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3 Aquatic CAFOs: Aquaculture and the Future of Seafood Production

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Seafood represents an increasingly important source of animal protein available to human consumers. Between 1950 and 2016, the global per capita supply of seafood more than tripled from 6 kg to 20.3 kg (FAO 2018b), more than pork, chicken, or beef (see chapter 1). Seafood also is more important in international trade, with 60 MMT—or 35 percent of total world production—entering export markets (FAO 2018b), compared to 27 MMT for all terrestrially produced meats (chapter 1). If we are going to talk about animal protein sources at a global level, we have to include seafood.

Seafood production comes both from harvests of wild stocks in marine and inland settings as well as from aquaculture. Capture fisheries are dependent upon biologically renewable resources that for the most part are fully exploited. Marine harvests peaked in 1996 and have declined slightly since then (FAO 2018b, 38). Reported harvests from inland capture fisheries have increased steadily since the 1950s, currently accounting for 13 percent of total harvests from all capture fisheries (Welcomme 2011). Aquaculture, in contrast, has emerged as the world's fastest-growing food sector with annual production of 80 MMT in 2016 compared to 1 MMT in 1950 (FAO 2009, 2018b). In 2016 aquaculture accounted for 53 percent of all seafood directly consumed by humans. The primary focus of this chapter will be on aquaculture not only because of its growing importance, but also because aquaculture presents far greater opportunities for corporate investments of the type found in animal agriculture.

In common with the growth of animal agriculture, increased demand for seafood stems from growth in human populations, greater purchasing power of emerging middle-class consumers, and changes in lifestyles and consumer preferences favoring seafood for health reasons. The ability of aquaculture to meet growing demand has been made possible by increasingly intensive production systems that mimic confined animal feeding operations (CAFOs) in animal agriculture. In common with their terrestrial counterparts, aquatic CAFOs can be highly productive and well suited to an industrial approach favoring corporate investors able to mobilize capital on international stock exchanges, including those in New York, Oslo, and Tokyo.

As other chapters in this book have documented (see chapter 2), corporate consolidation in animal agriculture has been driven by public subsidies and taken the form of vertically integrated industries where a handful of corporations control breeding programs, feed supply, processing, distribution, and marketing. Comparable levels of corporate consolidation have not yet taken place within aquaculture or capture fisheries. The model of vertical integration does not fit well with marine capture fisheries, but is more applicable to and is likely to shape the future of aquaculture. Compared to beef, chicken, and pork, however, and despite its recent rapid growth, aquaculture is a relatively new industry and is as yet far removed from oligopolistic control. This is not surprising as the groundwork for domination within animal agriculture was laid in the 1970s, decades before aquaculture began its rapid ascent.

We begin by describing factors behind the rise and continued growth of aquaculture and distinguishing between broad types of production. We will then examine the unintended consequences such as environmental risks and social impacts of aquacultural development. These factors, and in particular issues of environmental and therefore production risk, represent challenges to corporate penetration and domination. We do identify several factors associated with aquaculture that may, nonetheless, lead to concentration of economic power within this sector. One factor is the extraordinarily important role of international trade in seafood compared to animal agriculture, with consolidation of corporations engaged in such trade being one path to consolidation. A second factor is the central importance of feed in intensively managed aquaculture and the potential of corporations with major investments in feed mills to vertically integrate in much the same way as occurred in animal agriculture. A third factor is through corporate control of key breeding stock, including the introduction of genetically engineered fish and shrimp. Just as property rights over genetic materials gave a handful of corporations a dominant role in seed and chemical supply in agriculture, a similar pattern could develop in aquaculture.

The Rise of Aquaculture

Aquaculture has a long history in China and other parts of Asia but is a much more recent development elsewhere in the world. In the United States, for example, commercial production of channel catfish (*Ictalurus punctatus*) was established in the early 1970s (Perez 2006). Commercial production of Atlantic salmon (*Salmo salar*) in Norway started about the same time and was introduced to Chile (the second largest producer of Atlantic salmon) by Norwegian investors only in the 1990s. Commercial shrimp farming in the tropics began in the mid-1970s in Taiwan and expanded into Southeast Asia in the early 1980s, with parallel developments in Ecuador and then other nations of Latin America. Various tilapia species (e.g., *Oreochromis niloticus*) have been part of aquaculture production in Southeast Asia and parts of Africa for many years, but only since 1990 has this species attracted significant commercial investment, shifting tilapia's status from that of peasant food to wide acceptance among consumers of the global north.

