The future of U.S. seafood supply

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The Future of US Seafood Supply

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Abstract

The United States today imports most the seafood it consumes. Half of these imports are from aquaculture. Domestic wild capture production is limited and US aquaculture production has declined in recent years. Policy, socioeconomic, and regulatory obstacles stand in the way of expanded US aquaculture production. In this paper, we examine the implications of two future paths for seafood supply: an increasing reliance on imports, and a shift toward increased domestic aquaculture production. We examine global trends, likely future developments in US seafood demand and supply, and implications of the path of US aquaculture development for US seafood supply and prices, employment, ecological footprint, and seafood supply security and safety. We conclude with recommendations for a path forward that serves the interests of the nation and the global community in the search for economically sound and sustainable ways to feed a growing population.

Key Words or Phrases

Aquaculture, aquaculture economics, aquaculture policy, seafood supply

1. Introduction

The United States (US) began running seafood trade deficits in the 1970s and today imports most the seafood it consumes. Half of these imports are from aquaculture. Domestic wild capture production is limited by the productive capacity of US fishing grounds. Although rebuilt US commercial fish stocks may provide some increase in supply, most commercial species in US waters are exploited near long-term maximum sustainable yields (National Marine Fisheries Service (NMFS) 2012). US aquaculture production has declined in recent years; and there are few signs of significant movement on the policy and regulatory obstacles to expanded US aquaculture production. Unless the US changes direction, the nation will likely rely even more on imported aquaculture in the future to satisfy the demand of a growing and health-conscious population for seafood. If the price of imported aquaculture products rises due to increased demand for seafood elsewhere in the world, US consumers may shift to cheaper sources of protein.

Some aquaculture imports can be viewed as part of the broader supply chain of the US seafood industry: US investment, equipment, technology, feed, and food service companies participate in aquaculture production in other countries. But what is missing is the local US production component that creates jobs in coastal and agricultural communities, helps to maintain working waterfronts, and provides testing grounds for new technologies. And although imports are required to meet US food safety standards, seafood grown in the US is produced under stringent and transparent US federal and state environmental laws that do not have counterparts in all other seafood producing nations.

In this paper, we examine the implications of two possible future paths for seafood supply: a continued and perhaps increasing reliance on imports, and a shift toward increased domestic production through growth of US aquaculture. We examine global trends that frame the question of future US seafood supply, likely future developments in US seafood demand and supply, US seafood trade, and implications of the path of US aquaculture development for US seafood supply and prices, employment, ecological footprint, and seafood supply security and safety. We conclude with general recommendations for a path forward that serves the interests of the nation and the global community in the search for economically sound and ecologically sustainable ways to feed a growing population.

2. Global Trends in Seafood Supply and Consumption

From 1950 to 2010, global seafood supply increased steadily from 6 to more than 18 kg/person/year (Food and Agriculture Organization (FAO) 2012). Including seafood for non-food uses (that is, inputs to other production processes, e.g. for animal feed), global production increased five-fold in the six decades to 2010. Since the 1980s, when global production from wild capture fisheries reached a plateau, all of the increase has come from aquaculture (FAO 2012). Today, global aquaculture production accounts for about 50 million of the 125 million metric tons of seafood produced annually for human consumption. The farmgate value of global aquaculture production today is about the same as the value of global capture fisheries production, each around $100 billion/year. Seaweed harvested for human consumption contributes an additional volume and value equivalent to approximately 5% of finfish and shellfish production. It is possible that this may increase in market share and importance in the future.

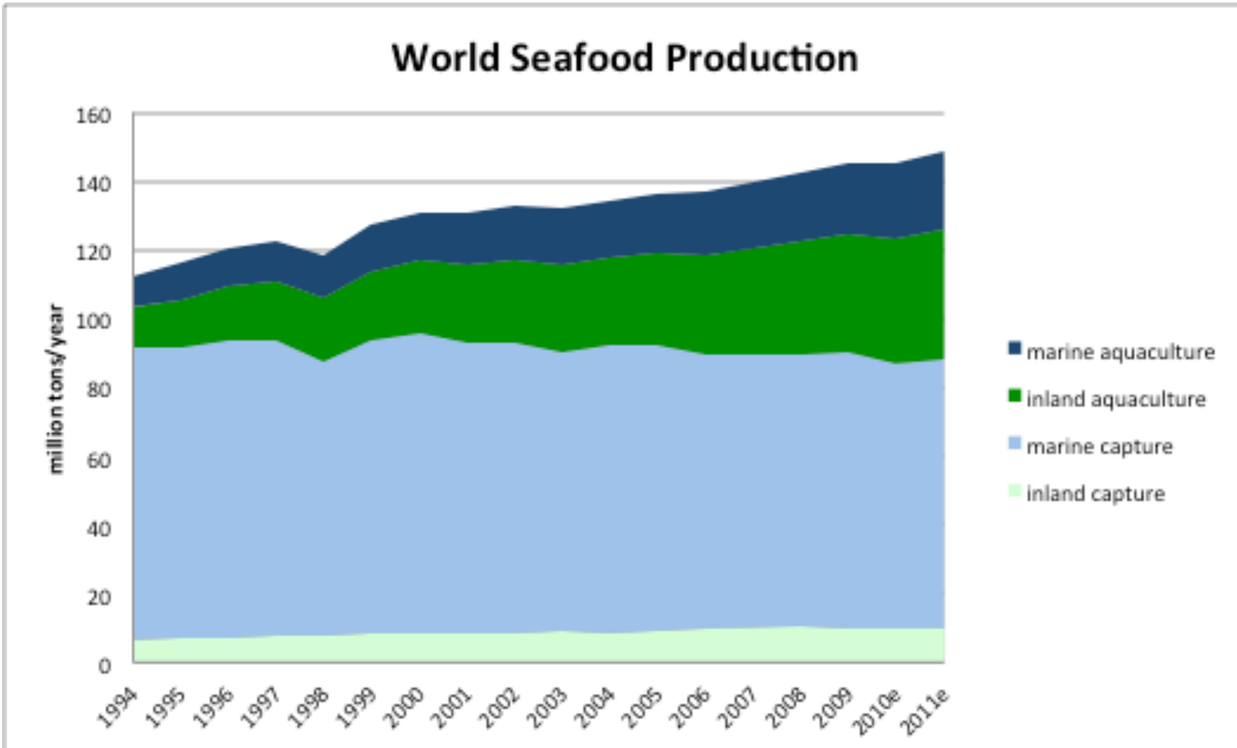


Figure 1: World seafood production. Source: FAO (various years).

