechnology, climate-induced yield variability and food security. At Stanford, Roz directs the Goldman Honors Program in Environmental Science, Technology and Policy; she is on the faculty for the new Interdisciplinary PhD Program in Environment and Resources (IPER); and teaches courses on the World Food Economy and Sustainable Agriculture. Roz was Fellow in the Aldo Leopold Leadership Program in Environmental Sciences in 1999 and Pew Fellow in Conservation and the Environment in 1994. She received her BA in Economics and Environmental Studies from the University of Colorado, her MSc in Economics from the London School of Economics and a PhD in applied economics from Stanford University.

Introduction

People have long regarded the oceans as vast, inexhaustible sources of fish — a view reinforced in earlier days by copious catches. Even when fish became harder to catch, many people continued to assume that more were available. In the past two decades, this view has been transformed. According to a recent FAO report (2002), over 60% of the marine fish stocks for which information is available are either fully exploited or over-exploited, and thirteen of the world's fifteen major oceanic fishing areas are now fished at or beyond capacity. Statistics show that annual global fish catches have plateaued at roughly 90 MMT (FAO 2002) and may even be declining (Pauly *et al.* 2003). Small fish at the low end of the food chain comprise an increasing share of global catch (Pauly *et al.* 1998), while populations of commercially valuable, large predatory fish — the type many human consumers prefer — continue to decline. Commercial fishing has wiped out an astonishing 90% of large fish such as swordfish, cod, marlin and sharks (Myers and Worm 2003).

In addition to overfishing, marine ecosystems and fisheries face serious threats from other sources: run-off of land-based pollutants, introductions and invasions of exotic species, coastal development and habitat alteration, unintended by-catch and climate change (Pew Oceans Commission 2003). 'Dead zones' associated with excessive nutrient run-off and oxygen depletion in marine ecosystems have recently been classified by the United Nations Environment Program as one of the top

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global environmental problems (UN 2003). Five to ten thousand species (estimated conservatively) are being transported each day from one part of the world to another by ballast water in the shipping industry alone, in many cases invading ecosystems where native species are vulnerable to extinction (Carlton 1999). Recent climate-related studies show that oceans have absorbed nearly half of the total amount of carbon dioxide released worldwide by human activities, such as fossil fuel burning (Sabine *et al.* 2004). This process is changing water chemistry in ways that threaten corals and other calcifying organisms such as shellfish, with potentially disastrous implications for marine food webs (Feely *et al.* 2004). The impact of any one of these threats is cause enough for concern and policy action. Together, they paint a grim picture for the health of ocean ecosystems and marine fisheries.

The oceans may now be poised for yet another transformation. Fisheries depletion has been a force in expanding seafood production through fish farming, or aquaculture. During the past decade, global production of farmed finfish and shellfish almost tripled in weight and nearly doubled in value (FAO 2004). Roughly 40% of all fish directly consumed by humans worldwide are now farmed. Although most aquaculture production to date has been of freshwater fish, marine aquaculture has been growing dramatically. Global production of farmed salmon, for example, has roughly quadrupled in weight since the early 1990s. This spectacular increase and the resulting decline in salmon prices (Naylor *et al.* 2003) have helped prompt aquaculturists to begin farming numerous other threatened marine finfish. New species farmed in open ocean netpens include bluefin tuna, Atlantic cod, Atlantic halibut, Pacific threadfin, barramundi and mutton snapper.

Can aquaculture help offset the multiple environmental threats to wild fisheries and ocean resources? Does aquaculture add to or diminish world fish supplies? These questions are addressed in this paper, with examples relevant to the burgeoning aquaculture industry in Australia.

Aquaculture in Australia

The aquaculture industry in Australia is growing rapidly and spans a region from the tropics to the high-latitude temperate zones (Fig. 1). Bluefin tuna, the most lucrative aquaculture species, are ranched along the southern coast and add to supplies and revenues from the sale of wild bluefin capture. Atlantic salmon and tiger prawns, two of the world's most dominant high-value aquaculture species, are also farmed in Australia, as are numerous species of molluscs, including pearl oysters. Rainbow trout and barramundi, both widely consumed finfish, are farmed in both ocean and freshwater systems and are sold predominantly in the domestic market.

The volume, value and growth of the leading aquaculture species in Australia are shown in Table 1. These data show phenomenal growth in both volume and value of farmed bluefin tuna, and impressive, though smaller, gains in prawn and salmon production and sales.