The rapid growth of aquaculture starting in the 1990s was made possible by major improvements in hatchery technology, fish genetics, nutrition, and disease management practices. Corporate investments in production facilities, feed mills, distribution networks, and advances in both selective breeding and genetic engineering may open a pathway leading to the expanded corporate domination in aquaculture. Hatcheries are necessary to produce adequate stocking materials in the form of small fish and shrimp to be raised in ponds, cages, or other structures. Fish breeding for many species of fish and shrimp is a relatively new phenomenon compared to plant and animal breeding, but has made rapid progress in part because of the short life spans and high fecundity of most commercially important species. The construction of feed mills has been of particular importance to the growth of aquaculture. Feed represents the highest-cost item in most aquaculture production systems and several of the largest corporations in the seafood industry have feed production as their primary business. The combination of fish and shrimp bred to thrive in congested conditions and intensive feed regimens creates water-quality problems and conditions for bacterial and viral diseases to proliferate. Breeding programs and management protocols have been designed to reduce risks associated with disease but as intensive aquaculture systems proliferate, antibiotic use is on the rise, contributing to the same resistance issues long associated with animal agriculture (Done, Venkatesan, and Halden 2015).

The rapid pace of aquaculture development has been led by producers in Asia, and in particular in China. East Asia, Southeast Asia, and South Asia combined account for 89 percent of total aquaculture production in the world and China alone accounts for 61.5 percent (FAO 2016, 27).[1]

Extensive and Intensive Systems

A key feature of aquacultural development over the past three decades has been the drive to increase intensity of production. Aquaculture systems can be described as ranging along a continuum from extensive to intensive based on stocking density and associated inputs—the higher the stocking density, the greater the need for feed, generally the single-largest variable cost item. Extensive systems are defined by limited or no use of production inputs other than construction of a pond or other enclosure into which wild fish, crustaceans, or mollusks enter, are trapped, and allowed to grow using naturally occurring nutrients. For example, in Southeast Asia brackish water production of shrimp involved opening up floodgates in coastal ponds during the lunar high tides and letting post-larval shrimp and other species such as milkfish (*Chanos chanos*) to enter the pond. Production of oysters and other mollusks may involve little or no use of inputs other than providing a substrate for the capture of juvenile shellfish. Such systems are termed "extensive" because they rely on a relatively large area in a nonintensive manner. Low-intensity "extensive" production systems rely on nutrients naturally occurring in the environment, sometimes supplemented by fertilizers to boost algal growth. A terrestrial equivalent might be grass-fed beef or free-range chickens instead of more intensively managed CAFOs where greater stocking densities combined with intensive feeding and other inputs generate higher yields.

Intensive aquaculture systems depend on supplemental feeds that typically include grains, proteins, essential amino acids, and vitamins. A good example of intensive production is the pangasius catfish (*Pangasius hypophthalmus*) in Vietnam where stocking densities of 40 to 60 fish per m^2 are common, producing fish up to 1.5 kg in a six-month growing cycle and yielding on average 250–300 mt/ha (metric ton/hectare) (Griffiths, Khanh, and Trong 2010). Stocking densities for *Penaeus vannamei*, a widely used shrimp species, commonly are up to 150 per m^2 with harvests of 7 mt/ha in a three-month growing season (Briggs et al. 2004).

Environmental Issues

Dramatic increases in commercial aquaculture production have added appreciably to the global supply of seafood, but not without serious environmental consequences. As with animal agriculture, feed necessary to support intensive aquaculture production systems is globally sourced. The argument that land used to produce animal feeds affects food security where feed grains are grown is applicable for aquaculture as well, but more important is the impact on marine ecosystems associated with production of fishmeal and fish oil. Intensive aquaculture operations also are prone to disease and parasite issues that affect production and can have wider ecosystem impacts. Escapes of exotic species from pens and ponds also pose threats to aquatic ecosystems. All of these issues will be discussed.

Marine Ecosystem Impacts

Each species has different feed requirements, but in broad terms we can speak of carnivores like salmon, shrimp, and tuna, and omnivores like tilapias and carps. The carnivores (or more specifically piscivores as they require protein from seafood) depend heavily on fishmeal and fish oil provided primarily from marine capture fisheries (with additional input from seafood processing waste[2]). Approximately 25 percent of all marine harvests from the wild (20.9 MMT) are small fish (e.g., anchoveta, menhaden, caplin) used for production of fishmeal and fish oil and not consumed directly by humans (table 3.1). Piscivores require feeds with 18 percent to 30 percent by volume of fishmeal as well as fish oil for optimal growth and flesh quality. Omnivores such as tilapia, carp, and pangasius catfish often are fed a diet containing small amounts of fishmeal supplemented by protein from plant sources, typically soybeans.