Global aquaculture production (excluding aquatic plants) has been dominated by fresh water culture of finfish such as carp and (more recently) tilapia, primarily in Asia (FAO 2012) (Figures 1 and 2). Fresh water culture of finfish and shellfish accounts for about 20% by weight of global seafood production, and salt and brackish water aquaculture accounts for about 12% (more in value terms). Marine and diadromous finfish farming produces about 3% of global seafood supply, and represents 10% by weight and 20% by value of global seafood aquaculture output (excluding aquatic plants; Figure 2).

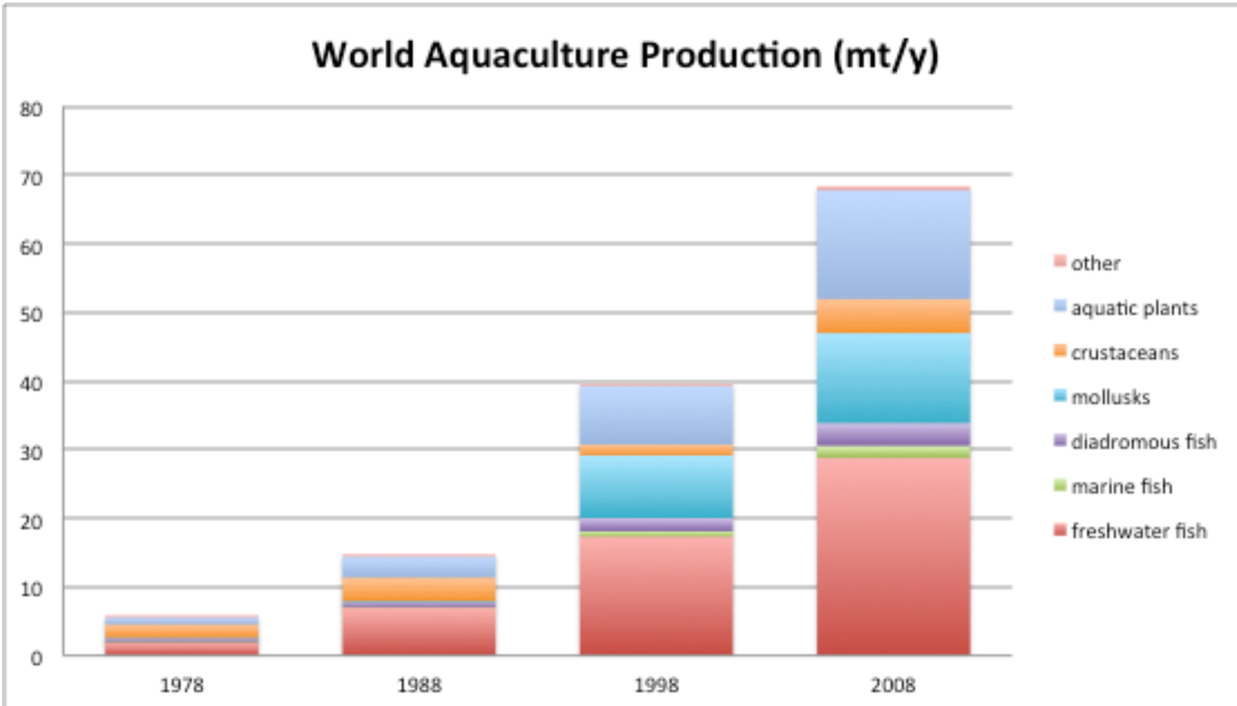


Figure 2: World aquaculture production. Source: FAO (various years).

Global population is projected to continue to increase from 7 billion in 2012 through most of the 21st century, and is projected to peak around 8.8 billion toward the end of the century (United Nations 2011). Seafood today makes up more than 6% percent of the global protein supply, and more than 15% of animal protein in the human diet (FAO 2012). Future increases in production of protein from terrestrial agriculture are likely to be modest due to limited availability of arable land and freshwater (Duarte *et al*. 2009). If per person seafood consumption doubles in the next 60 years (a more modest rate of increase than the last 60 years, and a possible scenario in light of ecological and health considerations, see below), this implies that global seafood production must at least double in the course of this century.

This kind of increase can only be achieved with aquaculture. Capture fisheries production has been shrinking slightly in recent years (Figure 3); and even with much better management, capture fisheries are not likely to be able to provide for more than a small fraction of future demand growth. Fresh water is expected to become an increasingly scarce and expensive commodity (Vorosmarty *et al*. 2000) as a result of climate change and demands from land-based agricultural production. There are signs that the strong growth in freshwater aquaculture of the past three decades is slowing in Asia (Figure 3), probably in part because most prime freshwater locations for aquaculture have been more or less fully exploited. It is likely, therefore, that future growth in aquaculture will have to look increasingly to marine locations and species and to culture of seafood in intensive tank systems on land.

In response to these demographic and supply drivers, many countries are moving to expand marine aquaculture. Countries such as Norway, Canada, Chile, China, Thailand, and Viet Nam already have significant marine aquaculture operations (e.g., salmon and shrimp). More recently, New Zealand, Brazil, Mexico, Morocco, and Saudi Arabia, and others have adopted aquaculture development plans or initiatives to attract private investment with the support of local governments under efficient permitting systems that include credible environmental and food safety safeguards.