The fastest growing and most lucrative species are all carnivores; that is, they rely on wild fish, either directly or processed as fishmeal and fish oil, for an essential part of their diets.

Oysters and mussels, on the other hand, are filter-feeding fish that derive nutrients from the ambient aquatic environment and do not rely at all on fishmeal and fish oil for food.

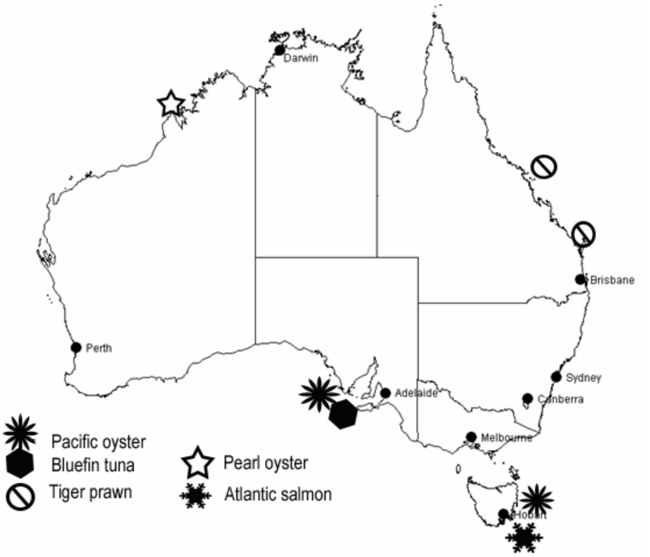

Figure 1. Approximate primary location of Australian aquaculture production

Table 1. Top five Australian aquaculture species by value and volume, 2002 (FAO 2004)

Value			Volume		
Species	Value (million US$)	Growth rate 1992–2002 (% annual)	Species	Volume (metric t)	Growth rate 1992–2002 (% annual)
Southern bluefin tuna	103.3	40.5	Atlantic salmon	14 356	15.8
Atlantic salmon	61.0	7.7	Total oyster	9 529	1.4
Giant tiger prawn	32.1	16.0	Southern bluefin tuna	4 011	28.2
Total oyster	30.7	-4.2	Giant tiger prawn	3 350	14.1
Rainbow trout	7.0	5.2	Australian mussel	3 053	15.4
All species	255.7	11.0	All species	38 840	9.0

Because of their dependence on the ambient environment, it is essential that these filter-feeding organisms be raised in uncontaminated water.

Feeding farmed fish: a global perspective

On a global scale, most farmed marine finfish are carnivores and therefore dependent on wild fisheries for fishmeal and fish oil used in fish feeds (Naylor *et al.* 2000). Roughly 30 MMT of anchovies, sardines, capelin and other small oily fish — close to one third of the current annual global fish catch — have recently been used each year for animal feed production (Pike and Barlow 2002). An increasing proportion of this catch is being used in aquaculture feeds as a result of industry growth and as livestock and poultry operations substitute less expensive ingredients for fishmeal. Farming carnivorous marine fish represents a net loss of fish protein, as 2–5 kg of wild fish are now needed for each kilogram of farmed fish harvested (Fig. 2). The good news is that conversion ratios are improving over time; fewer kilograms of wild fish were needed to produce each kilogram of farmed fish for all species categories in 2001 relative to 1997.

Despite improvements in feed conversion per fish, the aggregate amount of fishmeal and fish oil consumed by the global aquaculture industry continues to rise. Because feeds account for a large share of variable costs, aquaculturists raising carnivorous species are increasingly substituting plant-based products for fish products in fish feeds (Powell 2003), but not fast enough to reverse the trend in fishmeal use caused by rising aggregate production of carnivorous fish (Aldhous 2004). In 1988, only 10% of global fishmeal supplies went to the aquaculture industry while the remaining 90% went to livestock production (poultry and pigs) and to other industrial enterprises (IFFO 2001). Since then, the share of global fishmeal consumed by the aquaculture industry has risen to about 35% in 2002 (Pike and Barlow 2002). The conversion from wild to farmed fish is particularly high for some of the new species coming on line; for example, an estimated 20 kg of wild fish are used to produce each kilogram of farmed bluefin tuna (Tudela 2002).

