Agricultural Pollution
Aquaculture

WORLD BANK GROUP

Why Care about Aquaculture Pollution?

Global fisheries production has risen rapidly over the past 60 years at over two and a half times the rate of world population growth, and aquaculture today is among the fastest-growing food sectors. The rapid growth in fisheries products, and the rise in aquaculture in particular, enabled per capita fish consumption to nearly double globally between the 1960s and 2010, and more than triple in developing countries (see figures 2 and 3). While fisheries worldwide, like other agricultural systems, have long been affected by water pollution, the sector's rapid growth and intensification are increasingly contributing to that problem. This is not only damaging to aquatic ecosystems and water users at large, but also harmful to the fishing industry itself. A historic opportunity presents itself to tackle aquaculture pollution in step with industry growth, and to shape a more sustainable source of animal protein as demand for it grows.

Figure 1: Tilapia Farm in China

Source: © Unitedstill.com

Nature and Magnitude of the Problem

Aquaculture is by far the larger polluter within the fisheries sector, even though certain capture fishery practices—such as the dumping of organic wastes into marine environments—can be a cause for concern (see box 1). Indeed aquaculture, like land-based livestock rearing, generates spatially concentrated wastes that, if improperly managed, can result in significant water pollution problems.[1] Animal feces in particular give rise to a concentrate of nutrients, pathogens, suspended solids, and substances such as heavy metals, hormones, anesthetics (used to mitigate animal stress), antibiotics, and antimicrobials that are fed as supplements to animals. Other substances found in aquaculture waters include unutilized feed and drugs, fertilizers, discarded plant and animal residues (offal), piscicides and molluscicides, and chemical additives such as stabilizers, pigments, antifoulant paints, salts, and disinfectants (for example, chlorine).

While aquaculture and capture fisheries contributed in roughly equal proportion to global fisheries output in 2013, aquaculture was on a starkly different growth trajectory. Indeed, aquaculture has been increasing at a near-exponential pace since the 1960s, whereas capture fishing started to level off in the 1990s. Much of the growth witnessed over the past 25 years is attributed to the development of aquaculture in China, where domestic demand grew by around 6 percent per year between 1990 and 2010. Today, China is the largest aquaculture producer by far (see figure 4).

Going forward, continued growth in aquaculture products is likely given rising demand for animal products and seafood appreciation among the swelling middle classes of urbanizing, emerging economies—in Asia particularly—and the finite potential of capture fisheries. Meanwhile, competition for land and fishery resources needed to sustain aquaculture is likely to contribute to shaping the aquaculture sector, possibly driving it to develop in marine settings.

Impacts

Depending on how they are handled, aquaculture wastes—especially when they are concentrated—can fertilize bodies of water leading to eutrophication, toxicity, and hypoxia. They can disrupt ecosystems through temperature change, cloud surface waters, taint drinking water, provoke chronic and acute diseases, and contribute to antibiotics resistance. In aquaculture systems themselves, inadequately managed wastes can undermine produc-

1 Other ecological impacts not covered here include the destruction of mangrove forests and other natural ecosystems as a result of their conversion to fish ponds; pollution from the production of feed crops; and pressure on wild fish populations to the extent that these are also fed to farmed species (aquaculture accounts for well over half of global demand for fishmeal).

This note was written by Emilie Cassou. Full references and acknowledgments are available online.

Figure 2: Global Fisheries Production, 1950–2013

Millions of tons

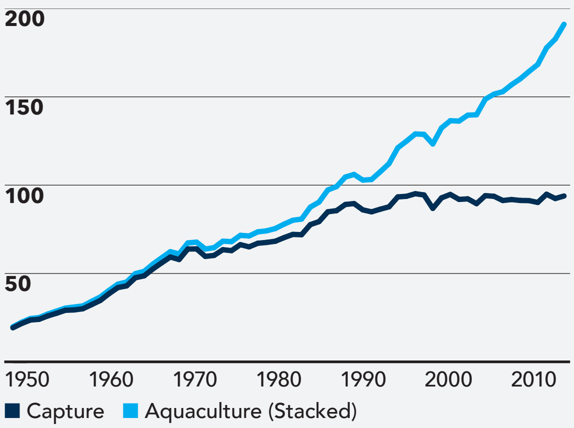
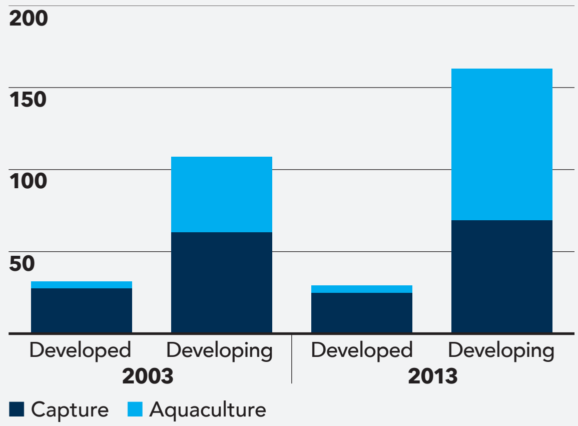