Demand for both fishmeal and fish oil is likely to continue increasing because the piscivores are high-value commodities particularly prized among consumers in industrialized nations of the global north. The supply of fishmeal and fish oil has long been recognized as a limiting factor in

Table 3.1
Global capture fisheries and aquaculture production and utilization, million metric tons, 2009–2016

	2009	2010	2011	2012	2013	2014	2015	2016
Capture								
Inland	10.5	11.3	10.7	11.2	11.2	11.3	11.4	11.6
Marine	79.7	77.9	81.5	78.4	79.4	79.9	81.2	79.3
Total capture	90.2	89.1	92.2	89.5	90.6	91.2	92.7	90.9
Aquaculture								
Inland	34.3	36.9	38.6	42.0	44.8	46.9	48.6	51.4
Marine	21.4	22.1	23.2	24.4	25.4	26.8	27.5	28.7
Total aquaculture	55.7	59.0	61.8	66.4	70.2	73.7	76.1	80.0
TOTAL	145.9	148.1	154.0	156.0	160.7	164.9	168.7	170.9
Human consumption	123.8	128.1	130.0	136.4	140.1	144.8	148.4	151.2
Non-food uses	22.0	20.0	24.0	19.6	20.6	20.0	20.3	19.7
Population (billions)	6.8	6.9	7.0	7.1	7.2	7.3	7.3	7.4
Per capital food fish supply (kg)	18.1	18.5	18.5	19.2	19.5	19.9	20.2	20.3

Source: FAO 2016, 2018b.

the expansion of aquaculture (Naylor et al. 2000; Tacon and Metian 2009). Research to improve feed conversion ratios has achieved significant success, but aquaculture feeds still utilize 68 percent of global supplies of fishmeal and 88 percent of global fish oil (Naylor et al. 2009). Demand for aquaculture feeds is likely to continue growing, putting increased pressure on small fish species that play a key role as forage fish in marine ecosystems supporting bird life, other fish, and human consumers (generally the poor in developing countries) who depend on small fish for food.

Disease and Parasites

Intensive production systems made possible through supplemental feeding offer the prospect of higher yields per hectare but they also pose higher risks. Disease is a constant threat in densely stocked ponds or cages due in part to crowding and stress, and caused also by water quality problems related to the production process itself (uneaten food and fecal materials, polluted water discharged into the environment by other aquaculture operations or other industries in the watershed). Controlling a disease outbreak in an aquatic ecosystem is difficult and disease organisms often spread rapidly across wide areas and even from one part of the world to another. For example, a virus causing infectious salmon anemia simultaneously affected Atlantic salmon produced in Norway, Scotland, Canada, and Chile. Salmon producers in Chile have been using large quantities of antibiotics, including 1.2 million pounds in 2014 (Esposito 2016); antibiotic use in aquaculture is a common practice in many parts of the world. Wild salmon in the Pacific Northwest have been affected by sea lice when they swim near caged salmon infested with this parasite (Krkošek et al. 2006). Disease outbreaks have been a constant problem associated with intensive production systems used by shrimp producers in Asia and Latin America. Channel catfish viral disease in the United States is a problem related to stress induced by high stocking densities in ponds.

Salmon farming also imposes a number of externalities, the severity of which will depend on physical conditions and how the production process is regulated and managed. Salmon are raised in large pens typically in protected seawaters such as fjords. Fecal waste and uneaten food pass through the pens and the water column to the ocean floor. If the waters are deep, there is thorough tidal flushing, and if the number of pens is appropriately limited, these wastes are easily assimilated through natural processes and the likelihood of diseases greatly reduced. Where these conditions do not exist, disease problems and the use of antibiotics become common.

Escapes

Another risk associated with farmed salmon involves escapes into the wild. Escapes are common both as small "trickles" of fish and in more catastrophic escapes. In August 2017, approximately 120,000 Atlantic salmon (*Salmo salar*) escaped from pens in Puget Sound, British Columbia (Mapes 2017). In this setting, Atlantic salmon are an exotic species, one that has established breeding populations in three streams in British Colombia, representing a potential threat to several species of Pacific salmon that are under heavy fishing pressure at sea and habitat loss on land (Thorstad et al. 2008). Escapes of Atlantic salmon from pens in Europe, where the species is native, also can be disruptive because the escapees have been selectively bred for adaptability to pen culture and willingness to feed on pellets. When domesticated and wild salmon interbreed in the wild, the resulting progeny have lowered fitness and reduced lifetime success (Thorstad et al. 2008).

