CHOICES

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Theme Overview: The Economics of U.S. Aquaculture

Trey Malone and Richard T. Melstrom

JEL Classifications: Q02, Q13
Keywords: Seafood, Food production, Imports

Though the global seafood market has increased dramatically in size over the past few decades, U.S. aquaculture operations meet only a relatively small portion of this burgeoning demand. Globally, about half of all seafood is now produced by aquaculture, making it a key source of income and food security for many countries. Aquaculture's contribution to U.S. domestic seafood production has increased far less rapidly, however, and currently sits at about 17% in terms of value and less than 10% in terms of weight as a share of total U.S. fish production (including mollusks and crustaceans). U.S. seafood imports have increased more rapidly than domestic aquaculture production in recent decades. Concerns about lackluster growth in domestic production and increasing import dependence culminated in a 2020 presidential executive order encouraging growth in U.S. aquaculture production.

This *Choices* theme covers ongoing social and economic issues in U.S. aquaculture. The authors are part of the Great Lakes Aquaculture Collaborative (GLAC), a National Oceanic and Atmospheric Administration and Sea Grant–funded project designed to disseminate relevant, science-based information that supports an environmentally and economically sustainable aquaculture industry in the Great Lakes region. As in the rest of the country, aquaculture producers in the Great Lakes region have struggled to develop at a pace that matches domestic seafood demand growth. A key objective for GLAC is to identify significant barriers to growth for a sustainable domestic aquaculture industry. Research by GLAC scholars will be of interest to stakeholders throughout the United States, and most of the papers examine social and economic issues in aquaculture through a national lens.

Concerns about the U.S. aquaculture industry are often motivated by questions about producing fish for food, but a large share of aquaculture production is not intended for food. Seilheimer, Wiermaa, and Jescovitch review distinctions between forms of wild-catch, aquaculture, and hatchery production. This article provides definitional clarity critical for understanding nuances in U.S. fish production.

U.S. seafood demand is dynamic, increasing steadily with population but shifting from tuna and cod to shrimp

Articles in this Theme:

and salmon, among other species, which the United States largely imports and to which aquaculture contributes substantially. Abaidoo, Melstrom and Malone compare growth in U.S. seafood consumption and aquaculture production to the rest of the world. Using production statistics dating back to the 1950s, their article documents the slow development of the U.S. aquaculture industry relative to the rapid expansion of U.S. imports.

Why the slowed growth? Some prior studies have indicated that regulatory burdens might play a critical role in hindering industry expansion. Indeed, industrialization and globalization have led to a mix of regulations, government advisories, and nongovernmental organization (NGO) programs focused on addressing environmental sustainability, animal welfare, food safety, and food traceability. Quagrainie and Shambach describe trends in production standards and certification programs used in seafood markets and aquaculture. Their article focuses on the rise of product labeling such as sustainability labels and organic certifications as a method for producers to educate and attract consumers.

What are the impacts of some of these labeling initiatives? Using data from a recent survey of consumers, Valle de Souza et al. describe consumer preferences for seafood in the United States. In addition to the importance of various product labels, their research provides insights into consumer preferences for different fish species, food-at-home versus food-away-from-home, and frozen versus fresh fillets. Although labeling is generally important to consumers, they find that consumers believed “wild-caught” and “farm-raised” to be the least important labels, behind those related to traceability, GMOs, and safety.

Complementing Valle de Souza et al.’s consumer research, Carlton, Shambach, and Hartenstine interview producers about the challenges of marketing farm-raised fish. Those interviewed describe the difficulties producers confront regarding pricing and regulations, which they found to be the most consistent challenges.

Finally, Staples et al. examine the U.S. aquaculture regulatory landscape by counting the number of restrictive words in federal and state laws linked to aquaculture. Their findings imply a need for nuance in understanding the role of regulatory burdens in aquaculture supply chains. This does not indicate that regulations are unimportant to the development of the aquaculture industry but rather that concerns about “over-burdensome” regulations are likely to require a deeper understanding of the costs and benefits to government intervention.

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The Economics of United States Aquaculture

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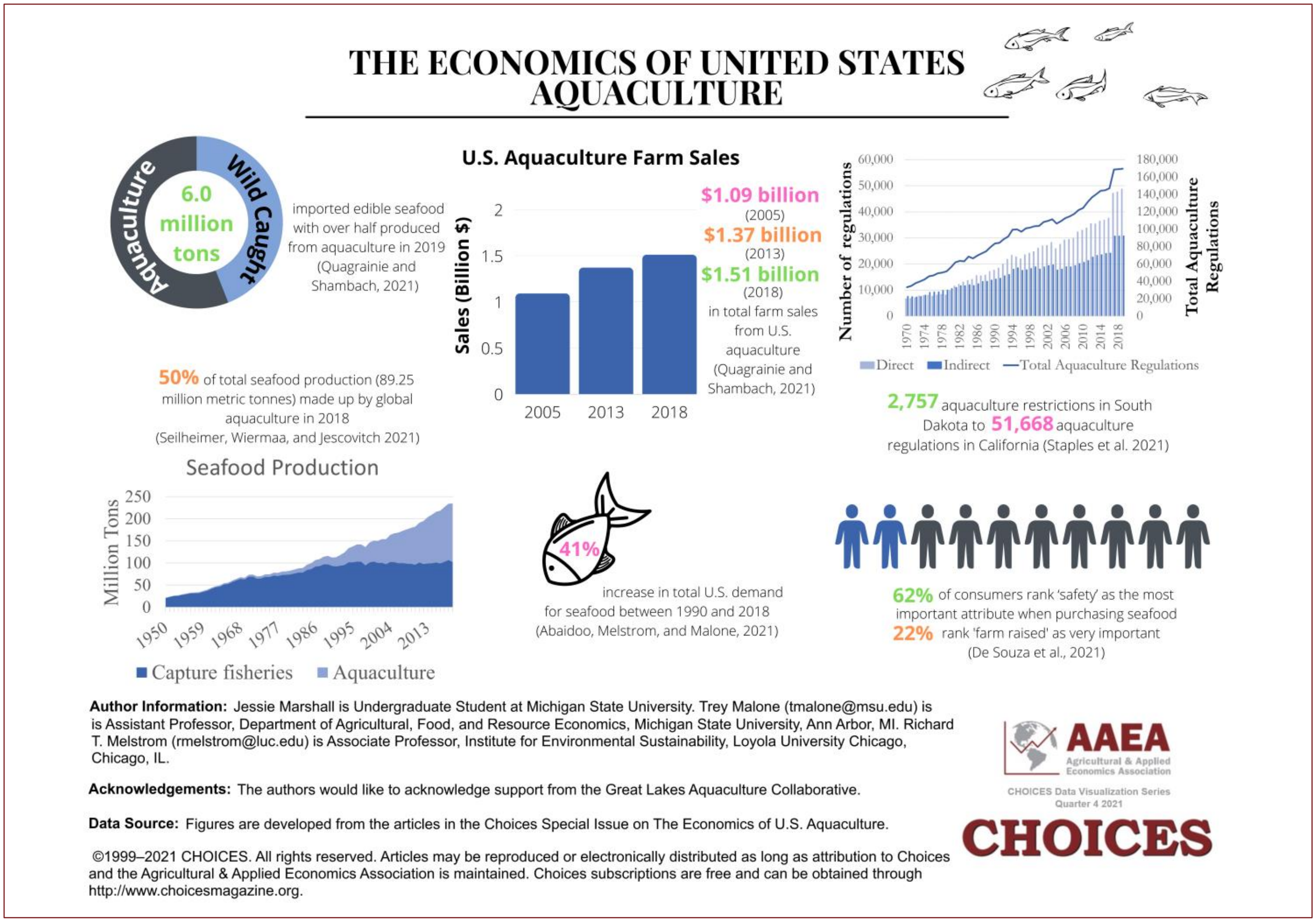
Background

U.S. seafood demand is dynamic, increasing by 41% from 1990 to 2018, and requiring 6 million tons of imported edible seafood by 2018. Indeed, about half of all seafood production comes from aquaculture production, making it a key source of income and food security for many countries. Aquaculture's contribution to U.S. domestic seafood production has increased to $1.51 billion in total U.S. aquaculture sales in 2018, though domestic production growth has lagged relative to the growth of imports. One possible reason for sluggish growth in aquaculture production is the number of regulatory burdens as the total number of regulatory restrictions in U.S. aquaculture supply chains has increased dramatically, with South Dakota having the fewest and California having the most. That said, regulatory burdens are likely to have their roots in environmental and food safety concerns, as 62% of consumers rank safety as the most important attribute when purchasing seafood while only 22% rank farm raised as very important.



Data Source

Figures are developed from the articles in the Choices Special Issue on The Economics of U.S. Aquaculture.

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Fisheries, Hatcheries, and Aquaculture—What's the Difference?

Titus S. Seilheimer, Emma Wiermaa, and Lauren N. Jescovitch

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Keywords: Aquaculture, Fisheries, Hatcheries

In 2018, global fisheries and aquaculture each made up roughly 50% of total seafood production totaling 178.5 million metric tons, with fisheries stable and aquaculture growing in proportion over the last thirty years (FAO, 2020). Fisheries and aquaculture can be classified as wild-caught and farm-raised, respectively. Although they are very different industries, fisheries and aquaculture often intersect in supply chains and can be collaborative in nature, such as in the regional foodscape. From a global and national perspective, Great Lakes fisheries and aquaculture are a fairly small player compared to much larger harvest volumes from coastal waters in regions like Alaska (NOAA Fisheries, 2021), but they continue to be locally, ecologically, historically, culturally, and economically important.

Fisheries (Wild-Caught Fishes)

The wild-caught fisheries sector includes the commercial, recreational, and charter industries. These types of fisheries are managed by state and provincial agencies as well as collaborations between states and tribal nations.

What Is Commercial Fishing?

Commercial fishing is the harvesting of fish from the wild in large volumes that can then be sold as a commodity (Figure 1), with harvesting methods depending on target species, best management practices, and regulations. The wide range of harvesting methods include entrapment (trap nets), entanglement (gill nets), and active (trawl nets). There are many pathways for these fish to be sold: direct to consumer or restaurant; wholesale to a processor for local, regional, or national sale; or exported internationally. Many Great Lakes commercial fishers are multigenerational small businesses that process their own fish and create value-added products. Common species harvested are lake whitefish and lake trout in the northern Great Lakes and yellow perch and rainbow smelt in Lake Erie.

What Is Recreational Fishing?

Recreational fishing is when individuals go out and catch fish for enjoyment, trophy, or subsistence fishing (Figure 2). Anglers—those who fish recreationally—are a major source of revenue across the Great Lakes region (not including the region's inland waters), where an estimated 1.8 million anglers spend $2.2 billion on trip expenses such as traveling, lodging, and equipment (U.S. Department of the Interior, 2016). The abundant waters in the region allow for diverse and varied opportunities for fishing, from perch to walleye to salmon.

What Is Charter Fishing?