Figure 3: Fisheries Production in Developed and Developing Countries, 2003 and 2012

Millions of tons of product



Source: Based on the Food and Agriculture Organization, Fisheries Global Information System data.
Note: Total fisheries output in 2013 was over 191 million metric tons. That year, aquaculture output overtook that of capture fisheries for the first time.

tivity, food safety, and profitability. They can also leach into and salinize agricultural soils, reducing farmland productivity. Bans on imports of chemical-contaminated shrimp have come at a great cost to China's aquaculture industry, for example. And for all the chemicals used to fight infection, one third to half of farmed fish and shrimp are lost due to poor health management before they can be marketed, according to a 2006 estimate.

In parallel, aquaculture can be a source of biological pollution. This results when escaped farmed species interbreed with, outcompete, or transmit parasites and diseases to wild species.[2] Interbreeding can reduce wild species' life-span and disease resistance, disrupt their natural life cycle, slow their growth, and even reduce their edible portion in some cases. The recent approval by U.S. regulators of a fast-growing, genetically engineered salmon (see figure 5), for example, has raised concerns about genetic pollution beyond national borders despite its high feed-conversion efficiency.

While the largest aquaculture facilities tend to be subject to environmental regulations, these are imperfectly enforced; and the bulk of global aquaculture production occurs in semi-intensively managed ponds that are not subject to or escape rigorous oversight. These, moreover, often have limited capacity to invest in or absorb abatement technologies. Polluting practices also stem from producers' partial awareness of the impacts of their practices, or a lack of near-term economic incentives to modify these.

Drivers

In absolute terms, aquaculture pollution is being driven by the broad changes that are leading to the subsector's rapid growth and intensification. Factors include in-

Box 1: Making Sense of the Fishery Sector: Aquaculture versus Capture Fisheries

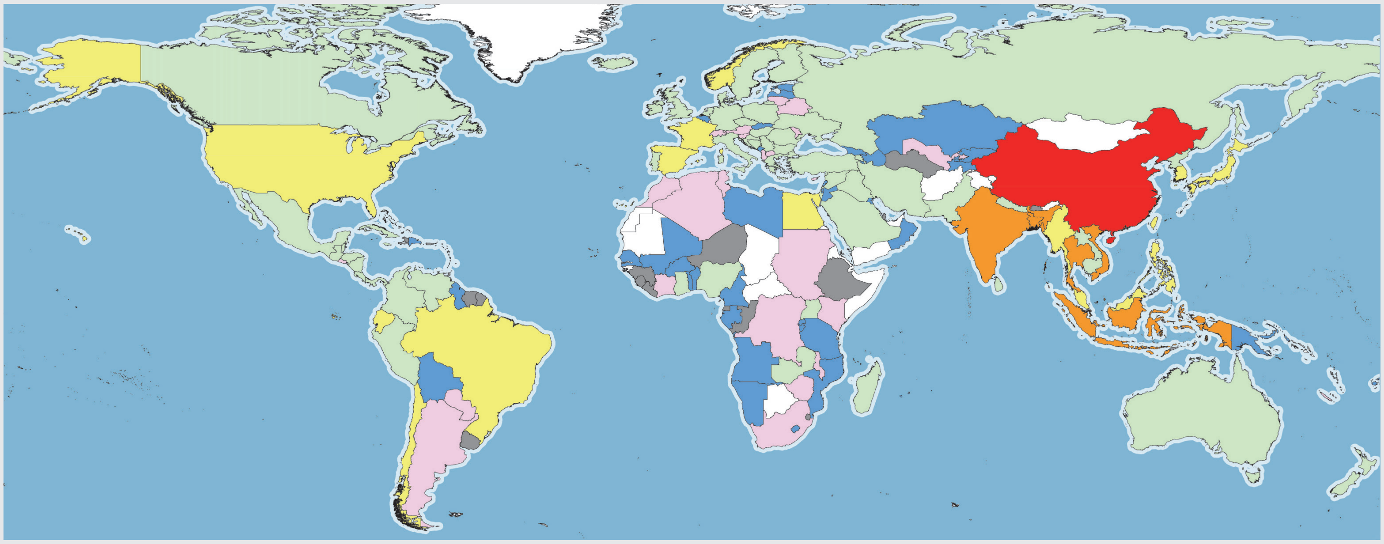
Aquaculture refers to the farming of aquatic organisms including fish, mollusks, crustaceans, and aquatic plants in either marine or freshwater environments. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, and so forth. It also implies individual or corporate ownership of the stock being cultivated during its rearing period. Aquaculture can take place in many settings, including in ponds, lakes, rivers, reservoirs, tanks, rice paddies, and the ocean (in cages).