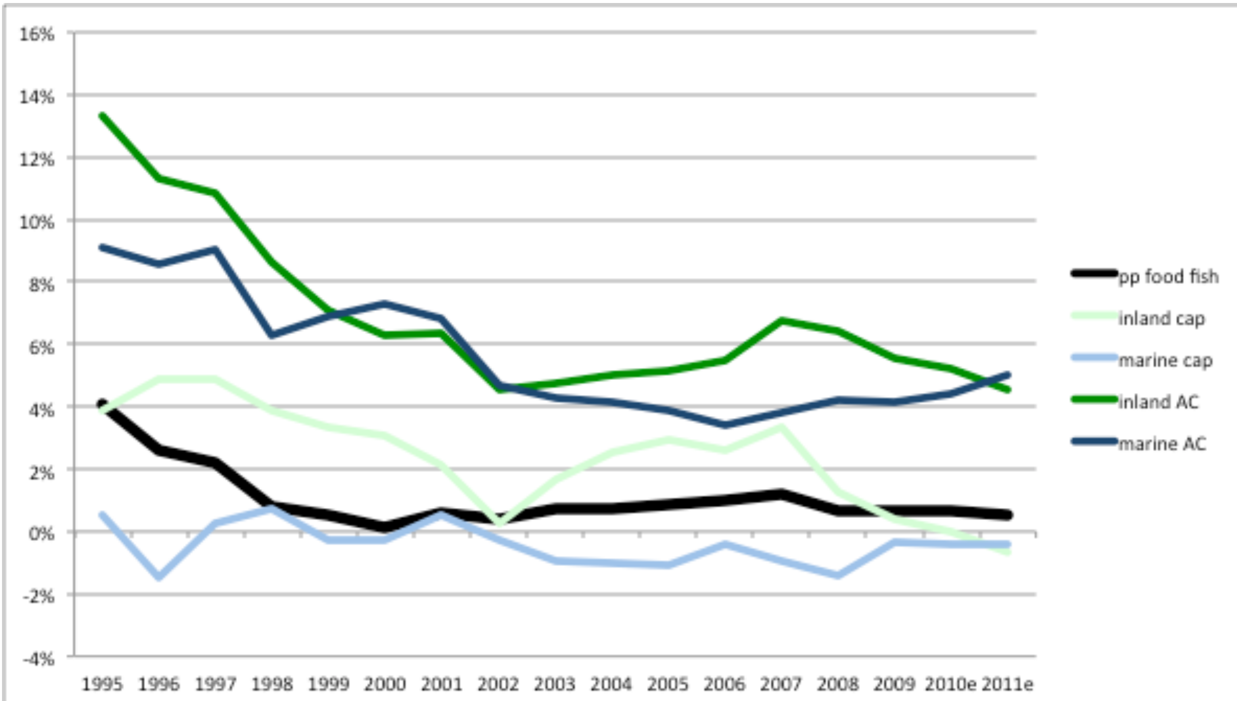


Figure 3: Smoothed annual growth rates of seafood consumption and production (5-year moving average). Source: FAO.

3. US Seafood Supply and Consumption

US seafood production (domestic landings from wild capture) has averaged around 4.5 million metric tons/year for several decades. Recently it dropped to under 4 million tons/year (3.7 million tons in 2010). Of this, about 3 million tons is for direct human consumption (half of this is exported), and the remainder is for industrial use (mainly fish meal and fish oil). US seafood production was valued at $4.5 billion (farm gate) in 2010 (NMFS 2011a), and accounts for about 3 percent of world seafood production. US wild capture fisheries production peaked in the 1980s along with global capture fisheries. Since then, increases in US demand for seafood have been met primarily by rising imports.

In recent years, the US has exported the equivalent of about 3 million tons/year, and imported more than 5 million tons/year (NMFS 2011a). Net supply (consumption) in 2010 was the equivalent of 5.6 million ton round (live) weight. This makes the US the third largest market for seafood in the world, behind Japan and China.

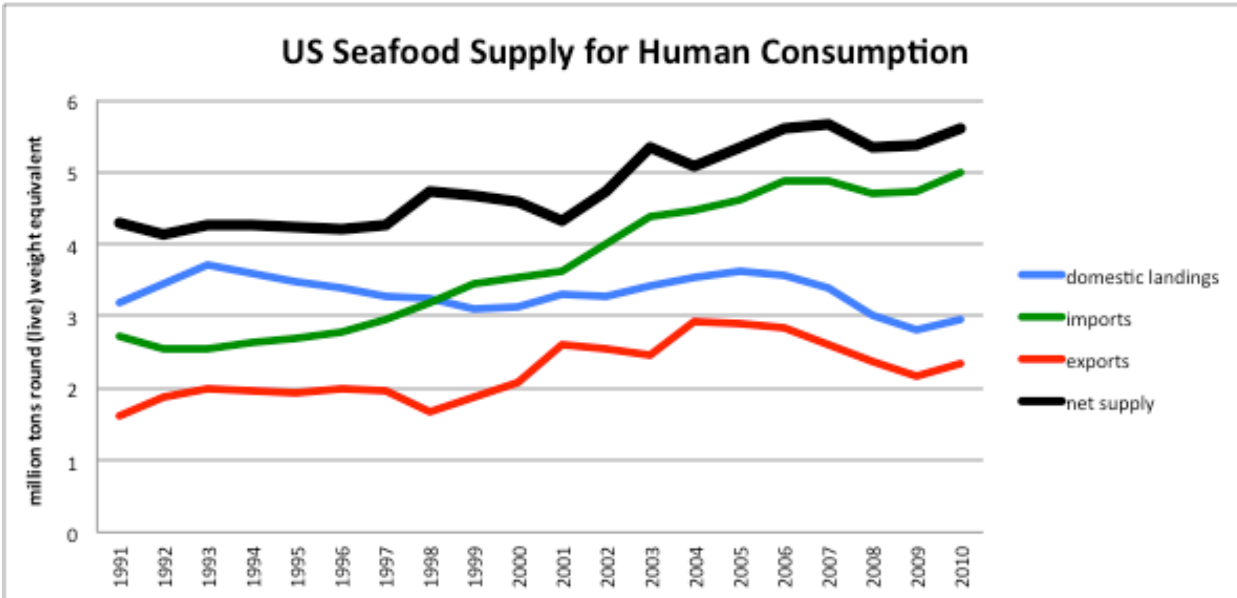


Figure 4: US seafood supply for direct human consumption, imports, and exports. Source: NMFS, 2011a.

US aquaculture production accounts for about 328,000 tons and $1.2 billion/year (NMFS, 2011a). A third of this (by value) is catfish. Salmon, tilapia, and trout are the other leading finfish species ($165 million). Another $311 million/year comes from mollusks (oysters, clams, and mussels) and crustaceans. In weight terms, US aquaculture production peaked in 2003 at just over 400,000 tons/year, and has been in decline since then, mainly because catfish production has fallen steadily (Figure 5).