Charter fishing and fishing guides (Figure 3) are services provided to individuals or small groups (clients) to take them fishing on Great Lakes waters or inland waters. Charter companies and guides provide the boats, all the required equipment, and expertise on the locations of targeted fish species to enhance their customers' fishing experience. Clients generally catch trophy or a large quantity of fish allowed by regulations; they may take the processed fish home or they can take the fish to restaurants that are part of programs like Michigan's Catch and Cook (https://www.michigancatchandcook.com/) and will cook it for them. Trips are generally half- or full-day excursions and are a popular choice for those new in an area who want to try trophy fishing.

What about Tribal Nations?

Tribal nations regulate and provide licenses to tribal members for commercial and subsistence harvest as well as ceremonial fishing (Figure 4). The Great Lakes has a substantial number of tribal commercial fisheries—especially in Lakes Superior, Huron, and Michigan—that are members of the Great Lakes Indian Fish and Wildlife Commission (GLIFWC; http://glifwc.org/) or Chippewa Ottawa Resource Authority (CORA; http://www.1836cora.org/). These ceded territories in the Great Lakes provide venues for various traditional harvesting methods including gill netting for commercial

Figure 1. Lake Whitefish Are Sorted from a Commercial Trap Net in Lake Michigan

Source: Wisconsin Sea Grant.

Figure 2. An Angler Holds a Brown Trout Caught in Milwaukee Harbor

Source: Wisconsin Sea Grant.

Figure 3. Charter Boat Customer Holding a Lake Michigan Salmon

Source: Wisconsin Sea Grant.

Figure 4. Tribal Commercial Gill Net Fishing Tug in Lake Superior

Source: Wisconsin Sea Grant.

fishing, ice spearing for lake sturgeon, and spear fishing for walleye.

Hatcheries

What Is a Hatchery?

A fish hatchery is aquaculture, or fish farming (as described below), which cultivates or grows aquatic animals in the early life stages (Figure 5). For most fish species, mortality can be very high in the first few weeks of life, so hatcheries can provide proper management conditions to improve survival during these times. The term "hatcheries" is commonly understood in the Great Lakes region as a culture system in which the end use of that fish is for stocking, or "planting" fish into a wild habitat as a natural resource initiative. However, hatcheries provide optimum growing environments for all fishes regardless of aquaculture systems or end uses; fish cultivated in aquaculture environments may be used for stocking, food, bait, or restoration efforts.

Tasks related to hatchery production include collecting gametes (eggs and sperm), hatching eggs, and growing larval fish through the early life stages. Eggs may be collected from captive or domesticated broodstock or from wild fish. Hatchery-raised fish may either continue to be raised in grow-out systems on the same farm, transferred to another system for grow-out, or stocked in natural waterways for conservation, restoration, or sport fishing end uses. Hatcheries may supplement commercial, recreational, or charter fishing fisheries by providing fish that can grow to catchable size in natural waters (e.g., Great Lakes Pacific salmon stocking by the states and provinces as fingerlings and yearlings), providing support to spawning stocks by enhancing their populations, or restoring species to areas in which they are no longer present or have experienced population declines (e.g., native mussel programs). In the Great Lakes region, there are many private, state (Department of Natural Resources), federal (U.S. Fish and Wildlife Service), and tribal hatcheries. Confusions within regulatory agencies and aquaculture associations are also amplified under the term "hatcheries," as many states legislatively began public aquaculture as a means for stocking under state departments of natural resources while private aquaculture began as a means for growing animals for food under the departments of agriculture. This distinction also contributes to the complexity in these industries' economic valuations.

Aquaculture (Farm-Raised)

What Is Aquaculture?

Aquaculture is the process of rearing and growing fish or other aquatic organisms by human interventions (regardless of system used or product end use).

Figure 5. Hatchery Tray with Larval Atlantic Salmon

Source: University of Wisconsin Stevens Point-Northern Aquaculture Demonstration Facility.

Aquaculture may also be called fish farming or fish culturing, and includes raising various fishes, crustaceans, bivalves, or plants (e.g., seaweed or kelp) in an aquatic environment. In addition to hatcheries, aquaculture can provide further control over environmental factors to enhance fish growth and survival. Generally, fish species raised using aquaculture are categorized into three groups based on their ideal temperature requirements for growth: cold water (e.g., trout and salmon), cool water (e.g., yellow perch and walleye), and warm water (e.g., catfish and tilapia). A region's water temperature is an important consideration when choosing the right species in terms of biology, survival, and costs. For an operation to be successful, it is crucial for aquaculturists (i.e., fish farmers) to fully understand the biological and environmental requirements of the species raised. This includes water quality (temperature requirements, biosecurity, and potential diseases), hydrology (flow rates and velocities), and feed and nutrition. Here, we highlight aquaculture as it pertains to raising fin fish, which are the most common sector of the aquaculture industry in the U.S. Great Lakes region.

Most aquaculture facilities in the United States are private businesses that grow fish as a primary or secondary source of income. Aquaculture facilities can also be public facilities such as hatcheries (described above) or farms utilized for educational or research purposes by schools, universities, and nonprofits. In general, private aquaculture businesses either raise fish for food, ornamental/pets, bait fish, or stocking (such as sportfish species in public or private waters). Besides the various species produced and end uses of aquaculture, these facilities can also have various scales of production intensification. Regardless of which system is utilized, it is important to fully understand permitting and regulations of each system regarding water usage and effluent (water leaving the facility). Here, we describe aquaculture from extensive to more intensive systems found in the U.S. Great Lakes region: ponds, raceways/flow-through systems, recirculating aquaculture systems, and aquaponics. We also touch on net pens; however, these are currently not being operated in U.S. Great Lakes waters.

Ponds

Fish production can occur in outdoor ponds either constructed specifically for aquaculture or in existing, natural ponds (Figure 6). Commercial production

Figure 6. Pond Growing Bluegill for Stocking in Michigan

Source: Michigan Sea Grant.

commonly utilizes constructed ponds with a collection kettle that allows the pond to drain and congregate the fish during harvest. Ponds are the most common production system around the world and are more forgiving in terms of risk and investment. However, ponds do require sufficient land and water surface area. Pond systems are commonly used to grow fish for stocking, bait, and food.

Raceways or Flow-through Systems

Raceways are a common type of flow-through system, in which water enters one end of a fish tank and exits the other end. (Figure 7). Older raceways are typically rectangular concrete tanks, while more modern flow-through systems utilize circular fiberglass tanks. Generally, raceways are either single pass or connect in series, where gravity and topography are utilized to drop water a few feet for re-aeration before flowing into the next raceway. Raceways are commonly used to grow cold-water species, such as salmon and trout, which typically require better water quality. Raceway systems can divert stream water into a facility and then discharge back into the same stream at a lower location. Artesian wells and groundwater are a more modern water source for raceways, as they can supply the large volumes needed for adequate flow and reduce the potential

Figure 7. Concrete Single Pass Raceways with Brown Trout at a Michigan Trout Farm

Source: Michigan Sea Grant.

environmental impacts. Due to the high water usage and nutrient discharges, these systems may require additional permitting and regulation costs. Raceways are common systems to grow fish for stocking and food.

Recirculating Aquaculture Systems (RAS)

A recirculating aquaculture system, or RAS, is a self-contained, indoor aquaculture system that can reuse over 90% of its water. These systems can also be highly customizable and optimized to meet various species needs (Figure 8). Water is recycled through various stages—including mechanical and biological filtration, oxygenation, and sterilization systems—before being reused in the fish tanks. RAS can provide numerous benefits including continuous market supply, enhanced biosecurity, increased optimization and control over the fish rearing environment, effective capture of waste, no interaction between farmed fish and wild fish populations, and potential for reduced overall carbon footprint by providing increased domestic seafood availability close to local markets. Although regarded as having a low environmental impact, RAS is an extremely intensive system that requires a large initial investment, specific expertise to run and manage, and very high risk with regards to product loss. The complexity and dependence of the system design mean that fish can be lost within minutes if issues are not quickly addressed. The increased energy use necessary to run these systems can also be challenging at large scales. Some important requirements or limitations for fish species raised in RAS include species with high market value as well as access to a consistent egg or fingerling supply to ensure consistent harvests of market size fish throughout the year. RAS is a common system used to grow ornamental species (e.g., tanks in pet stores) but is also commonly used to grow fish for food.

Aquaponics

Aquaponics is a type of RAS in which nutrients generated from fish waste are used to fertilize plants (e.g., lettuce, microgreens) using a hydroponic system, which can be sold as a commodity in addition to the sale of the fish (Figure 9). The plants and biological filtration from beneficial bacteria in the system help clean the water for reuse in the fish tanks. In a coupled system, the water can be returned to the fish tanks. In a decoupled system, fish are reared in a separate RAS and a side stream of nutrients is sent to the plants; water does not return to the fish. The primary product, or value, in an aquaponics system is generally the plants, while the fish is the secondary product. This is important in business planning and development as many aquaponic facilities can fail if the investment is greater than the return—which is commonly overlooked. Aquaponics is a system used to grow fish for either food or ornamentals.

Figure 8. An Indoor Recirculating Aquaculture System

Source: University of Wisconsin Stevens Point-Northern Aquaculture Demonstration Facility.

Figure 9. An Aquaponics System with the Greens in the Front and the Fish Tanks in Back

Source: University of Wisconsin Stevens Point-Northern Aquaculture Demonstration Facility.

Figure 10. Satellite View of Net Pens in Canadian Waters of Lake Huron

Source: Google Earth.

Net Pens

Although net pen aquaculture is common globally, with increased interest in expanding its use in U.S. federal waters, net pens are currently not being operated in the U.S. waters of the Great Lakes. Net pens are large cages placed in open waters (Figure 10) where there is adequate water exchange for large volumes of fish. This also leads to the fish food and fish waste being diluted and impacting the local environment. The only commercial net pen aquaculture currently operating in the Great Lakes is in the Canadian waters of Lake Huron. Some U.S. states allow limited net pens in streams and rivers—such as with stocked salmonids or sturgeon, which allows for imprinting on the stocking location and larger size at release (if feeding) and reducing predation at stocking. However, net pens are commonly used to grow fish for food.

This brief overview of common aquaculture systems utilized for raising fish and aquatic species demonstrates that, regardless of the system type, all systems need to use best aquaculture practices in order to maintain ideal conditions for the species being cultured. Aquaculture can be a sustainable way to enhance fisheries and provide global food security with an increasing global population.

Conclusion

The diverse fishery interests in the Great Lakes region include both fisheries (wild-caught) and aquaculture (farm-raised) fish. These fish-related businesses impact communities through tourism, food security and sales, cultural and historical value, and supporting local jobs. Future fisheries and aquaculture opportunities will need to consistently monitor changing markets and environmental conditions to maintain a sustainable, successful business.

For More Information

FAO. 2020. *The State of World Fisheries and Aquaculture 2020. Sustainability in action.* Rome. Available online: https://doi.org/10.4060/ca9229en.

Great Lakes Aquaculture Collaborative. 2021. Available online: https://greatlakesseagrant.com/aquaculture/.