Escapes of exotic species can cause havoc on aquatic ecosystems. Water is a highly connective medium and once a fish is released into the environment there is a real danger of it traveling along and across watersheds. Flooding of aquaculture operations in the early 1990s led to the escape of silver and bighead carp into the Mississippi River in the United States. These carp species have moved up the river, displacing native fish species. There is concern that these fish will make their way into the Great Lakes through the Chicago Ship and Sanitary Canal, which connects the Mississippi River to the Great Lakes. In 2017, an adult carp was found within nine miles of Lake Michigan, eighteen miles past an electronic barrier created to stop their spread. There is great concern that native species will be displaced if carp make their way into the Great Lakes (Alliance for the Great Lakes 2017).

Societal Dislocations

Environmental and societal disruptions caused by the introduction of intensive aquaculture systems can be separated analytically, but as the following example of shrimp farming demonstrates, social and environmental costs are two sides of the same coin. Mangrove destruction undermined local livelihood strategies and food security. In this section we focus on resource conflicts and food security as examples of societal dislocations that can be caused by the introduction of intensive aquaculture.

Resource Conflicts

Land and water used in aquacultural development did not suddenly appear from a big basket of unused resources. Rather, these resources often were used for other purposes, whether for agriculture or for ecosystem services. That aquacultural development can impose social and environmental costs has been known for at least thirty years, when the first critique of shrimp farming was published in the peer-reviewed academic literature (Bailey 1988). Central to this critique was the impact of rapidly expanding shrimp farms on millions of hectares of mangrove forests that were destroyed

(Thomas et al. 2017). Most investors were outsiders, urban elites who used their financial resources and political connections to gain access to what were generally regarded as public lands. Coastal fishing communities depended on mangrove resources for a wide range of products, including building materials and fuel wood. Mangrove forests were particularly valuable as a nutrient-rich habitat where many commercially important finfish and crustaceans found food and shelter as juveniles before making their way to the open ocean. Mangrove destruction undermined the resource base that coastal communities depended upon for subsistence and non-subsistence needs. Where small-scale extensive aquaculture was practiced in coastal areas, these producers were bought out or forced out by disease outbreaks associated by wastewater from shrimp farmers using intensive methods of production.

In more recent years, many shrimp farmers have learned that soils associated with mangrove often are unsuitable for sustained production of shrimp (due to acidic soil conditions) and have shifted operations to lands just outside the mangrove forests. In Asia, many of these lands previously were used for rice production. Intensive production of shrimp requires large volumes of fresh water to maintain optimal salinities as pond water evaporates. Coastal aquifers are vulnerable to over-exploitation and a common problem faced by coastal communities where shrimp farms are present is saline intrusion into freshwater aquifers. Where this happens, coastal residents may be forced to purchase fresh water for household purposes.

Resource conflicts between aquaculture and other industries are not uncommon. Industrial, urban, or agricultural land uses upstream can affect water quality and threaten or foreclose opportunities for aquaculture. Rice-fish culture, a low-intensity form of aquaculture practiced in Asia for millennia, has greatly diminished as farmers adopted herbicides and insecticides as part of more intensive rice production systems. Shellfish production effectively carves out a part of the near-shore coast, turning public access waters used by fishers and recreational users into private property. Because such shellfish are likely to be placed in the most productive waters, local fishers in particular might feel that their livelihoods are threatened by the spread of aquaculture. In extreme cases, aquaculturists have blocked off direct access to fishing grounds, making it necessary for fishers to travel extra distance each day.

Food Security

As is the case with animal agriculture, expanded production of protein does not necessarily translate into food security for all. There should be no surprise to this given the nature of markets in a global capitalist system where product flows to markets able to pay the most.

The intensification of aquaculture has contributed significantly to the growth of international trade in seafood, which in 2016 was valued at US$142 billion (compared to US$71.9 billion in 2004). The growing importance of international seafood trade has created new space for transnational corporations to expand their operations; most of the top corporations in the seafood industry are vertically integrated producers, processors, and distributors of seafood based in Japan and Europe (Österblom et al. 2015). Vietnam and Thailand alone accounted for 10 percent of global exports and four of the top seafood exporters in 2014 were non-industrialized nations of the global south (FAO 2016). Broadly speaking, we can describe a pattern of high-quality protein in the form of seafood being exported from the global south to the global north where consumer buying power creates the most profitable markets (Kagawa and Bailey 2006).

There are important caveats to this broad statement. Belton, Bush and Little (2018) argue that this critique misses the important role of commercial producers, particularly in Asia, who produce for poor and middle-income domestic consumers and who therefore make important contributions to food security. They make the important point that in many countries, over 90 percent of all aquaculture production is consumed domestically, though there are other countries (e.g., Thailand, Vietnam, etc.) where that figure is one-third or less of all production. Asche et al. (2015) argue that seafood exports generate income and employment in the global south and that seafood imports from the global north to south, which take the form of lower-valued products, balance out the net nutritional balance. These authors note in conclusion, however, that aggregate trade figures tell us nothing about the impact of seafood trade on the poorest of people in developing countries, only that international trade provides the means by which developing countries are able to improve societal welfare.