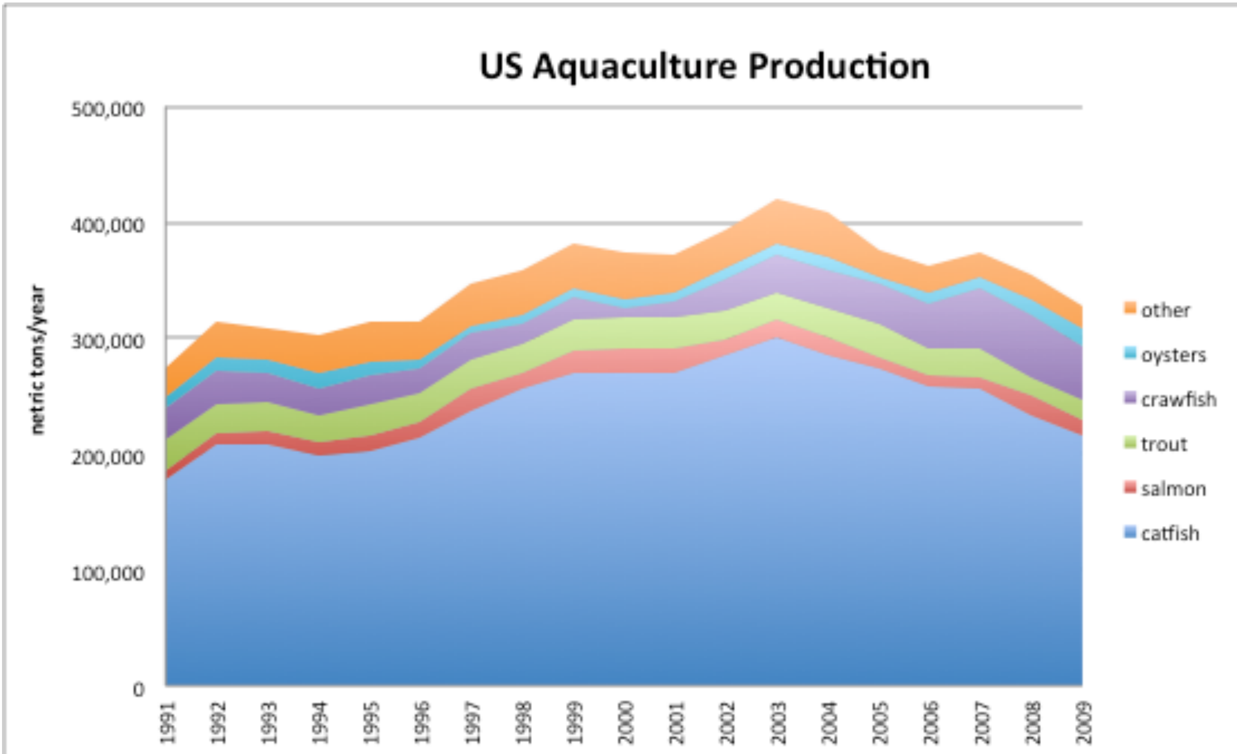
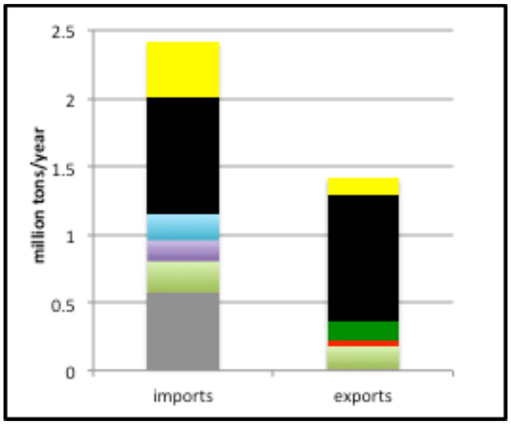


Figure 5: US aquaculture production. Source: NOAA.

In 2010, US seafood consumption was 15.8 pounds or 7.2 kg/person/year in edible weight equivalent terms, far exceeding domestic production, especially in species such as shrimp and salmon. Only about 15% of the seafood consumed in the US today is produced in the US – about 10% from wild capture fisheries, including hatchery raised and released Pacific salmon, and 5% from US aquaculture (NMFS 2011a). To make up the balance, the US imports about 86 percent of the seafood it consumes (by value), about half of that from foreign aquaculture production (NMFS 2011a); and these imports are increasing roughly with population growth. The US also exports about half of its wild catch of edible seafood and is one of the largest participants in the $100 billion/year global seafood trade. Some of these exports are processed and imported back into the US (reliable figures on re-imported product are difficult to estimate). US consumption per person has been rising more slowly (average 0.5%/year) in the past two decades than global consumption per person (1%/year).

US seafood exports include groundfish, flatfish, and canned seafood products. In 2011, imports included 575,000 tons of shrimp, 229,000 tons of salmon, and 622,000 tons of fresh and frozen fillets (Figure 6).