Great Lakes Fishery Commission. 2021. Available online: http://www.glfc.org/.

NOAA Fisheries. 2021. *U.S. Fisheries by the Numbers*. Available online: https://www.fishwatch.gov/sustainable-seafood/by-the-numbers.

NOAA GLERL. 2021. *About Our Great Lakes: Lake by Lake Profiles.* Available online: https://www.glerl.noaa.gov/education/ourlakes/lakes.html.

U.S. Department of the Interior, U.S. Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau. 2016. *2016 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation*. Available online: https://www.fws.gov/wsfrprograms/subpages/nationalsurvey/nat_survey2016.pdf.

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The Growth of Imports in U.S. Seafood Markets

Eric Abaidoo, Max Melstrom, and Trey Malone

JEL Classifications: Q21, Q22, Q27
Keywords: Aquaculture, Fish harvest, Seafood trade

Introduction

This article documents the importance of globalized seafood markets and aquaculture (where we define aquaculture as the farming of aquatic animals or plants in a controlled setting) in U.S. seafood markets. The United States has become a major importer of seafood products; between 1998 and 2018, U.S. seafood imports approximately doubled, from just over 1.5 million tons to 3 million tons (National Marine Fisheries Service, 2019). Two factors partially explain this transition: (i) steady increases in demand for seafood in the United States, mostly due to population growth and (ii) the fact that seafood production has grown more rapidly in other countries than in the United States, driven principally by developments in aquaculture. This article documents these trends using data on domestic consumption, capture fisheries versus farmed fish production, and U.S. seafood imports. Our analysis also traces the pattern of aquaculture growth in the United States relative to the major seafood suppliers. Close study of aquaculture is important because seafood markets have undergone a dramatic globalized transition over the past few decades, with many capture fisheries experiencing either unsustainable overfishing (34.2%) or catch that has reached its maximum sustainable yield (59.6%) (UNFAO, 2020). This implies that future increases in seafood supply will need to be met through aquaculture.

This article synthesizes the ongoing discussions on U.S. seafood markets in three ways. First, we describe the growth in seafood demand. Second, we document the rapid increase in other countries' seafood production, with a particular focus on the increase in aquaculture production in those countries relative to the United States. Third, we examine which countries are selling the highest value of seafood products in U.S. seafood markets.

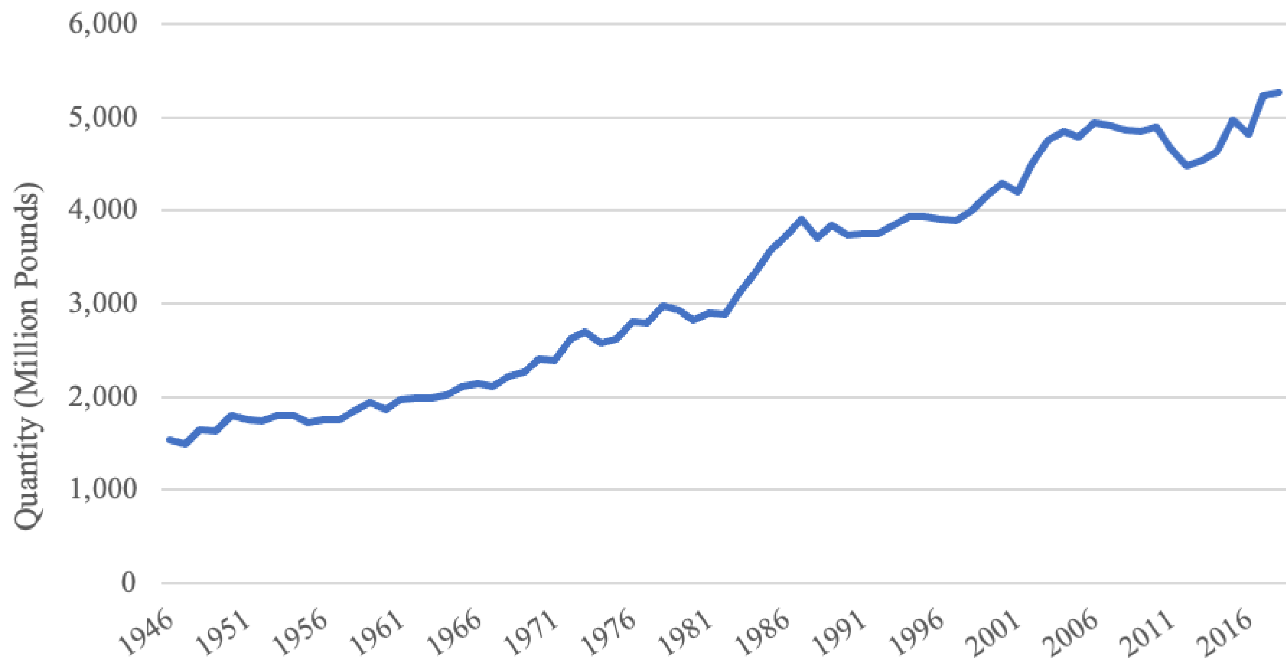
Increasing U.S. and Global Seafood Demand

Total U.S. demand for seafood increased 41% between 1990 and 2018 (Figure 1). Population growth is the primary driver behind this trend (Shamshak et al., 2019; Love et al., 2020). Between 1990 and 2020, the U.S. population increased from 250 million to 330 million. However, average individual consumption of seafood in the United States has changed relatively little over several decades (Figure 2), fluctuating around 15 pounds per person per year since the 1990s (Shamshak et al., 2019). It is worth noting, however, that there exists a marked spatial variability in seafood consumption across the United States. Seafood consumption rates among adults in the coastal Northeast and Pacific regions are among the highest in the United States and lowest in the inland Midwest and Great Lakes regions (Love et al., 2020).

Despite relatively flat per capita consumption, the composition of the U.S. seafood market is changing. Consumers are shifting away from products such as canned tuna, cod (mostly Atlantic cod), and Alaska pollock, which were among the most consumed species in the 1990s, to catfish (including *Pangasius*), tilapia, shrimp, and salmon (including Pacific and Atlantic salmon); along with canned tuna, these five species now make up 70% of total seafood consumption in the United States (Shamshak et al., 2019). Apart from canned tuna, it should be noted that aquaculture contributes heavily to the production volumes of these species (Anderson, Asche, and Garlock, 2018; Shamshak et al., 2019). Thus, consumption of farmed aquatic animals has increased markedly in the United States because of changing consumer tastes and preferences, and farmed species now have a large share of the overall U.S. food fish market.

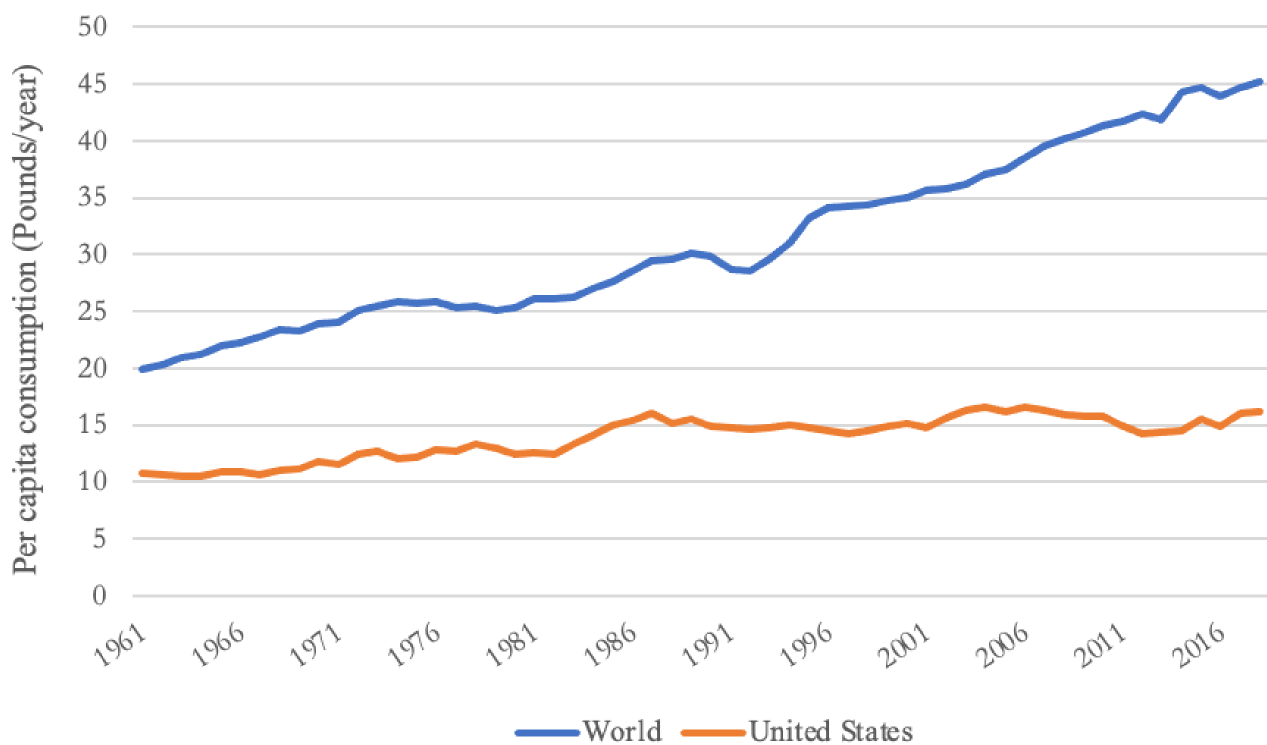
Global consumption of seafood per capita has risen steadily since 1961 (Figure 2). In contrast to the United States, per capita seafood consumption (by weight) more than doubled globally between 1961 and 2018. Rising incomes have contributed to this trend, with fish consumption accounting for 17% of the global population's animal protein intake (UNFAO, 2020). It is likely that this trend in global seafood demand will persist as global average income is expected to increase

Figure 1. U.S. Seafood Consumption (edible weight), 1946—2018



Source: U.S. Department of Agriculture (2021c) based on data from the U.S. Department of Commerce, National Marine Fisheries Service (NMFS).