Some aquaculturists argue that catching small, low-trophic-level fish to feed large, high-trophic-level farm fish is desirable, because this practice is more efficient than leaving small fish in the ocean to be consumed by the wild predatory fish caught

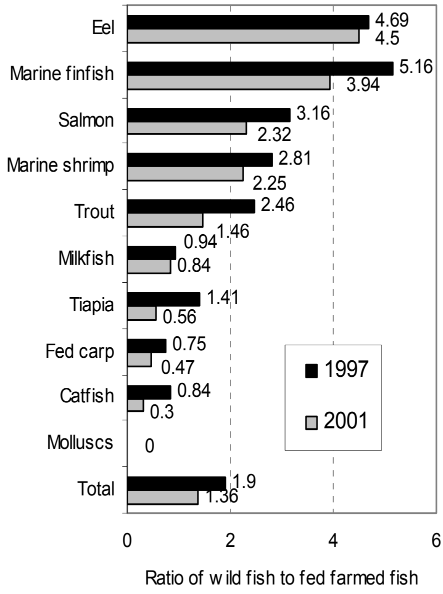

Figure 2. Ratio of wild fish to fed farmed fish, 1997 and 2001 Source: Naylor *et al.* 2000; A. Tacon (Biologist, U. Hawaii, pers. comm. 2004)

by fishermen (Hardy 2001). The relative efficiency of fish farming versus fishing is difficult to quantify, in part because energy transfer between trophic levels in marine systems is not well documented. Nevertheless fish farming is almost certainly more efficient, because farmed fish are protected from mortality sources such as predators.

Even if fish farming is comparatively efficient, fish farming's heavy dependence on wild fish inputs remains economically and ecologically problematic if aquaculture is intended to supplement, not substitute for, capture fisheries.

Not only is the supply of these low-trophic-level fish finite, but the small fish used to make fishmeal and oil are critical food for wild marine predators, including many commercially valuable fish (Naylor *et al*. 2000).

Moreover, if marine aquaculture begins to supplant capture fisheries, impetus will shift from managing the oceans for fisheries to managing them for aquaculture production.

Under such a scenario, capturing low-trophic-level wild fish for aquaculture feeds, with little concern for the effect on higher-trophic-level wild fish, could become the prevailing credo for economically rational — although ecologically irrational — ocean management.

Additional environmental threats

Marine aquaculture places a variety of stresses on the marine environment. Like industrial livestock systems, marine netpens contain large densities of fish in confined spaces which pollute surrounding waters. By one estimate, a relatively modest salmon farm of 200 000 fish releases an amount of nitrogen, phosphorous and fecal matter roughly equivalent to the nutrients in untreated sewage from 20 000, 25 000, and 65 000 people respectively (Hardy 2000). Antibiotics added to fishmeal or chemicals placed directly in open netpens to prevent the spread of diseases and parasites also flow directly into the marine environment (Goldburg *et al.* 2001).

Aquaculture presents risks of disease outbreaks, a proliferation of possible disease transmission routes in the environment, and decreased immunity of wild fish to disease — all of which can harm wild fish populations and the aquatic environments in which they live. Transmission of pathogens and diseases from aquaculture to vulnerable wild fish can occur through populations that are infected at the hatchery source, contact with wild hosts of the disease, infected fish that escape from netpens, and wild fish migrating or moving within plumes of an infected pen or disease outbreak (Naylor *et al.* 2004). Dense cultures often lead to clinical expressions of disease and a shedding of pathogens into the environment, and hence to a higher prevalence of disease overall.

In addition, the escape of farmed fish from ocean netpen systems — a common occurrence due to storms and human error — can lead to competition and interbreeding with populations of already threatened wild fish (Naylor *et al.* 2001, 2004). Most literature on the harmful effects of interbreeding between introduced (farmed and hatchery) fish and wild fish concerns salmon. These anadromous fish (i.e. they go from the ocean to coastal waters or streams to spawn) have subpopulations adapted genetically to local conditions in river drainages, and they are particularly prone to reduced fitness from interbreeding with escaped, genetically distinct farmed and hatchery fish. Other marine fish species now beginning to be farmed are less genetically differentiated, which may lessen the genetic impact of interbreeding between wild and farmed or hatchery fish. All the same, some marine fish do have distinct subpopulations. Atlantic cod, for instance, form aggregations that are genetically differentiated and appear to have little gene flow among them (Ruzzante *et al*. 2001).