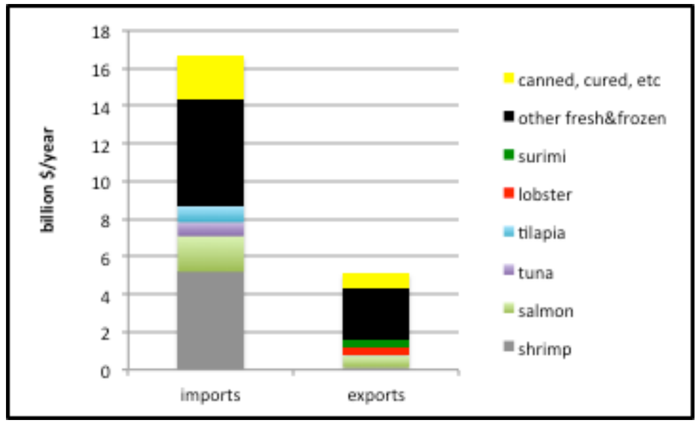


Figure 6: US seafood trade, edible seafood products, 2011. Source: NMFSb,

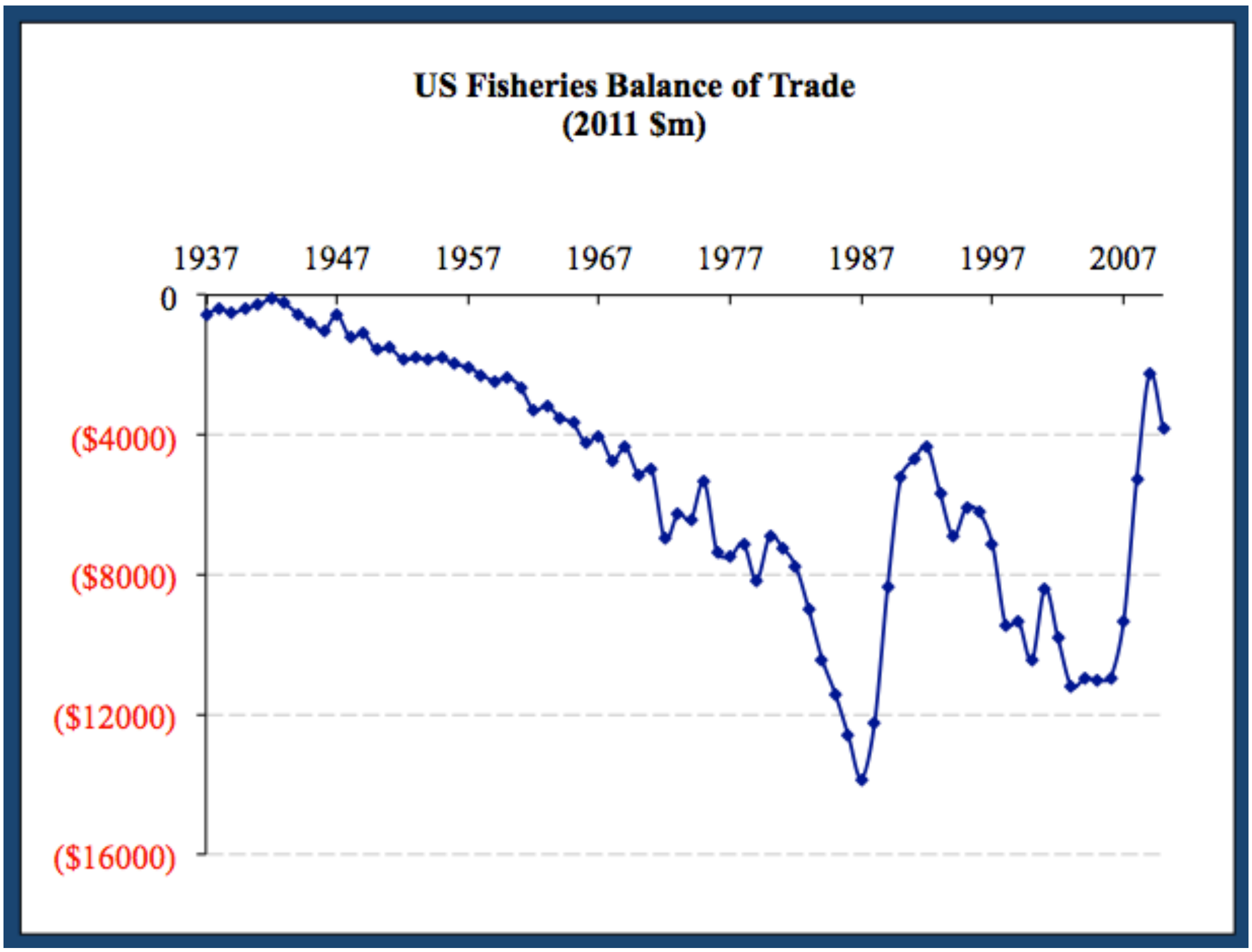


Figure 7: US seafood trade deficit. Source: US Bureau of Census.

To put the US seafood trade deficit in context, it is useful to compare it to US trade in agricultural products, where the US is a net exporter. US agricultural exports in 2010 were valued at $115.8 billion and imports at $81.9 billion, for a net trade surplus of $33.9 billion (US Department of Commerce 2012).

Given projected population growth for the US from 310 million (2010) to 440 million (2050), and assuming a stable per person seafood consumption rate, we can project that the US will need at least another 2 million tons/year of seafood by 2050, and perhaps twice that by the end of the 21st century. If health and ecological considerations lead over time to a doubling in US per person consumption of seafood – something that the US government is actively encouraging (United States Department of Agriculture 2011) – this would result in an annual increase in per person consumption of 1.5% (three times the recent US consumption growth rate) and require an additional 10 million tons by 2050 and perhaps 15 million tons by the end of the century (Figure 8).

For the world as a whole, continued per person consumption growth at recent rates (1%/year) suggests a doubling of global edible seafood production by the second half of this century (Figure 8). Both the US and the world as a whole will need a lot more aquaculture production.

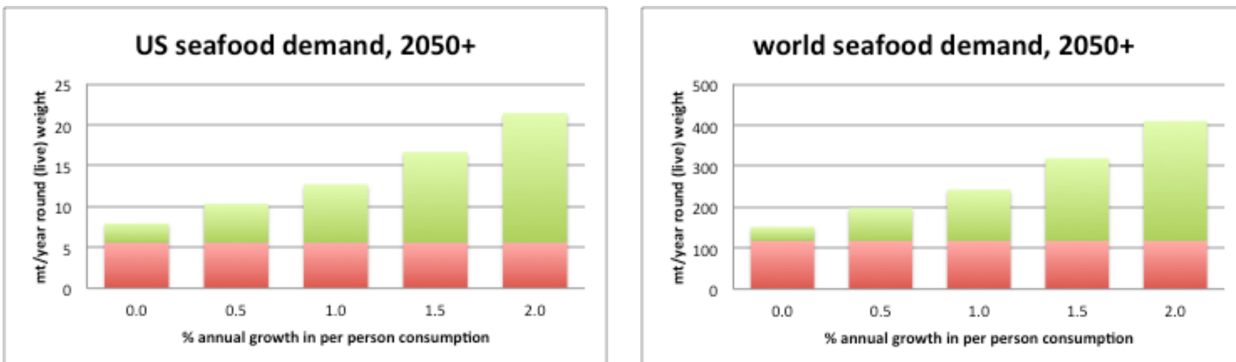


Figure 8: Projections of US and world seafood demand in second half of this century. 2010 consumption level is shown in red; future increase in green.

4. Implications of Alternate Future Paths

What are the implications of continued reliance on imported seafood and a decline in US aquaculture production? Should we care about the seafood trade deficit? There is no immediate threat of a supply constraint: US consumers have access to a wide variety of seafood at supermarkets and restaurants. In the context of US trade overall, seafood trade is not significant; and the US seafood trade deficit represents only about 1 percent of the total US trade deficit (which is dominated by petroleum, consumer goods, and industrial supplies). Eliminating the seafood trade deficit would not materially change the US balance of trade.

The US seafood and aquaculture industries are part of a larger global seafood supply chain. Some US seafood imports are produced in other countries with significant US inputs: US investment, equipment, technology, feed, and food service companies participate extensively in global aquaculture production. This global trade supports US jobs, investment income, and foodservice companies. For example, China imports over 6 million metric tons/year of US soybeans for aquaculture production (Cremer 2011).

Trade is a source of economic value, and it is sensible for the US to import seafood that can be produced or processed more efficiently elsewhere (in fact, the US exports nearly as much (unprocessed) Pacific salmon as it imports (processed) farmed Atlantic salmon.) In general, it makes economic sense to let the market sort out what should be produced where.

But there are other, perhaps more important, reasons to consider whether the US should take steps to increase domestic aquaculture production: employment and economic activity, availability and price of seafood (food security), the health of US consumers, and ecological footprint.

4.1. Employment and Economic Activity

Although a wide variety of US companies participate in the global seafood and aquaculture industry, what is missing is the local US production component. Local production creates jobs in seafood communities (some hard hit by the loss of fishing jobs), helps to maintain working waterfronts, and provides testing grounds for new technologies. US seafood companies with processing and distribution infrastructure in the US may benefit from near-by sources of supply.