Figure 2. Per Capita Consumption of Seafood, 1961—2018



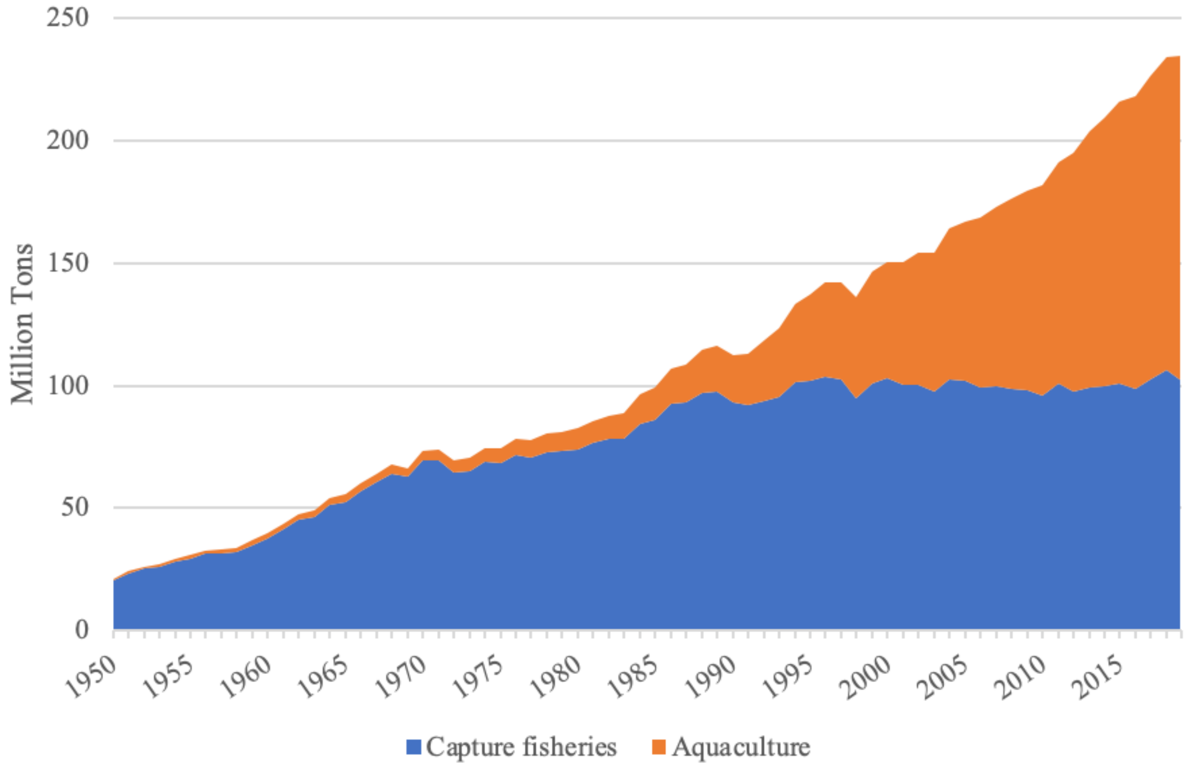
Notes: U.S. per capita consumption in edible meat weight (boneless equivalent weight). World per capita consumption comprises total supply available for consumption (live weight) without accounting for waste or losses; hence, these estimates are overestimated compared to actual intake.
Source: United Nations Food and Agriculture Organization (2020), Fish, Seafood-Food Supply Quantity (kg/capita/yr.) and U.S. Department of Agriculture (2021c).

significantly in the coming decades (Béné et al., 2015) and diets shift toward animal protein consumption. Increasing demand for seafood and other fish products has helped spur growth in global aquaculture production (Abate, Nielsen, and Tveterås, 2016; Cao et al., 2007; UN Food and Agriculture Organization, 2020).

Growth in Global Aquaculture Production

Seafood is produced from two main sources: capture fisheries and aquaculture. Given growing concerns about over-fishing, aquaculture production has gained prominence over the last few decades, nearly overtaking

Figure 3. Global Seafood Production of Capture Fisheries versus Aquaculture, 1950—2019



Source: United Nations Food and Agriculture Organization (2021).

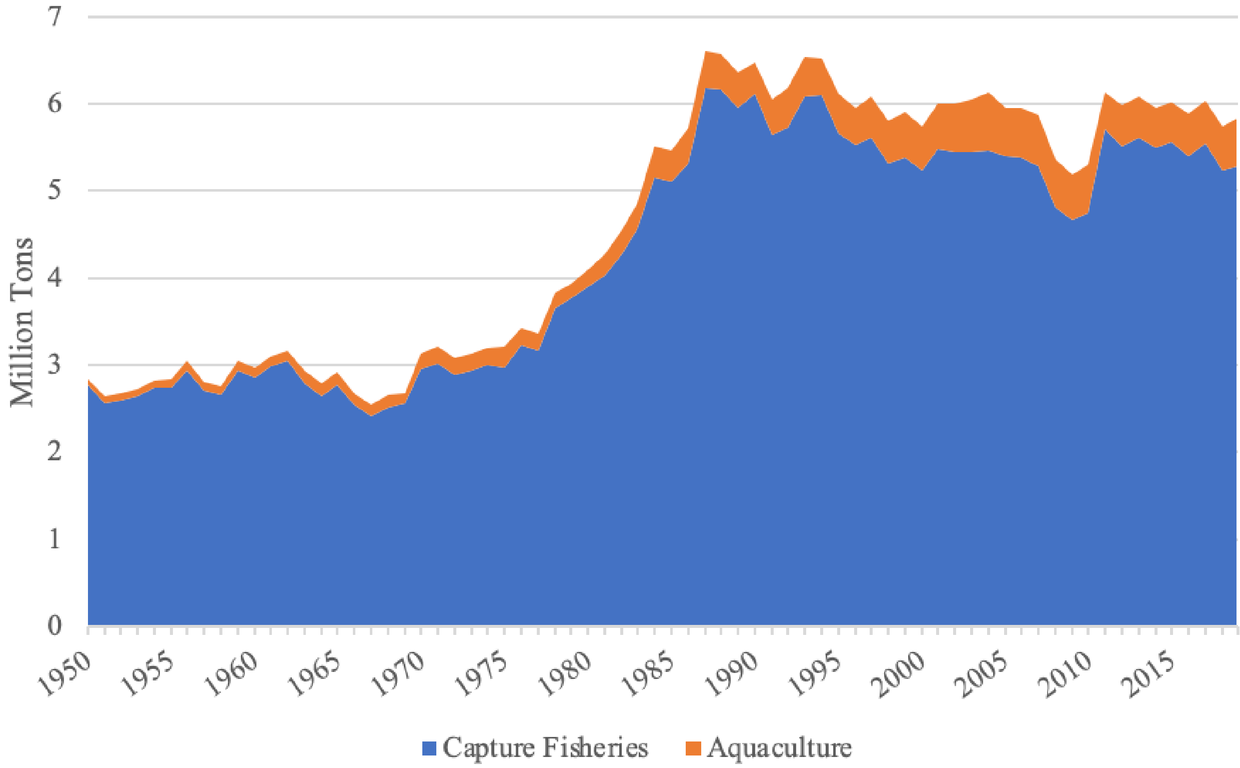
Table 1. Top 5 Seafood Producers in the World, 1990 versus 2018

1990	Country	Million Tons	Share of World Production
1	China	16.6	14.8%
2	Japan	12.1	10.7%
3	Russia (USSR)	8.4	7.5%
4	Peru	7.6	6.7%
5	United States	6.5	5.8%

2018	Country	Million Tons	Share of World Production
1	China	89.0	38.0%
2	Indonesia	25.3	10.8%
3	India	13.8	5.9%
4	Vietnam	8.3	3.5%
5	Peru	8.0	3.4%

Notes: Selected group species include the “fish, crustaceans, mollusks, etc.” category, ignoring aquatic plants and other aquatic animals and products production.
Source: United Nations Food and Agriculture Organization (2021).

Figure 4. U.S. Seafood Production of Capture Fisheries versus Aquaculture, 1950—2019



Source: United Nations Food and Agriculture Organization (2021).

capture fisheries in total volume. United Nations Food and Agriculture Organization (UNFAO) (2020) statistics reveal that aquaculture production made up about 46% of global seafood production and 52% of fish for human consumption in 2018. Total aquaculture supply increased significantly, from 47 million tons in 2000 to 126 million tons by live weight in 2018 (UNFAO, 2020).

Table 1 presents data on the shifts in general seafood production among the historical global-leading seafood producers, based on data from the UNFAO's FishstatJ Database. China, Russia, and Japan produced much of the world's seafood products in 1990; in that year, the top five producers of seafood accounted for close to half of the world's production volume. Three decades later, three of the five formerly top seafood-producing countries fell out of this list, replaced by Indonesia, India, and Vietnam. However, Chinese seafood production has increased nearly six-fold during this time, making it the leading producer of seafood products in 2018 by a large margin. China is both a leading exporter and importer of seafood products (UNFAO, 2020). As Chinese consumers' purchasing power continues to grow, early projections suggest that Chinese seafood consumption will soon surpass domestic production (Crona et al., 2020). If realized, this trend will have important implications for economies that depend on seafood imports as China redirects domestic production to meet local demand.

Given the global stagnation in capture fisheries, the surge in general seafood production among these emerging economies is mainly due to investments in aquaculture (Bush et al., 2013). The transition from capture fisheries dependence to aquaculture has been significant for each of the current top five seafood producers. As of 2013, aquaculture's share of seafood production was relatively greater than that of capture fisheries in China, India, and Vietnam, with aquaculture production volume growing at least twice as fast as volumes from capture fisheries (Belton and Thilsted, 2014). Apart from Peru, aquaculture now marginally dominates total capture fisheries production across these top seafood producers in terms of total volume.

The composition of seafood production in the United States, however, stands apart from this global trend. Farming of aquatic species constitutes a minimal fraction of U.S. seafood production. As of 2019, aquaculture contributed less than 1% of total U.S. seafood production volume (for both food and nonfood use) (Figure 4). Yet about half of U.S. seafood imports are produced by aquaculture, which thus feeds a large share of U.S. seafood consumers because more than half of U.S. seafood is imported. By contrast, over 99% of all chicken meat consumed in the United States (by weight) is domestically produced (U.S. Department of Agriculture, 2021a). U.S. aquaculture production grew from 0.51 million tons in 2000 to 0.54 million tons in 2019 (UNFAO, 2021). The last two decades have presented serious challenges to the U.S. aquaculture industry, including a surge in feed prices (Engle and Stone, 2013), several recessions, and increasing globalization. For domestic aquaculture producers, passing production cost increases on to U.S. consumers has become increasingly difficult due to competition with imported seafood (see Alabama Co-Operative Extension System, 2018, for comments on the effect of catfish-like imports on U.S. seafood markets).

Using the UNFAO's Global Aquaculture Production data, we describe how U.S. aquaculture has fared in terms of growth relative to the top seafood producing countries. In our analysis, we exclude production figures from aquatic plants, pearls, and mother-of-pearl for both food and nonfood use. Using production statistics from 1951, we compute the year-on-year growth in aquaculture production volume for the United States and compare these results with some of the world's leading seafood producers. These values are calculated as simple percentage changes from the previous year.