International trade in seafood from the global south to the global north involves more than the shipment of high-quality protein; it also represents allocation of water, land, and other resources to that end. Intensive production systems for shrimp, for example, have disrupted coastal ecosystems and undermined food security in many coastal communities in South Asia, Southeast Asia, and Latin America. The impact comes from not only the export of protein but also the transformation of ecosystems and the livelihood strategies associated with those ecosystems.

The Green Revolution of the 1970s led to dramatic increases in food production, but benefits did not always reach the landless or the poor. So too the growth of aquaculture has increased seafood supplies globally, an important point not to be missed. As with the Green Revolution, or any other major technological change, there are likely to be winners and losers. Consumers who can afford to buy fish, whether in developing or developed nations, are the beneficiaries of aquacultural development. Rural people displaced by aquacultural development may find employment in the ponds or processing facilities or other sectors of the economy. But we also can predict that there are those who will be left behind and who will experience increased food insecurity even as fish production increases simply because they cannot access the market.

Constraints to Corporate Penetration and Consolidation

There are multibillion-dollar corporations engaged in vertical integration involving some combination of marine fisheries, feed production, and aquaculture (as will be explained), but nothing exists remotely resembling the kind of oligopolistic structure found in pork, chicken, and beef described elsewhere in this volume. One reason for this is that aquaculture is simply a newer industrial actor. Animal agriculture had industrialized by the 1970s and the current corporate consolidation is simply the most recent phase of that process. Aquaculture, in contrast, only became a major source of production in the last three decades. Additionally, aquaculture remains a relatively risky enterprise compared to animal agriculture. This may change with research and experience, but problems of disease and parasites are more difficult to control in an aquatic environment than in a terrestrial one where animals can plainly be seen and air quality can quickly be improved with ventilation.

Perhaps a larger constraint to consolidation of corporate power has to do with the highly fractured nature of aquaculture in scale, technologies, and species, not to mention that the product—seafood in its many permutations—is also supplied by a largely separate industry that depends on marine harvesting of aquatic life-forms from the wild. Seafood production systems are highly diverse and may resist the kind of corporate consolidation found in animal agriculture. Because most marine fishery resources are effectively open access, the ability of corporations to dominate the marine sector is limited. There are niches where corporate investments rule the waves. Open ocean or distant water fisheries are the natural realm of corporate actors who invest in large factory ships that both catch and process fish into frozen fillets or other products. But the global fishing fleet in 2014 was made up of 4.6 million fishing vessels, more than one-third of which did not have engines. Of motorized craft, 85 percent were less than 12 meters in length (FAO 2018b, 35). Only 2 percent of all fishing vessels were longer than 24 meters in length. These larger vessels doubtlessly landed a disproportionate share of the total catch, but even so, the marine fisheries sector can be characterized as a sea of small boats serving numerous markets. Österblom et al. (2015) found that the 13 largest corporations in the world involved in marine capture fisheries accounted for 11–16 percent of global harvests. This is a significant fraction but far from the corporate concentration found in beef, chicken, and pork.

Aquaculture production systems also are highly diverse, with the FAO (2016) reporting 369 finfish, 109 mollusks, and 64 crustaceans being grown in fresh water, brackish water, and coastal marine settings from the arctic to the equator. This wide array of species is produced in earthen ponds, aboveground tanks, raceways, cages, and pens in freshwater, brackish water, and seawater. Production systems range from small backyard ponds where fish are fed kitchen scraps to intensively managed ponds with high stocking densities and feeding regimes. Some systems are built to be entirely self-contained, with filtration systems removing waste products before water is recycled into the tank or pond; in other systems wastes are absorbed into the larger ecosystem. Where use of inputs is limited, this presents few problems but where high stocking and feeding rates are used, eutrophication, disease outbreaks, and fish kills through oxygen depletion are serious risks. Managing such risks is an important part of intensive production systems of the type that would attract corporate investors.

Pathways for Corporate Penetration and Consolidation

Compared to capture fisheries, opportunities for corporate penetration and domination in aquaculture are greater because key factors of production are more easily controlled. In contrast with the open-access nature of most wild fisheries, property rights can be established over land and water used for aquaculture production either through direct ownership or through long-term leases. These property rights in turn enable investments in ponds, raceways, or other physical infrastructure. Aquaculture producers also are able to utilize key inputs including stocking materials and feeds to gain higher yields. Investments to maintain adequate water quality through pumping or aerators or both also can be employed to increase the intensity of production. In short, aquaculturists have a high degree of control over the production process.