In the US aquaculture industry today, direct farm employment is about 1 full-time job equivalent per $100,000 in farm production. Another 2-3 jobs are created per $100,000 in farm production in indirect and induced economic activity that supports farming, according to one estimate based on bio-engineering and input-output models for five species (Kirkley 2008). Other studies cite higher multipliers (for example Dicks *et al*. 1996). Depending on whether incremental US aquaculture production displaces imports or is exported, it can also support additional jobs in the processing, distribution, and retail sectors. Significant expansion of US aquaculture production could realistically create several 100,000 new jobs in the United States. Estimated direct employment in fisheries and aquaculture ranged from 5 to 50 jobs per thousand metric tons in over dozen studies summarized by Knapp (2008). Knapp estimated that a doubling of US aquaculture production (another 500,000 metric tons/year) would create an additional 50,000 jobs assuming 20 direct jobs per 1,000 metric tons produced and five total jobs for each direct job. Increasing US aquaculture production is not a cure by any stretch for the nation's current employment problems; but it could be significant for coastal communities, particularly those affected by downturns in fishing or other sectors.

Perhaps as significant as direct employment effects associated with seafood production and processing in the U.S. could be the support that a thriving US aquaculture industry would provide for US companies that supply equipment, technology, and services to the global aquaculture industry. Even without significant US aquaculture production, US research and technology development has played a key role in advancing global seafood farming in recent decades. The development of high health shrimp broodstock, submersible offshore cages, alternative feed formulations, and closed recirculating systems are some of the products of US research (Browdy and Hargreaves 2009). Thus, an argument can be made that we need to have some US aquaculture production as a platform for technology development that support the role of US companies in the global aquaculture industry.

4.2. Availability and Price of Seafood

The availability and price of US seafood will depend on many factors, including cost of production, technological change, prices of competing proteins, and consumer demand in the US and elsewhere. Two key factors are likely to affect supply and price in the US (in different directions): technological change and the rise in consumption of seafood in other countries.

Most of the seafood consumed in the US today is, like salmon, traded in international markets; and marginal increases in production from US aquaculture are not likely to change international supply or prices very much. So while US aquaculture production could increase the global supply of seafood, its effect on the prices US consumers pay would likely be limited.

The transition to farmed seafood production has increased global supply and lowered prices for species such as salmon and shrimp that are farmed on large, efficient scales. For example, from 1990 to 2007, US salmon consumption more than doubled due to the availability of farmed imports, while average price declined by more than 50% (Knapp *et al*. 2007; Asche 2008; Valderrama and Anderson 2010). This is consistent with economic theory – accumulated experience with large-scale production raises efficiency and lowers production costs; and increased supply enables markets to expand while lowering consumer prices. Lower seafood prices benefit consumers by making a healthy source of protein more easily accessible to the average family.

We are just at the beginning of the cost efficiency curve for most aquaculture products. Work in the fields of genomics, genetics, feed delivery, and aquatic health management, for example, will likely lower the unit costs of aquaculture production as it has done for poultry during the last century (Shamshak and Anderson 2008). The cost of production will likely come down significantly for species that receive research attention and industry investment in large-scale production systems.

Another important factor, now recognized by US seafood and food service companies, is the rise in seafood consumption in other countries, especially by the fast growing middle class in Asia. China, for example, may soon be a net importer of seafood. China is already the third largest importer of seafood products (FAO 2012) after the US and Japan. As the middle classes grow in Asia, the seafood the US now imports from Asia may stay in Asia and may not be available to US consumers, or available only at higher prices.

4.3. Ecological Footprint

An environmental argument can be made for growing more seafood in the US. Apart from being good for human health (see below), increasing the amount of seafood in the human diet is likely to be good for the planet, especially in an era of increasing resource constraints and concern over carbon emissions. Aquaculture is increasingly recognized as one of the most resource efficient ways to produce protein. And although imports are required to meet US food safety requirements, seafood grown in the US is produced under stringent US federal and state environmental laws that do not have direct counterparts in all other seafood-exporting nations.

When evaluating the environmental sustainability or ecological footprint of aquaculture, the main issues are related to resource efficiency (i.e., comparison to terrestrial animals, use of forage fish in feeds, and space utilization) and to environmental effects (waste, genetics, aquatic health, and effects on marine mammals and birds, as well as the potential to introduce non-native species).

A report by the World Fish Center and Conservation International (Hall *et al*. 2011) and previous studies (Bartley *et al*. 2007, Torrisson *et al*. 2011, Brooks 2007) indicate that aquaculture is one of the most efficient ways of feeding people with animal protein. Fish are extremely efficient at producing edible products from feed. Because most fish do not need energy to maintain body temperature, and live in an environment that supports their weight against gravity, they require less food energy and a smaller skeletal system to grow and survive. This translates into more energy and protein available for muscle growth. For example, Hall *et al.* (2011) compared the protein efficiency of different animal food producing sectors and found that carp had high protein conversion efficiency (30%) relative to land animals (5-30%). Torrisson *et al*. (2011) point out that Atlantic salmon may be the most efficient domesticated farm animal, as 100 kg dry feed yield 65 kg of Atlantic salmon fillets, compared to only 20 kg of poultry fillets or 12 kg of pork fillets. Other fish species such as cod, cobia, and tilapia yield 30% less than salmon but are still superior on this measure to land based protein. The efficiency of aquaculture makes it an increasingly attractive way to fulfill human nutrition needs.

Comparing the resource efficiency of fish farming to terrestrial farming or to wild capture fisheries is difficult and the subject of much recent research, e.g. on life cycle costing. Although it is difficult to generalize from the studies published so far, by some calculations fish farming imposes lower resource costs on the planet than most other sources of animal protein in the human diet. For example, farmed salmon produces between 1.2 and 2.1 tons of CO_2 emissions per ton of food, compared to 3.2 tons of CO_2 per ton for pork, 14.5 for feedlot beef, and 18.5 for sheep (Pelletier and Tyedmers 2007; Troell *et al*. 2004; Tyedmers *et al*. 2005). When salmon is raised on a reduced fish meal/fish oil diet (1.2 tons of CO_2/ton), it compares favorably with capture fisheries (1.7 tons CO_2/ton) (Pelletier and Tyedmers 2009). Only poultry (1.1 tons CO_2) and plant-based food (corn, 0.4 tons CO_2) are less carbon-intensive that efficiently farmed seafood – and some types of farmed seafood, such as marine shellfish on longlines and extensive freshwater pond culture of carp and tilapia, can rival wheat and corn in the efficiency of energy to protein conversion (Troell *et al.* 2004; Tyedmers *et al*. 2005).