Table 2 shows the rate of aquaculture production growth by country between 1951 and 2019. The United States has the lowest average annual growth rate in the period under consideration. Since 1951, aquaculture production in the United States grew by an average rate of 3.6% annually, compared to 10.0% in Vietnam, 7.2% in the

Table 2. Aquaculture Growth by Country, 1951—2019

	Growth Rate (%)					
Year	United States	China	India	Indonesia	Philippines	Vietnam
1951	10.6	93.8	9.2	1.4	16.5	0.3
1955	14.1	17.0	9.6	13.2	13.4	12.9
1960	1.3	6.7	10.0	0.6	3.6	7.9
1965	7.0	14.0	10.4	0.8	2.7	5.7
1971	-1.8	21.0	12.3	5.0	4.0	4.6
1972	4.9	11.0	12.6	4.2	1.6	4.2
1973	-1.9	-8.3	12.4	9.1	3.3	4.2
1974	-1.9	8.4	11.1	4.9	26.2	4.0
1975	30.8	9.2	11.2	9.8	-4.7	4.1
1976	-15.8	-2.4	11.4	4.8	7.4	4.0
1977	-5.2	32.4	11.3	10.9	13.2	4.1
1978	-8.9	7.1	11.3	8.9	37.7	4.3
1979	-12.5	-2.9	11.3	6.8	16.6	4.3
1980	21.1	7.0	11.3	11.4	27.7	4.7
1985	-0.9	17.7	10.7	8.7	3.5	8.8
1990	-14.5	3.6	1.3	13.6	6.6	-1.7
1995	5.6	16.1	9.2	5.6	8.2	13.1
2000	-4.7	6.2	-9.0	12.5	5.0	24.2
2005	-15.4	4.8	6.0	44.6	10.4	19.7
2010	3.2	3.7	-0.2	33.2	2.8	5.1
2011	-20.0	2.8	-3.0	26.4	2.4	5.9
2016	4.4	5.0	8.3	2.3	-6.3	3.1
2017	-1.1	3.3	8.5	0.7	1.7	7.0
2018	6.0	2.8	16.1	-2.1	3.0	8.6
2019	5.2	3.5	8.6	0.8	2.3	7.0
Average	3.6	11.4	9.3	9.4	7.2	10.0

Source: United Nations Food and Agriculture Organization (2019).

Philippines, 9.4% in Indonesia, 9.3% in India, and 11.4% in China. Table 2 also shows that the United States has experienced several years of declining aquaculture production since the 1970s. That is, not only has U.S. aquaculture been unable to keep pace with the growth in farmed seafood among the global leaders, but it has in fact lost ground compared to historical U.S. production volumes. For example, one of the worst declines in aquaculture production in the United States occurred in 2011, when the industry recorded a growth rate of -20%. Import competition and surging input costs affecting the U.S. catfish industry, which dominated domestic aquaculture production at the time, explain part of this contraction (Alabama Co-Operative Extension System, 2018). Vietnam experienced a similar-sized dip in growth in 1995, but this decline was largely offset by periods of strong recovery in the following years. Although much of China's growth in aquaculture production was realized early on (in the 1950s), the industry achieved annual growth rates greater than 10% until the late 2000s; since then, growth rates have ranged between approximately 3% and 6%.

By contrast, other top seafood producers—such as Indonesia and India—continue to report sustained growth in aquaculture production. For these emerging economies, rapid dietary diversification—fueled by rising incomes—toward meat and seafood have revolutionized domestic aquaculture production, such as in the rapid commoditization of nonnative, efficiently farmed species like tilapia (Hernandez et al., 2018). Seafood is becoming an integral part of the diets of many households in developing countries, creating private and public interest in aquaculture.

The Rise of U.S. Seafood Imports

The United States is a large net importer of seafood, with between 70% and 85% of seafood consumed domestically originating abroad (NOAA, 2021a), although some estimates imply a lower range of 62%–65% (Gephart, Froehlich, and Branch, 2019). Approximately half of these seafood imports are farmed (aquaculture products). Import volumes remain high despite some top aquaculture exporting countries having been accused of unfairly dumping to gain larger shares of U.S. seafood markets. Dumping occurs when producers export a product at a price lower than the normal market price. For example, in June 1997, Chilean salmon exporters were accused of receiving government subsidies and practicing dumping on U.S. markets (Bjørndal, 2002). Thorough investigations into Chilean exporters' practices revealed that some Atlantic salmon producers were guilty of illegally undercutting the going market price, which eventually led to the imposition of additional import duties (Bjørndal, 2002). Despite a guilty verdict and import duties, exports of Chilean salmon to U.S. markets have continued to grow. Similarly, the U.S. Department of Commerce placed anti-dumping duties on Vietnamese catfish-like products (*Pangasius*), although these were subsequently lowered upon appeal (Dao, 2018).

China, Chile, and Vietnam have proved crucial in meeting the growing demand for seafood in the United States. (Aquatic Network, 2021). However, this also represents an opportunity for domestic aquaculture producers to capture some market share. Figure 5 reports historical data on the total value of U.S. seafood imports across all species. The overall trend remains the sustained growth in U.S. seafood imports since 2000. Figure 5 indicates that seafood imports have largely survived the recent protectionist policies that adversely impacted other imported products and commodities.

Canada exports the most by value to the United States, followed by India and Indonesia. Canada commands a strong niche in Atlantic salmon production (Nguyen and Williams, 2013; Weitzman and Bailey, 2019). The Canadian aquaculture industry provides an interesting case study from which some lessons can be drawn. Open net-pen salmon farming dominates Canadian aquaculture, which has become a driving force behind Canada's strong aquaculture growth (Weitzman and Bailey, 2019).

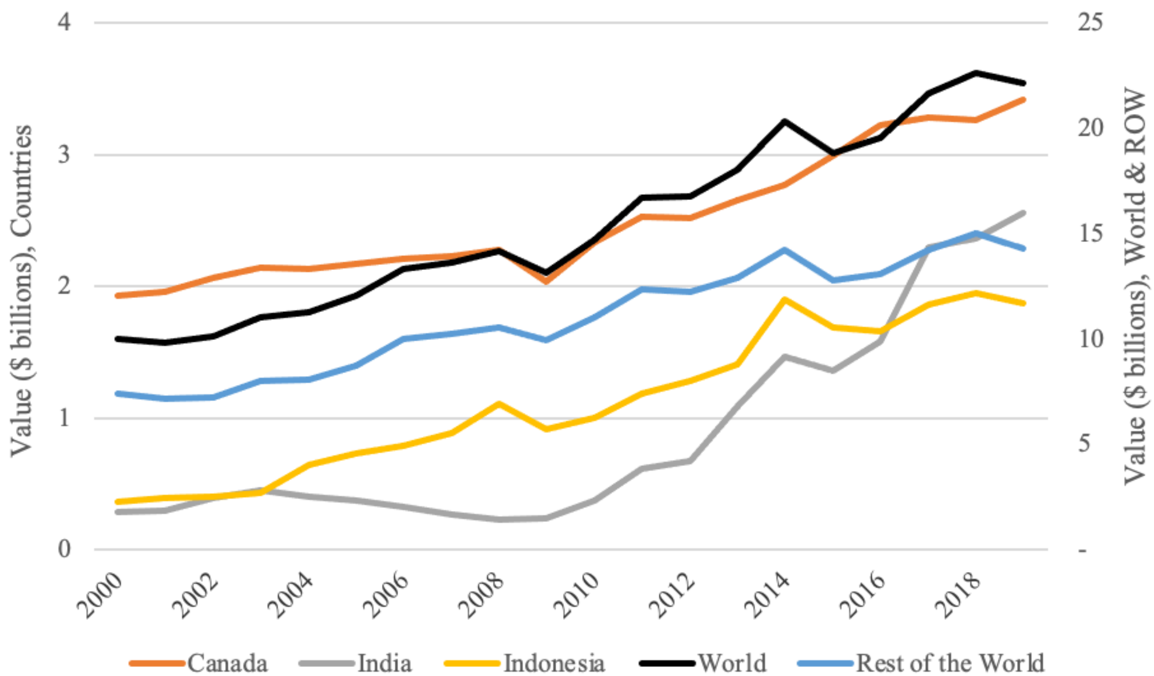
For other countries such as Chile—where salmon is not a native fish (Bjørndal, 2002)—the rise to capture a sizable market niche in salmon production is quite notable. Chile benefits from a rugged coastline with

Table 3. Aquaculture and Capture Fisheries Production among Top Suppliers of Selected Species, 2018

Country	Leading species	Total Aquaculture Production (million tons)	Total Capture Fisheries Production (million tons)
China	Catfish (including *Pangasius*), Tilapia	52.5	16.2
India	Shrimp	7.8	5.8
Chile	Salmon	1.4	2.3
Thailand	Tuna	1.0	1.9

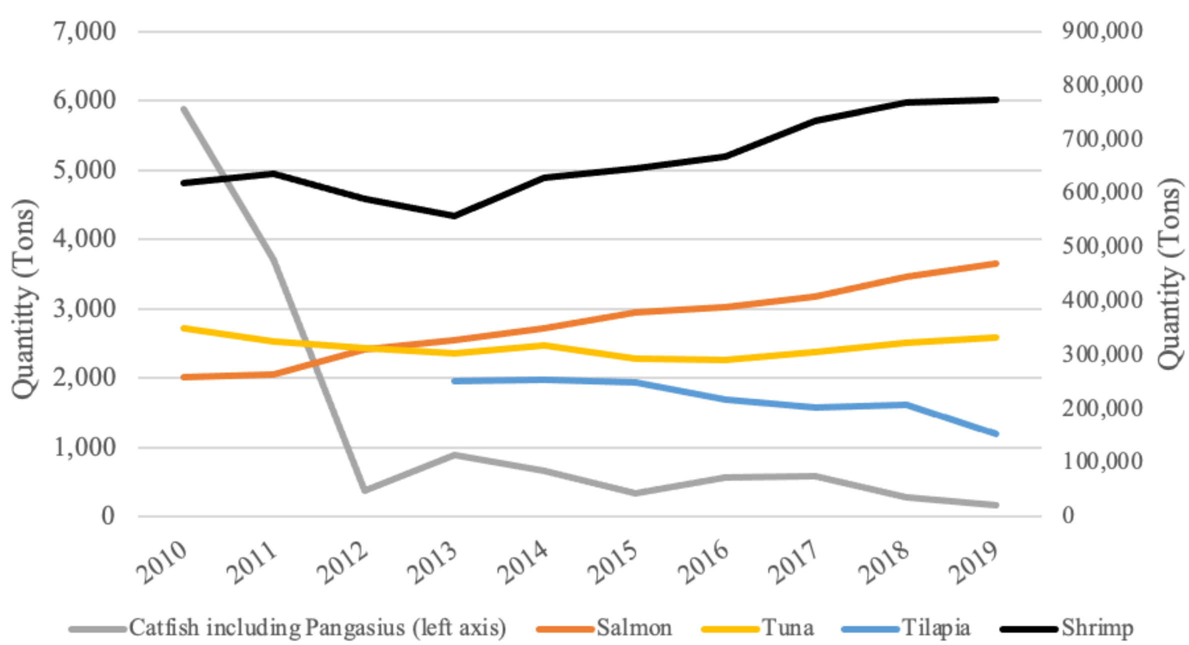
Source: United Nations Food and Agriculture Organization (2021).

Figure 5. U.S. Value of Total Seafood Imports, 2000—2019



Source: U.S. Department of Agriculture (2021b).