We see three pathways through which consolidated corporate power in aquaculture could emerge. The first has to do with control over international trade, the second with vertical integration centered on domination of feeds, and the third through control of genetic materials. These pathways are analytically separable but are likely to be pursued simultaneously by corporations seeking to establish a dominant role in aquaculture.

International Trade

One path to corporate consolidation in aquaculture is through control of international trade, which represents 35 percent (by value) of global seafood production, capture and culture combined (FAO 2018b). Production systems for wild harvests and aquaculture are very different but once seafood enters the market, differences between captured and cultured seafood disappear, not only from the perspective of individual consumers but more importantly because corporations that trade in seafood handle product from both sources.

The high value in international trade is central to understanding the profitability of corporations in the seafood industry. The United States and Japan were the leading importers, together accounting for one-quarter of global seafood imports in 2016 (FAO 2018b, 55); the United States ran a seafood deficit of US$14.7 billion in 2016. China and Norway were the world's largest exporters, together shipping almost $US31 billion worth of seafood around the world. Fish exports from the global south made up 54 percent of total value and 59 percent in total weight in 2016 with a net trade balance of $37 billion, higher than tobacco, rice, sugar, and other types of meat combined (FAO 2018b, 57). Unlike trade in other types of meat, where trade flows generally are from the global north to the global south (chapter

1), the flow of seafood moves primarily from the global south to nations of the global north.

The largest corporations in the seafood industry are the large trading houses of Japan. Maraha Nichiro has operations in 65 countries while Nippon Suisan Kaisha and Kyokuyo operate in 32 and 15 countries, respectively (Österblom et al. 2015). The top one hundred seafood corporations had combined revenues of US$93 billion in 2015. The ten largest of these all had revenues over US$2 billion and accounted for more than one-third of total revenues (Undercurrent News 2016). These are large corporations but still small in comparison with Tyson Foods (n.d.), with sales of US$38.3 billion in 2017.

Vertical Integration around Feed Mills

Several corporations with origins in seafood trade are expanding investments into feed mills, seafood processing, and aquaculture production facilities. As is true for animal agriculture, intensification of aquaculture production is highly dependent upon feed mills which use many of the same inputs as found in other animal feeds, but with a higher concentration of fishmeal and fish oil derived primarily from wild stocks of small pelagic fish such as anchoveta, menhaden, and capelin. Fishmeal and fish oil are particularly important elements in feeds for carnivorous species such as salmon and shrimp and also are used in small quantities for feeds formulated for noncarnivorous species such as tilapia and carp. Corporations involved in seafood trade are well placed to access raw materials used to produce aquaculture feeds, and even more so if they also are involved in seafood processing, since wastes from such facilities are the second most important source of fishmeal and fish oil.

The importance of feed in aquaculture is highlighted by FAO (2018b, 22) data showing that the percentage of cultured species provided supplemental feeds versus those that are not increased from 45 to 70 percent between 2001 and 2016. On the supply side, six of the world's top 12 seafood corporations identified by Österblom et al. (2015) were involved in feed production. Four of these six are integrated either in the harvest of small pelagic fish for fishmeal and fish oil (Austevoll Seafood of Norway and Pacific Andes of China) used in the production of feeds or are involved in aquaculture production (Dongwon Group of South Korea and Charoen Pokhand of Thailand). Belief that aquaculture is an attractive investment in

2015 led Cargill to purchase the Norwegian feed manufacturer EWOS. The Dutch holding company SHV purchased Nutreco, owner of Skretting of Norway. Corporate buyouts are of course one strategy through which large corporations like Cargill establish a position in a market in order to grow their business. Feed is the single largest cost item in aquaculture production and feed suppliers are in a position to offer other products and services to producers. What has not yet emerged in aquaculture is the type of vertical integration seen in hog and poultry production whereby a producer buys stocking materials and feed from a corporation and then sells the harvest back to that corporation for subsequent processing, distribution, and marketing. However, the potential exists for this to occur.

From Selective Breeding to Genetic Engineering

The pace of selective breeding has accelerated in the past several decades due to scientific advances in genetic and molecular biology. Because of their high fecundity (ability to produce a large number of eggs) and short lifespans, fish are excellent candidates for research on genetic improvement. As an example, Norwegian salmon farmers began to experiment with selective breeding in the early 1970s, looking for fish that tolerated crowded conditions, fed well, were disease resistant, grew rapidly, and had the right flesh color and fat content. Gjøen and Bentsen (1997) reported that after four generations, the growth of selected salmon to smolting (the life stage where salmon adapt to seawater) was twice as fast as for wild salmon.