In terms of biotic resource use efficiency, farmed seafood is also less resource-intensive than capture fisheries. Comparing feed efficiencies (and fish in to fish out ratios) of various species is difficult, and results depend heavily on the methods and assumptions used. By one estimate, carnivorous finfish in the ocean require about 10 kg of food fish to produce one kg of their own body mass (Pauly 1996). By contrast, most farmed finfish require about one to four kg of food fish input to produce one kg of body mass (Tacon and Metian 2008; Naylor *et al*. 2010; Jackson 2010; Torrisson *et al*. 2011; International Fish Meal and Fish Oil Organization 2012). This more efficient food conversion is due to the fact that aquaculture diets for farmed fish are formulated for maximum feed conversion, and that farmed fish do not have to expend energy hunting for their food. In ecological terms, farmed salmon by one estimate require between 8.1 and 13.7 tons of net primary production (phytoplankton) per ton of seafood output, compared with 32.8 tons for capture fisheries (Pelletier and Tyedmers 2007). Cultured mollusks and seaweeds are arguably more resource efficient than finfish. These species do not rely on prepared feeds and remove nutrients from the water, thus creating net positive ecological side effects (Shumway 2011). This topic of feed conversion and ecological efficiency is complex and deserves more research attention; but the evidence so far suggests that farmed seafood is an ecologically efficient way to produce protein for the human diet.

But how significant is the ecological cost of transport if the seafood is produced far from the centers of consumption (see Tlusty and Lagueux 2009)? Modern transportation, especially transportation by ship, is extraordinarily efficient, and supports much of the wealth that has been created in trading nations in the course of the last 200 years. Transport by freezer ship from Asia to the US adds only about $0.10 to the cost of a pound of seafood; the equivalent for fresh seafood transported by air is $0.75/lb. This means that transport costs are only 5-10% of US seafood import value, and sets a high standard for production efficiency for US fish farmers who want to compete with foreign producers.

All human activities have environmental effects; and aquaculture has the potential to create negative environmental impacts in the form of pollution, disease transfer, and genetic effects of aquaculture on environment or wild species. These issues have been addressed in a number of recent studies (Hall *et al*. 2011; Duarte *et al*. 2009; Diana, 2009). In the course of the past decade, management practices have been developed for responsible aquaculture that minimize or eliminate many potential negative environmental effects (Hall *et al*. 2011); and some forms of aquaculture, such as bivalve shellfish farming, generally have benign or positive ecological side effects (NRC 2010). This does not mean that responsible practices are used everywhere. But countries like the United States have explicit and transparent state and federal regulatory requirements designed to address environmental effects, as well as the enforcement mechanisms to back them up (Cincin-Sain *et al*. 2001, Stickney and McVey 2002, Tucker and Hargreaves 2008).

All of this means that if we want to increase the resource efficiency and ecological sustainability of global food supplies, it will be beneficial to increase the global seafood supply. There is no better way for the US to advance this cause than by developing the knowledge and technology for seafood production at home, in an environment that is supportive of innovation and features strong environmental, ecological, and human health safeguards and regulations.

4.4. Human Health and Seafood Safety

Diet plays a large role in human health. Among the US population, poor diet and lack of exercise have led in the last 40 years to an "epidemic of overweight and obesity" and increased prevalence of diet-related health problems that include cardiovascular disease, hypertension, diabetes, cancer, and osteoporosis (US Department of Agriculture (USDA) 2011). The economic cost of health effects related to US diet have been estimated at more than $70 billion/year (Frazao 1999), the equivalent of about 5% of total US spending on health costs.

Problems in the present US diet include excess amounts of fats and sugars, and a combination of protein sources that includes five ounces of red meat and three ounces of poultry for every ounce of seafood. The US government's most recent dietary guidelines (USDA 2011) include a specific recommendation to “[i]ncrease the amount and variety of seafood consumed by choosing seafood in place of some meat and poultry” and set a goal of roughly doubling the average intake of seafood in the US diet. This change would bring US consumption of seafood in line with the global average.

There are health risks associated with seafood consumption as well, but the cost of these risk is probably an order of magnitude smaller than the benefits. Mozaffarian and Rimm (2006) reviewed numerous studies and concluded that the benefits of seafood consumption far outweigh the risks. Hibbleln *et al.* (2007) found beneficial child development effects from increased seafood consumption. Ralston *et al.* (2012) estimated the acute health costs due to consumption of contaminated seafood in the US at $660 million per year. It is not known what fraction of these costs arise from imported as opposed to domestically produced seafood; but questions remain about feed content, additives, and water quality used in the production of some imported seafood; and inspection of imports is limited (Government Accountability Office, 2011). The US seafood industry has made extensive investments in seafood quality control in the US, and works closely with overseas partners to ensure quality of imports. Nonetheless, part of the cost advantage enjoyed by seafood producers in other countries may be due to less stringent environmental and food safety regulations than those facing US producers. From 2006 to 2011, the European Union issued some 335 alerts regarding seafood product imports from China that did not meet EU food safety standards (Blomeyer *et al.* 2012).

5. Increasing US Aquaculture Production

Increasing US aquaculture production was articulated as a national goal by the US Congress in the National Aquaculture Act of 1980 and in several subsequent federal plans, including the US Commission on Ocean Policy in 2004 and the 2011 aquaculture policies of the US Department of Commerce (DOC) and National Oceanic and Atmospheric Administration (NOAA).

Increasing US aquaculture production is technologically feasible. The US has the necessary natural resources, a long coastline, plentiful agricultural products, and 40 years of experience with aquaculture production systems. Nash (2004) examined existing technologies, available sites, and plausible scenarios to project species-group-level production targets for expanded US aquaculture production. These included 760,000 metric tons of finfish, 47,000 metric tons of crustaceans, and 245,000 metric tons of mollusks. At this point, Nash’s plans for increased production of about 1 million metric tons of live weight imply a tripling of present US aquaculture production. Given recent trends, this seems ambitious.

Several factors account for the lack of growth in US aquaculture production, including (Tiersch and Hargreaves 2002; Marine Aquaculture Task Force 2007; Rubino 2008; Browdy and Hargreaves 2009; Chu *et al*. 2010; Boulet *et al*. 2010; Forster 2010; Getchis and Rose 2011; Nash 2011):

- limited possibilities for freshwater pond production due to water supply constraints and high value alternatives for use of agricultural land;

- difficulty in securing access to sites in coastal and marine waters due high levels of use conflicts (coastal land and waters are heavily used for tourism, recreation, real estate development, and other purposes that are seen to conflict with aquaculture);
- high cost of production in recirculating systems;
- complex, uncertain, overlapping, time consuming, and costly regulatory requirements; and
- opposition from some fishermen and environmental organizations to aquaculture.