Figure 6. U.S. Seafood Imports by Selected Species, 2010—2020



Source: U.S. Department of Agriculture (2021b).

close to ideal habitat conditions. However, Chile's giant leap in aquaculture production cannot be attributed solely to its suitable growing conditions. Cost advantages from low wages at both the farming and processing stages in the value chain have contributed to the industry's success. Vertical integration is another feature characterizing Chilean salmon production. Since the early 1990s, the average firm size in the industry has continued to grow as companies assume greater responsibility for the farming, processing, and marketing of Atlantic salmon and trout (Bjørndal, 2002). Overreliance of the industry on imported fish eggs (about one-third imported from the United States) and rising fish meal costs, however, represent potential threats to its competitiveness.

Figure 6 illustrates U.S. seafood import volumes since 2010 for the top five most consumed species. Our analysis does not allow us to distinguish imports for food consumption from other possible uses. Shrimp is the most imported species by volume and that, since 2010, the volume of imported shrimp into the United States (mostly from India and Indonesia) has increased by about 33%. On the other hand, tuna imports (in all forms) into the United States have changed little, with a small increase after 2015 mostly because of strong growth in canned tuna and frozen tuna fillet imports (NOAA, 2021b).

Atlantic salmon is the second most imported species into the United States. It remains one of the most important sources of seafood in the diets of U.S. consumers. Between 2010 and 2019, the total volume of U.S. salmon imports almost doubled, from 258,000 tons to 470,000 tons. By contrast, U.S. tilapia imports declined by 39% between 2013 and 2019 (see Figure 6). This declining trend may offer credence to some of the highly publicized issues of food contamination and adulteration in Asia, mostly China, given that China is the leading exporter of tilapia to the United States (Ortega, Wang, and Widmar, 2014). Another species with most U.S. imports originating in China is catfish-like fish (including *Pangasius*). Similarly, we observe a declining trend in U.S. catfish (including *Pangasius*) imports, with a particularly drastic dip between 2010 and 2012. Figure 6 also shows that catfish imports have more or less stabilized since then.

Conclusion

Formerly a top world seafood producer, the U.S. share of global seafood supply has declined over the past several decades, with imports now contributing to the bulk of domestic seafood consumption. U.S. seafood consumption per capita is stable, but aggregate consumption is increasing; thus, it is likely that imports of the top species into the U.S. seafood market will experience sustained growth. Growth of U.S. production has lagged that of the top international seafood producers, mainly because of minimal growth in the U.S. aquaculture industry.

A natural response to information about the state of U.S. seafood production and imports is to ask why other countries have come to dominate production, particularly in aquaculture. Unfortunately, this question has not yet received enough study that we can provide an answer with confidence. Aquaculture experts and academic research suggest that the difference may be partially due to regulatory hurdles. Regulations are designed to affect production practices that, in turn, can affect producers' ability to grow their business. One should not be surprised that U.S. regulations may be relatively more burdensome, due to the country's federal governing structure, record of strong environmental and food safety laws, and public and agency concerns about water quality (Knapp and Rubino, 2016). However, the sum effect of these factors on the U.S. aquaculture industry remains unclear and needs further study. Research using producer surveys and cross-country analysis points toward a link between production volumes and regulations (Engle and Stone, 2013; Abate, Nielsen, and Tveterås, 2016), although there has yet to be a study establishing a robust, causal pathway. Nevertheless, government action in some form appears necessary to make U.S. aquaculture a more significant contributor to domestic and global seafood production. This could range from streamlining state and federal laws to incentivizing seafood co-operatives or offering financial and technical support for producers. Similar actions have occurred in countries that have become dominant in aquaculture and seafood production, such as Norway, where producers apply for a general permit through the national authority and a single license through the regional government to limit regulatory complexity (Alexander et al., 2015).

For More Information

Abate, T.G., R. Nielsen, and R. Tveterås. 2016. "Stringency of Environmental Regulation and Aquaculture Growth: A Cross-Country Analysis." *Aquaculture Economics & Management* 20(2): 201–221.

Alabama Cooperative Extension System. 2018. *Aquatic Resources Team: Project Activities and Impacts 2017*. Alabama A&M and Auburn Universities Extension publication ANR 2458.

Alexander, K.A., T.P. Potts, I.D. Freeman, J. Johansen, D. Kletou, M. Meland, D. Pecorino, C. Rebours, M. Shorten, and D.L. Angel. 2015. "The Implications of Aquaculture Policy and Regulation for the Development of Integrated Multi-trophic Aquaculture in Europe." *Aquaculture* 443: 16–23.

Anderson, J.L., F. Asche, and T. Garlock. 2018. "Globalization and Commoditization: The Transformation of the Seafood Market." *Journal of Commodity Markets*, 12: 2–8.

Aquatic Network. 2021. *U.S. Seafood Import and Export Trends*. Available online: https://www.aquanet.com/us-seafood-trends.

Belton, B, and S.H. Thilsted. 2014. “Fisheries in transition: Food and nutrition security implications for the global South.” *Global Food Security* 3: 59–66.

Béné, C., M. Barange, R. Subasinghe, P. Pinstrup-Andersen, G. Merino, G.I. Hemre, and M. Williams. 2015. “Feeding 9 Billion by 2050—Putting Fish Back on the Menu.” *Food Security* 7: 261–274.

Bittenbender, S. 2018, December 14. “NOAA Fisheries Reports Increase in Seafood Consumption and Landings.” *SeafoodSource*. Available online: https://www.seafoodsource.com/news/supply-trade/noaa-fisheries-reports-increase-in-seafood-consumption-and-landings.

Bjørndal, T. 2002. “The Competitiveness of the Chilean Salmon Aquaculture Industry.” *Aquaculture Economics & Management* 6(1–2): 97–116.

Boyd, C.E., and A.A. McNevin. 2015. *Aquaculture, Resource Use, and the Environment*. Hoboken, NJ: Wiley.

Bush, S.R., B. Belton, D. Hall, P. Vandergeest, F.J. Murray, S. Ponte, P. Oosterveer, M.S. Islam, A.P.J. Mol, M. Hatanaka, F. Kruijssen, T.T.T. Ha, D.C. Little, and R. Kusumawati. 2013. “Certify Sustainable Aquaculture?” *Science* 341(6150): 1067–1068.

Cao, L., W. Wang, Y. Yang, C. Yang, Z. Yuan, X. Shanbo, and D. James. 2007. “Environmental Impact of Aquaculture and Countermeasures to Aquaculture Pollution in China.” *Environmental Science & Pollution Research* 14(7): 452–462.

Crona, B., E. Wassénius, M. Troell, K. Barclay, T. Mallony, M. Fabinyi, W. Zhang, V.W.Y. Lam, L. Cao, P.J.G. Henriksson, and H. Eriksson. 2020. “China at a Crossroads: An Analysis of China’s Changing Seafood Production and Consumption.” *One Earth* 3(1): 32–44.

Dao, T. 2018, March 21. “High Antidumping Duties Have Vietnam’s Pangasius Vendors Forsaking U.S. Market.” *SeafoodSource.* Available online: https://www.seafoodsource.com/features/high-antidumping-duties-have-vietnams-pangasius-vendors-foresaking-us-market.

Engle, C.R., and N.M. Stone. 2013. “Competitiveness of U.S. Aquaculture within the current U.S. regulatory framework.” *Aquaculture Economics & Management* 17: 251–280.

Engle, C.R., and D. Valderrama. 2002. “The Economics of Environmental Impacts of Aquaculture in the United States.” In J. Tomasso, ed. *Aquaculture and the Environment in the United States*. Baton Rouge, LA: U.S. Aquaculture Society.

Gephart, J.A., H.E. Froehlich, and T.A. Branch. 2019. “Opinion: To Create Sustainable Seafood Industries, the United States Needs a Better Accounting of Imports and Exports.” *Proceedings of the National Academy of Sciences* 116(19): 9142–9146.

Hernandez, R., B. Belton, T. Reardon, C. Hu, X. Zhang, and A. Ahmed. 2018. “The ‘Quiet Revolution’ in the Aquaculture Value Chain in Bangladesh.” *Aquaculture* 493: 456–468.

Knapp, G., and M.C. Rubino. 2016. “The Political Economics of Marine Aquaculture in the United States.” *Reviews in Fisheries Science & Aquaculture* 24(3): 213–229.

Love, D.C., F. Asche, Z. Conrad, R. Young, J. Harding, E.M. Nussbaumer, A.L. Thorne-Lyman, and R. Neff. 2020. “Food Sources and Expenditures for Seafood in the United States.” *Nutrients* 12(6): 1810.

Ortega, D.L., H. Wang, and N.O. Widmar. 2014. “Aquaculture Imports from Asia: An Analysis of U.S. Consumer Demand for Select Food Quality Attributes.” *Agricultural Economics* 45: 1–10.

National Marine Fisheries Service. 2019. *Commercial Fisheries Statistics*. Available online: https://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/index.

National Oceanic and Atmospheric Administration. 2021a. *U.S. Aquaculture*. Available online: https://www.fisheries.noaa.gov/national/aquaculture/us-aquaculture.

National Oceanic and Atmospheric Administartion. 2021b. *U.S. Trade in Fishery Products*. Available online: https://www.fisheries.noaa.gov/foss/f?p=215:22:20165797972349::NO:::.

Nguyen, T., and T. Williams. 2013. "Aquaculture in Canada." Library of Parliament, Canada, Publication No. 2013-12-E, February.

Shamshak, G.L., J.L. Anderson, F. Asche, T. Garlock, and D.C. Love. 2019. "U.S. Seafood Consumption." *Journal of the World Aquaculture Society* 50: 715–727.

United Nations Food and Agriculture Organization. 2019. *FishstatJ Universal Software for Fishery Time Series*. Rome, Italy: FAO Fisheries and Aquaculture Department.

United Nations Food and Agriculture Organization. 2020. *The State of the World Fisheries and Aquaculture: Sustainability in Action*. Rome, Italy: FAO.

United Nations Food and Agriculture Organization. 2021. *Fishery and Aquaculture Statistics. Global Aquaculture Production 1950-2019 (FishstatJ)*, Updated 2021. Available online: www.fao.org/fishery/statistics/software/fishstatj/en.

U.S. Department of Agriculture. 2021a. *Livestock and Poultry: World Markets and Trade*. Washington, D.C.: U.S. Department of Agriculture, Foreign Agricultural Service, July. Available online: https://downloads.usda.library.cornell.edu/usda-esmis/files/73666448x/9593vs24n/4m90fs46x/livestock_poultry.pdf.

U.S. Department of Agriculture. 2021b. *Global Agricultural Trade System Online*. Washington, D.C.: U.S. Department of Agriculture, Foreign Agricultural Service. Available online: https://apps.fas.usda.gov/GATS/default.aspx.

U.S. Department of Agriculture. 2021c. *Food Availability (Per Capita) Data System*. Washington, D.C.: U.S. Department of Agriculture, Economic Research Service. Available online: https://www.ers.usda.gov/data-products/food-availability-per-capita-data-system/.

Weitzman, J., and M. Bailey. 2019. "Communicating a Risk-Controversy: Exploring the Public Discourse on Net-Pen Aquaculture within the Canadian Media." *Aquaculture* 507: 172–182.