Advances in genetic and molecular biology have provided a scientific basis for improving the genetic composition of farmed fish whether through conventional selective breeding, interspecies hybridization, or genetic engineering. Each of these technologies creates opportunities for more intensive production practices in industrial CAFO settings. More importantly, a pathway to corporate power is created by controlling the genetic material that provides for faster growth, disease tolerance, and other desirable traits.

The ability to control sex is an important and widely used tool in aquaculture. Energy used to produce sexual organs, sperm, or eggs can be harnessed to increase growth rates and often to improve flesh quality. Male channel catfish and tilapia grow faster than females, making production of a single-sex male population an important management goal. The sexual characteristics of fish and other aquatic organisms can be manipulated relatively easily through use of hormone treatments or changes in pressure or temperature at certain stages in the growth cycle.

The relatively plastic genetic makeup of fish allows for genetic improvement through polyploidy. Most fish species are diploid, meaning that they contain two sets of chromosome pairs, one inherited through the mother and one through the father. Triploid fish can be created through abrupt pressure and/or temperature changes or through chemical exposure. Triploids have a third set of chromosomes representing additional genetic material in each cell and as a consequence, each cell is somewhat larger (as is the whole fish). The key advantage of triploids is that they are sterile but they also tend to grow more quickly because energy is directed to body growth rather than growth of sex organs. Triploidy often is promoted where a high proportion of an animal's energy goes into reproduction. Triploidy represents a step beyond simple mono-sexing and a further step in the path toward intensification.

Hybridization can involve breeding programs involving individuals of the same species but from different strains that have different genetic backgrounds. Such hybridization results in greater genetic variation in the offspring and the potential for hybrid vigor. In the United States, crossing of the channel catfish with the blue catfish has produced a hybrid that grows 25 percent more quickly than either channel or blue catfish, tolerates lower oxygen levels, has a better fillet percentage, and is more resistant to disease. The production of hybrids opens up commercial opportunities for breeders and increases potential for more intensive CAFO operations.

Mono-sexing, triploidy, and hybridization are now standard approaches to improving the genetic resources available to aquaculture producers. More recently, major advances are being made in mapping the entire genome of several commercially important aquacultural species including salmon, catfish, cod, rainbow trout, tilapia, carp, striped bass, shrimp, oyster, and scallop. Such mapping allows researchers to know where genes controlling desirable traits are located, allowing for highly efficient and targeted selective breeding for such traits as disease resistance.

Investments in selective breeding programs, genome mapping, and development of hybrids have economic value as a form of intellectual property over which certain rights are protected either by contract or by patent. Research on hybrid catfish at Auburn University resulted in a license to Eagle Aquaculture, Inc. to develop this technology. In Europe, major corporations including Wessjohan, Landcatch, and Stofnfiskur have begun to exert a stronger proprietary interest in the genetic resources that they control. The German EW Group (a leader in poultry genetics through its subsidiary Aviagen) has gained majority ownership of AquaGen AS, a Norwegian company with 35 percent of the world market on salmon (Rosendal, Oleen, and Tvedt 2013).

The next step in opening space for corporate growth within aquaculture is likely to be through genetic engineering (GE). GE research on fish is underway in China, Cuba, India, Korea, the Philippines, Thailand, and the United States (Fu et al. 2005). The U.S. Food and Drug Administration (FDA) approved the first transgenic animal, a genetically engineered Atlantic salmon, for human consumption in 2015 and Health Canada issued its own approval in 2016 (U.S. FDA 2015; Health Canada 2016). AquaBounty Technologies (ABT) of Massachusetts is a small company that spent almost two decades developing and obtaining FDA approval for this transgenic Atlantic salmon that they claim can reduce the time needed to reach marketable size from thirty to eighteen months.

Future Directions

Aquaculture as an industry is a relatively new actor on the global meat world stage. Nonetheless, scientific, technical, and organizational changes that have shaped contemporary animal agriculture, described elsewhere in this volume, provide the basis for anticipating the future of seafood production.

The rise of aquaculture and growth in international seafood trade are closely linked and there are a number of transnational corporations that have built their fortunes in the larger seafood industry, with investments in some combination of fishing vessels, aquaculture facilities, feed mills, and international trade. In their study of 160 corporations in the seafood business, Österblom et al. (2015, 4–5) found that the top 10 percent accounted for 38 percent of total revenues and were especially dominant in production of feeds for salmon and shrimp (68 percent and 35 percent of global totals, respectively). They likened these corporations to “keystone species in ecological communities in that they have a profound and disproportionate effect on communities and ecosystems and determine their structure and function to a much larger degree than what would be expected from their abundance" (Österblom et al. 2015, 1). In other words, a small number of large corporations in the seafood industry have a strong influence on specific segments of the industry.