Capture fishing, by contrast, is the harvesting of aquatic organisms that occur naturally in marine or freshwater environments and are exploitable by the public as a common property resource—with or without appropriate licenses. Capture fisheries are generally either industrial, small-scale/artisanal, or recreational. (Based on United Nations Food and Agriculture Organization definitions.)

2 The introduction of uncommon species can also attract predators.

Figure 4: Aquaculture Production of Aquatic Animals for Human Consumption, 2011

Metric tons



No Data ■ 0–100 tons ■ 101–1,000 tons ■ 1,001–5,000 tons ■ 5,001–200,000 tons
■ 200,001–1,000,000 tons ■ 1,000,001–5,000,000 tons ■ >30,000,000 tons

Source: FAO Fishery and Aquaculture Statistics. ***Note:*** Production of aquatic plants not shown.

creasing demand for animal protein, the overexploitation of wild fishery resources, and increasing scarcity of land, labor, and other resources. In Vietnam, increasing saline water intrusion linked to sea level rise and subsidence in the Mekong River Delta has, for instance, led growing numbers of rice farmers to grow shrimp, which are both more salt-tolerant and in demand.

In more relative terms—recognizing the degree to which aquaculture pollution can vary from one system to another—aquaculture pollution is largely attributable to the lack of economic incentives for adopting or even developing more ecologically-friendly systems. This partly reflects producers' insulation from the social and environmental costs of pollution. It also reflects their inability to obtain a higher market return on more sustainably produced products—whether due to market realities (for example, weak or fickle demand for higher quality), or to a lack of awareness, know-how, technology, product differentiation ability, or investment capacity. While market demand for greener aquaculture products is developing, the market signal and regulatory demands on the industry in many parts of the world have evidently driven limited environmental awareness and investment on the part of producers. The result has been underinvestment in research on locally adapted species and aquaculture management practices, in traceability systems, and in industry coordination and technology dissemination. In the Philippines, for example, aquaculture growth has centered in large part on non-native fish species as this has allowed industry to import or replicate existing aquaculture models and technologies, without having to devote extensive time and resources to research and development pertaining to native species. Where regulatory frameworks are weak or inadequately enforced, the development of new aquaculture operations and how these are run are often divorced from an understanding of ecosystems' carrying capacity. A number of cases, meanwhile, point to the potential for the environmental performance of highly intensive systems to improve as they mature and are subject to increasingly stringent regulatory and market demands. Both organic waste and antibiotics use have declined in the Norwegian salmon industry, for instance, even as production has risen (see figure 6).

Figure 5: AquaBounty Salmon

Source: © AquaBounty Technologies.
Note: Size comparison of an AquAdvantage® Salmon (background) vs. a non-transgenic Atlantic salmon sibling (foreground) of the same age. Both fish reach the same size at maturity but the non-transgenic salmon will take twice as long to grow to the mature size.

What Can Be Done?