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Aquaculture Markets in the Twenty-First Century

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Seafood Supply

Global seafood supply significantly increased from the late twentieth century, with aquaculture becoming an important source of seafood, supplementing supplies from wild-capture fisheries. Recent estimates from the United Nations (UN) Food and Agriculture Organization (FAO) indicate that global fish production in 2018 was about 197 million tons, compared to an average global annual fish production of 112 million tons from 1986 through 1995 (FAO, 2020) (Table 1).

In 2018, seafood supply from aquaculture (90.5 million tons) accounted for 46% of total global supply, compared to the 15% contribution of aquaculture to global seafood supply from 1986 to 1995. About 172 million tons, representing 87% of total global fish, was consumed as food, with supply from aquaculture production contributing 52%, a trend expected to continue because of advancements in fish-farming technology (Kumar and Engle, 2016; FAO, 2020). Aquaculture is on track to be the main supplier of seafood for human consumption by 2030 (Kobayashi et al., 2015). Seafood produced for human consumption includes finfish, crustaceans, mollusks, and other edible aquatic plants and animals.

The main drivers of aquaculture growth from the supply side are improved fish genetics and hatchery technology, enhanced feed nutrition and disease management, labor-saving technology and intensification, and efficient technology diffusion (Kumar and Engle, 2016). Another contributing factor is sustainability challenges with respect to increasing depletion of wild fish stocks. China, the dominant global fish-producing nation, supplied 35% of 2018 global seafood, far more than total fish production in any other regions of the world. For example, in 2018, supplies from Asia (excluding China) made up 34% of global production; the Americas, 14%; Europe, 10%; Africa, 7%; and Oceania, 1% (FAO, 2020).

Though Asia dominates global seafood production, the United States is a major source of supplies from capture fisheries, accounting for 5% of global capture fisheries; the United States ranks sixth in global capture fisheries production (FAO, 2020). U.S. seafood production from aquaculture is minimal compared to the rest of the world and has remained relatively stable for about two decades. USDA (2020) census data indicate total farm sales from U.S. aquaculture of $1.09 billion in 2005, $1.37 billion in 2013, and $1.51 billion in 2018. Total U.S. seafood production for human consumption in 2019 is estimated to be about 4.1; 3.8 million tons from capture fisheries (93% of production) and 0.3 million tons from aquaculture (7% of production) (NOAA, 2021; USDA, 2020).

Seafood Demand

Global per capita fish consumption in 2018 was 45.2 pounds (FAO, 2020). Of the various forms of seafood used for direct human consumption, live, fresh or chilled fish accounted for 44% of products; frozen seafood, 35%; prepared and preserved fish, 11%; and cured 10% (FAO, 2020). Estimated U.S. per capita seafood consumption in 2019 was 19.2 pounds, of which 15.0 pounds was fresh and frozen seafood (9.0 pounds of finfish and 6.0 pounds of shellfish), 3.9 pounds was canned seafood products, and 0.3 pounds was cured fish (NOAA, 2021). In 2019, consumption experienced a slight increase over 2018 to 19.0 pounds, a 1.05% increase attributed to a small increase in canned seafood consumption (NOAA, 2021). A few seafood species dominate the international market—notably shrimp, salmon, tilapia, catfish, and pangasius—most of which are supplied by aquaculture. In the United States, the top ten seafood products consumed (in decreasing order) are shrimp, salmon, canned tuna, Alaska pollock, tilapia, cod, catfish, crab, pangasius, and clams; these ten species account for 74% of total seafood consumed in the United States (NFI, 2021) (Table 2).

Globally, increasing global population trends and demand for animal protein has led to an increase in seafood consumption. However, consumption levels vary by nation and region. For example, seafood is traditional component of diets in Southeast Asian

Table 1. World Captures Fisheries and Aquaculture Production (million tons)

	1986–1995 Average per year	1996–2005	2006–2015	2016	2017	2018
Wild-capture fisheries						
Inland	7.1	9.1	11.7	12.6	13.1	13.2
Marine	88.7	91.5	87.4	86.3	89.5	93.0
Total capture fisheries	95.8	100.6	99.1	98.9	102.6	106.3
Aquaculture						
Inland	9.5	21.8	40.6	52.9	54.7	56.5
Marine	6.9	15.9	25.1	31.4	33.1	34.0
Total aquaculture	16.4	37.7	65.7	84.3	87.7	90.5
Total world production	112.2	138.3	164.8	183.2	190.4	196.8

Source: FAO (2020).

Table 2. Top-10 Species of Seafood Consumed in the United States, 2019

Rank	Species	Per Capita (lb)	% Market Share
1	Shrimp	4.7	24%
2	Salmon	3.1	16%
3	Canned tuna	2.2	11%
4	Alaska pollock	0.996	5%
5	Tilapia	0.98	5%
6	Cod	0.59	3%
7	Catfish	0.55	3%
8	Crab	0.52	3%
9	Pangasius	0.36	2%
10	Clams	0.3	2%
Total Top 10		14.28	74%
all other species consumption		4.92	26%
per capita consumption		19.2	100%

Source: NFI (2021).

countries, which remain among the top seafood-consuming regions worldwide. In 2018, about 71% of total global seafood supply was consumed in Asia (excluding Japan); the United States, European Union, and Japan consumed 19%; and other regions accounted for the remaining 10% (FAO, 2020). The U.S. and E.U. markets are target destinations for many exporting nations (Tveteras, 2015; Engle, Quagrainie, and Dey, 2017).

Because U.S. domestic production is insufficient to meet demand, the United States continues to be a major seafood importer in terms of both value and quantity. Federal agencies and industry groups estimate that the United States imports anywhere from 70% to 85% of seafood to meet domestic demand. In 2019, the United States imported 6.0 million tons of edible seafood, with over half produced from aquaculture; by accounting for domestic production and export, total seafood supply available for human consumption was 12.8 million tons (NOAA, 2021).

International Seafood Trade

Increasing global seafood demand is a result of availability, rising disposable incomes, urbanization, price competitiveness with other proteins, and health and nutrition attributes of fish (Alfnes, Chen, and Rickertsen, 2018; Asche et al., 2015; FAO, 2020;

Shamshak et al., 2019). Improvements in seafood supply chain and logistics as well as bilateral and regional trade agreements have also supported increased seafood availability at relatively lower costs. Consequently, seafood markets are no longer considered local markets but rather international markets with trade implications (Anderson, Asche, and Garlock, 2018; Asche et al., 2015; Shamshak et al., 2019).

Salmon and shrimp are the most globally traded seafood in terms of value, and these are predominantly sourced from aquaculture (FAO, 2020). In 2018, salmon—mostly Atlantic salmon—accounted for about 19% of the total value of international seafood trade, while shrimp and prawns accounted for about 15%. About 61% of total global shrimp supply and 78% of salmonids come from aquaculture (NOAA, 2020). In 2019, the United States imported 1.5 billion pounds of shrimp, valued at $6.0 billion and representing 27% of total edible import value, and about 886.4 million pounds of salmon, valued at $4 billion (NOAA, 2021).

Seafood Market Trends in the Twenty-First Century

The globalization and competitive nature of seafood markets have resulted in diverse programs by various entities. Governments, nongovernment organizations (NGOs), associations, major seafood buyers, and other stakeholders have established regulations, standardization, and certification programs associated with environmental sustainability and conservation, water quality, animal welfare, production methods, labor standards, origin, food safety, traceability, and labeling as well as other informational programs (Prag, Lyon, and Russillo, 2016; Alfnes, Chen, and Rickertsen, 2018). While some regulations and informational programs have existed for years, others were developed more recently, and the number of these continues to increase. Many of the programs are transnational and have been largely developed in response to consumer attitudes and preferences and health, safety, and environmental concerns. The goals for these programs are to assure environmental and social responsibility, safety and quality standards, and consumer confidence in seafood (Alfnes, 2017; Del Giudice et al., 2018). Major seafood buyers may also use the programs for product differentiation (Alfnes, 2017).

While some of the information programs may be mandatory, they may also apply to either wild-capture fisheries, aquaculture, or both and can vary from region to region. The programs come in various forms, including internationally accepted protocols, national government requirements and certifications, third-party certifications, and private labeling schemes (Alfnes, Chen, and Rickertsen, 2018; Del Giudice et al., 2018). Alfnes, Chen, and Rickertsen (2018) present an extensive review of different labeling schemes pertaining to aquaculture; below are the main highlights of certifications and general informational labeling programs being adopted in the seafood marketplace.

Certification Programs

Sustainability

Sustainability in capture fisheries is aimed at minimizing overfishing of important species; protecting habitat ecosystems; and decreasing harvest of nontarget species and bycatch. Sustainability in aquaculture is based on ecological, environmental, and social responsibility and fish production practices (Prag, Lyon, and Russillo, 2016; Alfnes, 2017; Engle, Quagrainie, and Dey, 2017). Sustainability garners the most attention with regard to seafood and has attracted various standards, certification, and verification programs. Concern for sustainability in capture fisheries has persisted for decades with labels like “dolphin safe” tuna, which is an international trade label requirement (UNCLOS, 1982).

The number of third-party certifications and corporate verifications of more broad-based sustainability objectives focused on multiple issues has increased in recent years. Organizations like the Marine Stewardship Council (MSC) (www.msc.org), Friend of the Sea (www.friendofthesea.org), the Aquaculture Stewardship Council (ASC) (www.asc-aqua.org), Best Aquaculture Practices (www.bapcertification.org), and Global G.A.P. (www.globalgap.org) have developed sustainability standards and a producer implementing them can use the respective certification labels for marketing purposes (Figure 1). Major seafood retailers in the United States and European Union have adopted these certification programs.

High-volume seafood buyers and large retailers in developed countries also have sustainability requirements in sourcing seafood as part of their corporate social and environmental responsibility programs (Alfnes, 2017). Major food retailers such as Walmart, Whole Foods, and TESCO maintain private labels for sourcing sustainable seafood (Figure 2).

Organic

NGOs such as Naturland, the Soil Association, and the International Federation of Organic Agriculture Movements (IFOAM) began organic certification decades ago following their organic production principles in traditional agriculture. Various nations—including Canada and the European Union—also developed their standards with guidelines and requirements on genetically modified organisms (GMO) in aquaculture; use of antibiotics, hormones and synthetic additives; stocking densities; feeding; water quality; and fish handling (Canadian General Standard Board , 2018; European Union, 2021a). Requirements can be quite specific for some species. For example, the EU guidelines lay out some specific requirements for salmon and seaweed relating to production.

Figure 1. Examples of Seafood Sustainability Certification Labels

Figure 2. Examples of Retailer Seafood Products with Sustainability and Verification Information

The United States currently does not have aquaculture standards though the USDA's National Organic Program (NOP) constituted a working group that developed organic aquaculture standards for U.S. aquaculture in 2016. A proposed final rule reviewed by the Office of Management in Budget (OMB) has yet to be published in the *Federal Register* for public comments. Meanwhile, because the United States is a target market for seafood exporters in other nations, certified organic seafood products in the U.S. market use various international organic aquaculture standards from NGOs, other nations, and private initiatives. "Organic" labeled seafood in the U.S. market is estimated to account for 0.5%–1% (Orlowski, 2017). In general, organic products attract higher premiums than conventional aquaculture products; they remain a niche market (Orlowski, 2017; Ankamah-Yeboah et al., 2019).