Property rights over seed technologies have led to a concentration of corporate power in agriculture (Kloppenburg 2004) and the ability to patent transgenic fish opens the door to similar opportunities. If ABT's transgenic salmon proves a commercial success, other transgenic species will enter the market. If GE provides for improved growth rates and other production advantages, not only will transgenic fish gain a share of the seafood market but also corporations able to patent these fish will have established key positions within the industry. Through the process of corporate merger, corporate innovators such as ABT might be purchased by larger corporations once these potential buyers are convinced that the technologies have merit.

At present, corporate investments in aquaculture are highly concentrated on a small number of high-value species, particularly shrimp and salmon, which serve markets of the global north. These high-value species are the ones that are attracting corporate investments in selective breeding and genetic engineering because that is where financial gains are most readily realized. The same is true with investments in feed mills, which are likely to be placed near production sites for species with the greatest international markets, including shrimp, salmon, tilapia, and pangasius catfish. These investments in seed and feed will result in increased corporate power among producers and processors of a limited set of important species.

There remains the question of how corporate interests will interact with the millions of limited resource aquaculturists around the world with small ponds or cages, few financial resources, and limited technical expertise. Seventy percent of all aquacultural production comes from producers using supplemental feeding. Included in this total are many small-scale producers. Importantly, 30 percent of all aquaculture production does not include supplemental feeds, representing a potential growth market. Small-scale producers may not be tied to global markets but increasingly they are being influenced by transnational corporations that supply feed, pharmaceuticals, and other inputs to support higher productivity. In the absence of effective extension programs in most parts of the developing world, such input suppliers often provide, directly or through their sales agents, technical advice and credit to all types of producers eager to increase their production through increasing stocking density and input use. In this way, even where corporations are not directly engaged in production and where the product does not enter global markets, the influence of corporate actors can be expected to penetrate deeply into many parts of the world.

The likelihood that aquaculture might follow the path of chicken production, with a small number of integrators dealing with individual producers, is a realistic prospect in the decades to come for a limited number of high-value species. The aquaculture sector is likely to develop a relatively small number of well-capitalized intensive production systems serving urban markets of the industrial north and the newly prosperous elites of emerging nations. At the other end of the spectrum will be limited resource producers who use few if any purchased inputs to supply local markets. In between there will be a diverse mix of producers serving local, regional, or even national markets and operating somewhere on the continuum between intensive and extensive production systems.

Corporate consolidation in the aquaculture sector may be further advanced through certification efforts, pushed by environmental, nonprofit organizations and embraced by major retailers in the global north, designed to encourage environmentally sound and socially just production of seafood. Conservation and consumer activist groups have built on the experience of the Forest Stewardship Council and the Marine Stewardship Council to develop the Aquaculture Stewardship Council, which will certify seafood products. The Global Aquaculture Alliance, an organization of corporate actors within the seafood industry, has established its own Best Aquaculture Practices certification program. Certification programs involve third-party evaluations and cost more money than most small-scale producers in the tropics can afford. The difficulty in assuring chain of custody of seafood from numerous small-scale producers through middlemen and on to processors, exporters, and retailers is a serious obstacle to participating in certification programs (Tran et al. 2013). Because major retailers like Wal-Mart are moving towards limiting the sale of seafood to certified products, in response to consumer demand, the ability to participate in certification programs will dictate the ability to access the most lucrative markets. Corporate producers will have the advantage of scale and technical expertise to meet certification standards and be able to afford costs of certification.

In sum, we expect corporations in the seafood industry generally, and the aquaculture sector in particular, to play an increasingly important role. Some small-scale producers will either be eliminated or incorporated into vertically-integrated commodity systems as contract growers. We have already seen corporate mergers and movements toward vertical integration in this sector. Technological changes, including genetic engineering, will contribute to further consolidation in aquaculture production. And finally, certification systems may provide important advantages to corporate producers compared to small-scale producers in gaining access to the most lucrative of markets.

Notes

1. There have been disputes regarding the accuracy of fisheries data from China, particularly regarding marine capture fisheries (Watson and Pauly 2001) and there is some uncertainty regarding accuracy of FAO statistics on some forms of aquaculture production, notably from China (Campbell and Pauly 2013; FAO n.d.).

2. Waste by-products from pangasius catfish are now used as inputs for fishmeal production in Vietnam.

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