Pollution, disease and escapes from marine netpens add to the underlying environmental degradation already plaguing marine ecosystems from other human activities. Although the geographic extent of aquaculture is limited, the ecological impact on marine resources if often much greater than the area suggests, since fish farming heavily depends upon and interacts with wild fisheries.

Steps toward a sustainable future

A viable future for marine ecosystems will require integrating management for fisheries, fish farming and conservation. It will also require integrating technological, ecological, economic and political approaches to solving some of the largest environmental threats. For example, despite extensive criticism, fisheries management continues to be based largely on single-species models for which there are often inadequate data and which do not reflect interactions in marine ecosystems. Many scientists have called for a more risk-averse, ecosystem-based approach to fisheries management (NRC 1999; Dayton *et al.* 2002). As aquaculture grows, a more ecosystem-based approach will be critical to help balance the competing demands for low-trophic-level fish captured as feed or left in the oceans to support capture fisheries and conservation objectives. Just what an ecosystem-based approach to management should entail, however, remains murky, and it is a topic ripe for extensive research.

Improving fisheries management is not solely a matter of better management science. Economic (and therefore political) factors play a major role. Fisheries are generally a 'commons' and fishermen lack a financial incentive to leave fish in the water for the future (NRC 1999). Steps to alter this economic distortion include removing fishing subsidies (Milazzo 1998) and using tools such as individual fishing quotas that create long-term fishing rights and incentives for fisheries conservation (Fujita *et al.* 1996). The success of new approaches will need to be validated as they are implemented (e.g. Newell *et al.* 2002).

Improvements in aquaculture production can also be made through scientific and technological advances aimed at improving feed conversion, reducing pollution, and removing farmed fish from the environment where their wild counterparts live. Trial systems exist for on-land cement tanks and enclosed bag netpen operations that prevent waste and escaped fish from moving into marine ecosystems. Unfortunately, while these systems are feasible biologically and technologically — and have the capability of protecting the environment — they are prohibitively expensive for most aquaculture producers under current market conditions.

In the United States, where expansion of salmon farms in coastal waters has met local opposition and state-level restrictions, the US National Oceanic and Atmospheric Administration (NOAA) is pursuing the development of large offshore aquaculture operations, primarily in the Exclusive Economic Zone (EEZ), beyond the reach of state laws (DOC 2004). In some areas, such as the Gulf of Mexico, offshore oil and gas rigs, some of which would otherwise have to be decommissioned, are being pursued as platforms for new aquaculture facilities. The advantages of such systems for marine environments is that flushing rates are high, the facilities are far from spawning rivers of wild fish (i.e. in the case of salmon), and near-shore pollution problems are reduced (Stickney 1997). The risks of large-scale open-ocean farming for the sustainability of marine fish and mammal populations have not been adequately quantified or publicly discussed, however. A general fear among the environmental community is that an approach that relies on 'dilution as a solution to pollution' and 'out of sight, out of mind' is likely to be unsustainable. Despite such risks, offshore aquaculture facilities are beginning to spring up around the world, often several miles from shore.

Innovative approaches to fish farming, as well as a more sophisticated understanding of the potential cumulative impacts of large-scale ocean farming, could help marine aquaculture become more environmentally sustainable. Identifying lower-trophic-level marine finfish amenable to farming may be one step towards more sustainable aquaculture. Integrated aquaculture, in which mussels, seaweeds and other species are grown in close proximity with finfish to recycle wastes shows great promise (Neori *et al.* 2004), but further elucidation of the interactions and processes among jointly cultured species, as well as larger-scale experimentation, are among the steps necessary to help make integrated marine aquaculture commercially viable (Troell *et al.* 2003).

Protecting ocean resources may require deliberative processes to partition them — for example, designating certain areas of the ocean for certain uses or non-use. The development of marine protected areas where fishing and other activities are not permitted is under active testing as a tool both for conservation and fisheries management (Palumbi 2002), but there has been little systematic investigation of possibilities for demarcating the ocean in other ways (e.g. temporally) or for other purposes (e.g. aquaculture).

The future prospects for ocean fisheries are grim, given current trends in fish production. Many capture fisheries are declining, and marine aquaculture — the alleged escape valve for fisheries — carries its own set of problems, including a heavy dependence on fisheries resources. The solutions to these issues are at best only partially in hand, but incorporating an ecological perspective into policies governing fisheries management, aquaculture systems and the rationalisation of ocean resources will be essential to implementing viable, long-term solutions.

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