Limits to pond culture: US aquaculture production has declined slightly in recent years (NMFS 2011), largely because catfish production is down in the face of low-cost Asian competition, increased cost of feed (due to higher corn and soybean prices), and higher value uses of land such as farming soybeans (The Fish Site 2009).

Limits to marine aquaculture: US seafood purchasing trends indicate there is an increasing demand for marine aquaculture products (fish, shellfish, and seaweed). But nearshore marine locations along much of the US coast have water quality issues, use conflicts (such as tourism and real estate development), and space constraints that may limit coastal aquaculture development potential (Cicin-Sain et al 2001; Rubino 2008). Coastal use conflicts occur in some other parts of the world as well. Nearshore challenges have prompted some to seek sites further offshore (Corbin 2010; Benetti *et al.* 2010). For US federal waters (three to 200 miles offshore), however, the federal government has yet to adopt clear rules and regulations for leasing and permitting of aquaculture operations.

High cost of recirculating aquaculture: Obtaining acceptance from neighbors and permits to grow seafood on land in tanks (partially or fully closed systems that recycle water) may be easier than obtaining permits for a site in public state or federal waters. But the high cost of operating on-land systems (see Summerfelt and Vinci 2008; Boulet *et al*. 2010) so far limit their financial viability to high value species aimed at the white table cloth restaurant market, or ethnic markets seeking live fish. Costs of closed systems are likely to come down in future years as technology and operational experience improve.

Inefficient regulations: Environmental laws and regulations serve important conservation mandates. But numerous and overlapping local, state, and federal regulations, including environmental regulations, have created a costly and uncertain regulatory process for aquaculture in the US (NRC 1978; Jensen 2007; and NRC 2010). For US federal waters (three to 200 miles offshore), the federal government has yet to adopt clear rules and regulations for leasing and permitting of aquaculture operations.

Some government agencies are working to make the process more efficient while still maintaining their stewardship missions. Several states, for example, have created "on stop permit shops" where a lead agency works with permit applicants and coordinates the state and federal permit process.

Access to sites, especially in public waters, also depends upon local, state, and federal zoning and use priorities. The development of aquaculture will be facilitated if local, state, and federal marine resource management plans, laws, and regulations recognize aquaculture as a legitimate or priority use of coastal and ocean space alongside other new and established marine activities, and provide access to appropriate areas for aquaculture development, where this makes economic sense, under reasonable lease and permitting terms.

Opposition by some fishermen and environmental organizations to aquaculture: For some fishermen (and existing aquaculture producers), additional aquaculture production represents unwanted competition. For example, Alaska has banned finfish farming, in part to protect the existing wild and hatchery-based salmon harvest (Knapp *et al*. 2007). Environmental groups and others have raised concerns about environmental impacts from aquaculture (Clay 1997; Naylor et al. 2005). If US seafood production is to be increased, these fishing and environmental concerns will have to be addressed. One promising direction is the search for common ground among the aquaculture industry, seafood processors, fishermen, and environmental organizations (Costa-Pierce 2010; Tlusty 2012). As the US salmon market has shown, it is possible for wild capture and aquaculture product to co-exist in the US seafood market (Knapp *et al*. 2007; Valderrama and Anderson 2010). Similarly, as increasing the share of cultured seafood in the human diet is understood to have ecological advantages and to confer human health benefits, it may be possible for the seafood industry and consumer and environmental groups to find common ground on expanding aquaculture production, using species and farming techniques that are environmentally sound and socially acceptable.

6. Summary

In the course of the 21st century, we will likely have to increase production of seafood for human consumption by at least 40 million tons/year just to maintain present per person consumption levels. That number will be significantly higher, perhaps over 100 million tons/year, if per person consumption of seafood increases – a scenario that we consider to be likely. In the context of growing concerns over unhealthy diets, carbon emissions, and resource constraints facing fresh water supply, arable land, and agricultural production, increased reliance on seafood would have positive ecological and human health consequences, and may well be promoted by public policy. For example, if US consumers increase their seafood consumption as recommended by the US government guidelines, the US alone will require an additional 10 million tons per year by the end of the century. These increases in seafood supply can only be achieved with significant aquaculture in the mix; and in light of increasing constraints on fresh water supply, marine aquaculture is likely to play a major role.

The US can obtain additional seafood from a combination of increased domestic production and imports. Regardless of the source, the incremental supply will mostly be farmed. If the US chooses to increase domestic seafood production, a number of positive consequences are possible:

- potentially hundreds of thousands of new jobs in seafood farming, processing, and supporting industries;
- strengthened US role as a leader in technology and science to support the global aquaculture industry that will provide the protein for an increasingly crowded and hungry planet;
- stronger ability for US to help develop best practices for ecologically and environmentally sound seafood production; and
- reduced seafood trade deficit through greater exports and perhaps reduced imports.

To accomplish this, it will be necessary for US federal, state, tribal, and local governments to develop more efficient or streamlined processes for permitting and access to sites for seafood farming without compromising environmental quality. That, in turn, will require a new kind of partnership between the public, government, industry, and environmental groups for the governance of aquatic resources supporting for aquaculture production. For example, in Maine, culture of salmon, oysters, and mussels has increased and culture of cod and seaweed started thanks to a combination of efficient permitting, state support for aquaculture development, and political and social support from coastal seafood communities (Morse and Pietrak 2009).

US seafood supply can develop along a spectrum of possible paths in the course of this century. At one extreme, the US can continue on its recent course of gradual decline in domestic production, and growing reliance on imports – perhaps more than doubling net import volume in the course of the century. At the other extreme, the US can actively pursue policies to foster increased aquaculture onshore and in coastal and federal waters, leading to greater US seafood production for domestic consumption and export, and a reduction in the seafood trade deficit. Such a course would not eliminate all US seafood imports – US aquaculture would have to focus on species for which it can compete effectively, and these are unlikely to include shrimp, for instance – but it could boost exports and reduce some categories of imports. With the exception of catfish, US producers currently focus on high value, fresh and live, niche markets, where they have a competitive advantage from lower shipping costs and quicker time to market than most imports. Some high-value fresh US product such as geoduck, oysters, and other shellfish also ship to Asian markets; but for the foreseeable future, most future increases in US aquaculture production are likely to target domestic markets.

Our present reliance on imported seafood is at least in part a consequence of choices we have made to give preference to other uses of coastal waters. If we change our priorities, the US can easily produce much more seafood in our coastal waters than we do today. Nash (2004) estimated that the US could produce 1 million tons, most of it marine (including salmon), using a tiny percentage of its marine/coastal waters.

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