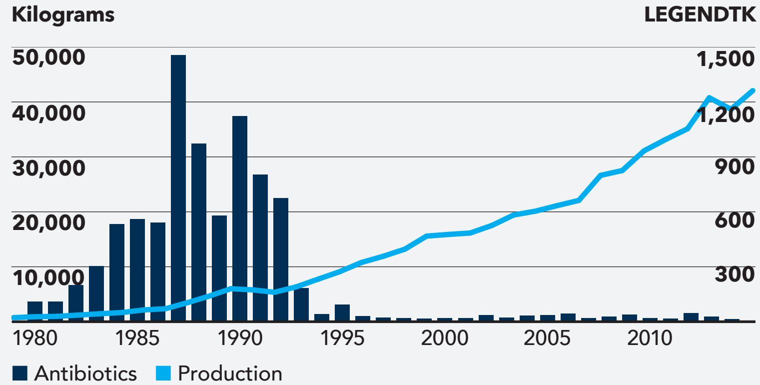
Direct mitigation through changes in management practices (feed, additive, and effluent management). Pollution from aquaculture systems can be directly mitigated through the adoption of alternate technologies and management practices, some involving the modification of system inputs, and others, changes in the management of system outputs. On the inputs side, for example, the use of nontraditional feed ingredients (for example, eubiotics) and drug alternatives (for example, immunostimulants and nutraceuticals) can improve health and production while reducing the need for chemicals and drugs typically used in aquaculture.

On the outputs side, effluent management practices have significant bearing on water pollution, particularly in intensive systems that generate concentrated wastes. Available mitigation options are highly site-specific and depend a great deal on the dilution of effluent. In most cases, pond wastes are too dilute for conventional sewage treatment technology. Where there is an abundance of adjacent land, aquaculture effluent can be used to "fertigate" cropland, or be sent to constructed wetlands or settling basins. The land intensity of these practices, however, limits their applicability, and in some cases, the use of effluent on cropland presents food safety concerns. Partitioned aquaculture systems approach the problem by aiming for zero discharge. These circulate tainted waters through treatment tanks and ponds, making use of phytoplankton and higher-order species that serve a filtering function. The more general practice of implicating multiple species in waste management is further discussed below (species selection). The fallowing of modern fish farms is a less technically demanding solution to effluent treatment, but one that implies foregone revenues in exchange for lower upfront investment costs. Regardless of the approach, effective monitoring is generally required at both the farm level and downstream—and is often a weak link—when it comes to effluent management.

Indirect mitigation through efficiency gains (breeding). Mitigation can also be achieved indirectly, through actions that enable efficiency gains. For each gram of protein, aquaculture products already tend to convert feed more efficiently, and emit less nitrogen and phosphorous, than livestock products—notably beef and pork (whereas poultry and milk are comparable to aquaculture). Nonetheless, there is room for improvements in aquaculture productivity, some of which may be achieved through further intensification, and others through changes in existing, intensive or semi-intensive systems. To the extent that many aquaculture operations are still relatively young, for example, the domestication and selective breeding of aquatic organisms for feed conversion efficiency, rapid growth, and disease resistance have the potential to improve the environmental performance of existing aquaculture systems over time. These considerations need to be balanced with concerns for genetic pollution related to the release or escape of non-native or invasive species in aquatic ecosystems (hence the genetically engineered salmon controversy).

Indirect mitigation through changes to sector structure (site and species selection). Changes in site and species selection—though more accessible to new operations than as retrofits to existing ones—can have significant ramifications for pollution and its impacts. Distancing aquaculture from sensitive ecosystems and dense population centers can be one way of reducing harm. Conversely, the adjacency of cropland, vegetative buffers, or space for treatment ponds can open possibilities for mitigation (as noted above). Certain aquatic environments, such as the deep sea, can have the advantage of diluting and flushing waste to a point of doing little harm—provided that they are not proximate to sensitive marine ecosystems—but these are not always an option, limit species selection, and can present other drawbacks.

Figure 6: Norwegian Salmon Production and Antibiotics Use, 1980–2014



Source: Based on data from the Norwegian Directorate of Fisheries, provided by Frank Asche. Permission required for reuse.

Certain species and varieties, meanwhile, are inherently more resilient and less demanding with regard to inputs or waste management than others (for example, the white shrimp or *P. vannamei* in figure 7). More transformational, the production of multiple species—aquatic or land-based—in a single, integrated system can be an attractive means to prevent pollution by converting one species' waste into another's feed, thus giving it value. Far from new, this form of polyculture is already widespread—Asian rice growers have raised fish in paddies for centuries[3]—but its practice has increasingly given way to intensive monocultures able to produce higher volumes, with greater quality and consistence. Similarly, the use of livestock manure to fertilize ponds is a practice that is being abandoned as it can impart unwanted flavor on seafood. Growing interest in sustainable production,

Figure 7: White Shrimp

Source: © Seven Seas International USA

3 When aquatic animals are farmed in conjunction with crops such as rice (directly in fields or in nearby, connected reservoirs or ponds), fish wastes help fertilizer rice crops, reducing the need for synthetic fertilizer and reducing nutrient pollution from fish fecal matter. When they are cultivated directly in rice paddies, certain aquatic species also play a pest management role, helping farmers reduce their reliance on synthetic pesticides.

however, has driven an increasing number of businesses to experiment with integrated systems that can meet the demands of today's consumers and tomorrow's markets. Various trials have been conducted combining fish with lower trophic-level species such as seaweeds, oysters, and mussels.

Indirect mitigation through the management of industry size and intensity. In the longer run, other indirect mitigation strategies include curbing industry growth and certain aspects of intensification, though these need to carefully weigh the environmental trade-offs they imply, with consideration for the environmental impacts of substitute products and production systems.

Public sector role and instruments. Some of the above changes can pay for themselves through near-term to midterm returns in efficiency, product quality (including safety), and market access, though they may initially require a number of market-enabling investments, channeled through public-private partnerships. These can include investments in research and technology commercialization, awareness-raising and behavior change among both producers and consumers, and systems that enable product differentiation, risk monitoring, and traceability. The case of the Thai shrimp industry (box 2) illustrates how the public sector can help industry address its environmental impact in ways that improve its positioning in the market. In this example, the government acted not only as a regulator but also as an advocate, facilitator, and partner, and as a funder of research and extension; and it mobilized the private sector by treating environmental challenges as being central to productivity, quality, food safety, and competitiveness.

Many changes in aquaculture management practices—the treatment of effluent or the fallowing of ponds for example—impose costs on the sector, eating into profit margins. Industry uptake thus often calls for more robust and sustained intervention on the part of the public sector to modify aquaculture operators' economic calculus by imposing and enforcing regulations, subsidizing improved practices, and taxing or fining bad ones. In the Philippines for example, the Government has established mariculture parks in selected coastal areas of the country with the intent to not only alleviate pressure on capture fisheries and stimulate aquaculture employment opportunities, but also to develop areas with appropriate infrastructure and equipment and promote the use of environmentally friendly inputs and practices in a targeted way.

Box 2: Managing the Environmental and Quality Risks of Intensification: Thai Aquaculture

Aquaculture intensification has been associated with such food safety and environmental problems as disease outbreaks in domesticated and wild stock, antibiotic residues, water salinization and pollution, biodiversity loss, and the depletion of wild resources. In the 1990s, Thailand's shrimp industry faced a looming crisis as international concern about the safety and environmental impacts of Asian aquaculture led to import restrictions and a tightening of quality of standards. But whereas Taiwan, China saw its shrimp industry collapse in the 1990s, Thailand raised its reputation as a reliable source of quality and safe shrimp in international markets.

Proactive government involvement in the development and implementation of both public and private quality certification programs has, over the past 15 years, allowed the Thai shrimp industry to achieve high levels of compliance with international standards. The Thai Government has taken multiple steps in this period to improve industry practices. To address hygiene and safety, for example, it developed a good aquaculture practice guide (GAP) and voluntary certification program and took measures to control and monitor antibiotic use. The Government's Q-Mark labeling program, introduced in 2004, gave producers the opportunity to seek certification for meeting a code of conduct (CoC) that went beyond GAP in addressing environmental management and traceability. The CoC incorporated multiple international standards and guidance developed by Codex, the International Standards Organization (ISO) and the FAO.

Several factors helped businesses conform to GAP, the CoC, and a host of private voluntary standards that have reshaped the industry. Industry concentration was one factor, as vertically integrated and contract-based operations more easily met certification requirements than independent micro, small, and medium enterprises. Another factor was the introduction of a domesticated, disease-resistant variety of white shrimp (P. vannamei, see figure 7) that requires less antibiotic, water, and feed than the previously dominant Thai black shrimp. Other factors of success included the Government's commitment to industry participation in standard development and program design, and its investments in industry capacity for monitoring, surveillance and testing, and hence compliance. Lead firms and farmer clubs also played a role in diffusing improved management practices by disseminating knowledge and innovations.