Genetically Modified Seafood

In 2015, the U.S. Food and Drug Administration (FDA) approved a genetically modified Atlantic salmon from AquaBounty Technologies (aquabounty.com/about-us) for human consumption. A limited quantity of the salmon is available in the Canadian market and began appearing in the U.S. market in 2021 (AquaBounty Technologies, Inc., 2021). It is worth noting that there is no mandatory requirement for AquaBounty's salmon to be labeled "genetically modified."

Seafood Guides and Advisories

Besides certifications, various government agencies, and industry and advocacy groups on seafood have released guides and advisories. In the United States, while government agencies provide recommendations on seafood consumption based on human health and risks benchmarks, NGOs have program guides based on the sustainability of seafood sources. In the United States, the FDA, the Environmental Protection Agency (EPA), the Department of Health and Human Services (DHHS), the USDA, and various state governments have published advisories on seafood that consumers should avoid due to risks to human health and recommendations for seafood dietary intake for health benefits.

NGOs provide guides to inform consumers about sustainability issues with a goal of promoting sustainability of fisheries and aquaculture in seafood consumption decisions. Some common guides are from the Monterey Bay Aquarium Seafood Watch program (www.seafoodwatch.org/recommendations/download-consumer-guides), World Wildlife Fund's Seafood Guide (wwf.panda.org/act/live_green/out_shopping/seafood_guides/), Environmental Defense Fund's Seafood Selector (seafood.edf.org/), Fish Choice (fishchoice.com/), and Environmental Working Group's Consumer Guide to Seafood (www.ewg.org/consumer-guides/ewgs-consumer-guide-seafood).

Informational Labeling

Species Naming and Identity

A unique quality of seafood is the number and diversity of species with different common and scientific names. To ensure consistency and use of commonly acceptable names, the FDA (2021) has released a list of acceptable market names for seafood that should be used for labeling the species. EU labeling requirements for retail sale of seafood include information on the commercial designation as well as the scientific names of the species; individual EU countries also have respective national lists of accepted commercial designations (European Union, 2013). These labeling requirements are also meant for transparency—especially for processed seafood—to avoid product substitutions and mislabeling.

An emerging dimension of species naming relates to seafood developed from cell culture technology. The cellular technology involves the potential for producing seafood from fish cell and tissue cultures utilizing biomedical engineering with aquaculture techniques (Rubio et al., 2019). The FDA (2020) sought comments and information on the technology in the *Federal Register* to guide labeling requirements for such products.

Farm-Raised (Farmed) Information

As noted earlier, seafood supply from aquaculture production accounted for 52% of total seafood consumed as food in 2018, with some major species—such as shrimp, salmon, tilapia, catfish, and carp—predominantly farmed. These seafood species are commonly available to consumers in the marketplace and may not be totally different from wild-captured seafood, though there are mandatory requirements for providing information on production method (European Union, 2013; U.S. Department of Agriculture, 2021). Consumer preference for farmed fish is generally mixed and species dependent. While several studies have reported consumer preference for wild-capture seafood, demand for farmed seafood has remained high for some species because of control in the production process, price, and availability (Claret et al., 2016; Rickertsen et al., 2017; López-Mas et al., 2020).

In the United States, production method (wild and/or farm-raised) must be properly labeled or designated on seafood. Acceptable designations are "wild caught," "wild," "farm-raised," "farmed," or a combination if the product is blended from both wild and farm-raised fish or shellfish. The information designation is a requirement for retailers but not food service establishments.

Product Origin

Product origin can be country of origin or a specific marine area where wild capture seafood is harvested. Country of origin is a mandatory requirement in the United States and European Union (European Union, 2013; U.S. Department of Agriculture, 2021). Origin information has allowed countries with strong sustainability guidelines to build reputations on quality and environmental responsibility, differentiating their products from competing nations (Alfnes, 2017). Common examples are American lobster, Alaska pollock, seafood from Norway, Atlantic cod, and European seabass. EU quality programs such as the Protected Geographical Indication (PGI) and Protected Designation of Origin (PDO) are used to promote general food quality (European Union, 2021b). Farmed and wild-capture salmon from Scotland use PGI status for marketing.

One of the major violations NOAA's office of law enforcement deals with is intentional mislabeling of seafood for profit, but the broader benefits of country-of-origin labeling are for traceability and minimizing fraudulent practices associated with labeling.

Conclusion

Global seafood supply from aquaculture has significantly increased from the late twentieth century and currently accounts for about 52% of total global seafood used for human consumption. Seafood consumption is also increasing, driven by increased availability, increased disposable incomes, urbanization, price competitiveness with other proteins, and health and nutrition attributes of fish. Seafood is a major internationally traded commodity resulting in competitive markets. Consequently, increased standardization, certification and verification, and other informational programs have been developed and are being implemented in response to consumer attitudes and preferences as well as health, safety, and environmental concerns. The ultimate goals for these programs are to assure environmental and social responsibility, safety and quality standards, and consumer confidence in seafood in the marketplace.

For More Information

Alfnes, F. 2017. “Selling Only Sustainable Seafood: Attitudes toward Public Regulation and Retailer Policies.” *Marine Policy* 78: 74–79.

Alfnes, F., X. Chen, and K. Rickertsen. 2018. “Labeling Farmed Seafood: A Review.” *Aquaculture Economics and Management* 22(1): 1–26.

Anderson, J.L., F. Asche, and T. Garlock. 2018. “Globalization and Commoditization: The Transformation of the Seafood Market.” *Journal of Commodity Markets* 12: 2–8.

Ankamah-Yeboah, I., J.B. Jacobsen, S.B. Olsen, M. Nielsen, and R. Nielsen. 2019. “The Impact of Animal Welfare and Environmental Information on the Choice of Organic Fish: An Empirical Investigation of German Trout Consumers.” *Marine Resource Economics* 34(3): 247–266.

AquaBounty Technologies, Inc. 2021, May 4. “AquaBounty Technologies Announces First Quarter 2021 Financial Results.” *Yahoo News*. Available online: https://finance.yahoo.com/news/aquabounty-technologies-announces-first-quarter-200500216.html.

Asche, F., M.F. Bellemare, C. Roheim, M.D. Smith, and S. Tveteras. 2015. “Fair Enough? Food Security and the International Trade of Seafood.” *World Development* 67: 151–160.

Canadian General Standard Board. 2018. *Organic Production Systems: Aquaculture - General Principles, Management Standards and Permitted Substances Lists*. CAN/CGSB-32.312-2018. Available online: http://publications.gc.ca/collections/collection_2018/ongc-cgsb/p29-32-312-2018-eng.pdf.

Claret, A., L. Guerrero, I. Gartzia, M. Garcia-Quiroga, and R. Ginés. 2016. “Does Information Affect Consumer Liking of Farmed and Wild Fish?” *Aquaculture* 454: 157–162.

Del Giudice, T., S. Stranieri, F. Caracciolo, E.C. Ricci, L. Cembalo, A. Banterle, and G. Cicia. 2018. “Corporate Social Responsibility Certifications Influence Consumer Preferences and Seafood Market Price.” *Journal of Cleaner Production* 178: 526–533.

Engle, C.R., K.K. Quagrainie, and M.M Dey. 2017. *Seafood and Aquaculture Marketing Handbook*, 2nd ed. Chichester, UK: Wiley-Blackwell.

European Union. 2013. “Markets in Fishery and Aquaculture Products.” *Official Journal of the European Union* L354/1–21. Available online: https://eur-lex.europa.eu/lexuriserv/lexuriserv.do?uri=oj:l:2013:354:0001:0021:en:pdf.

European Union. 2021a. “Organic Production and Products: Rules on Wine Aquaculture and Hydroponics.” *European Commission*. Available online: https://ec.europa.eu/info/food-farming-fisheries/farming/organic-farming/organic-production-and-products_en#rulesonwineaquacultureandhydroponics.

European Union. 2021b. “Quality Schemes Explained.” *European Commission*. Available online: https://ec.europa.eu/info/food-farming-fisheries/food-safety-and-quality/certification/quality-labels/quality-schemes-explained_en.

Food and Agriculture Organization (FAO). 2020. “The State of World Fisheries and Aquaculture 2020. Sustainability in Action.” Rome, Italy: Food and Agriculture Organization of the United Nations.

Food and Drug Administration (FDA). 2020. “Labeling of Foods Comprised of or Containing Cultured Seafood Cells; Request for Information.” *Federal Register* 85(195): 63277–63280. Available online: https://www.govinfo.gov/content/pkg/fr-2020-10-07/pdf/2020-22140.pdf.

Food and Drug Administration (FDA). 2021. *The Seafood List*. Available online: https://www.cfsanappsexternal.fda.gov/scripts/fdcc/index.cfm?set=seafoodlist.

Kobayashi, M., S. Msangi, M. Batka, S. Vannuccini, M.M. Dey, and J. Anderson. 2015. “Fish to 2030: The Role and Opportunity for Aquaculture.” *Aquaculture Economics & Management* 19(3): 282–300.

Kumar, G., and C. Engle. 2016. “Technological Advances that Led to Growth of Shrimp, Salmon, and Tilapia Farming.” *Reviews in Fisheries Science and Aquaculture* 24(2): 136–152.

López-Mas, L., A. Claret, M.J. Reinders, M. Banovic, A. Krystallis, and L. Guerrero. 2020. “Farmed or Wild Fish? Segmenting European Consumers Based on Their Beliefs.” *Aquaculture* 532: 735992.

National Fisheries Institute (NFI). 2021. “NFI’s Top 10 List Suggests Consumers Diversifying Seafood Consumption.” Available online https://aboutseafood.com/press_release/nfis-top-10-list-suggests-consumers-diversifying-seafood-consumption/.

National Oceanic and Atmospheric Administration (NOAA). 2020. *Fisheries of the United States, 2018*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Available online: https://www.fisheries.noaa.gov/resource/document/fisheries-united-states-2018-report.

National Oceanic and Atmospheric Administration (NOAA). 2021. *Fisheries of the United States, 2019 Report*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Available online: https://www.fisheries.noaa.gov/resource/document/fisheries-united-states-2019-report.

Orlowski, A. 2017, December 17. “Organic Standards for US Farmed Seafood Going Nowhere Despite Market Demand.” *SeafoodSource*. Available online: https://www.seafoodsource.com/features/organic-standards-for-us-farmed-seafood-going-nowhere-despite-market-demand.

Prag, A., T. Lyon, and A. Russillo. 2016. “Multiplication of Environmental Labelling and Information Schemes (ELIS): Implications for Environment and Trade.” OECD Environment Working Papers No. 106. Available online: https://doi.org/10.1787/5jm0p33z27wf-en.

Rickertsen, K., F. Alfnes, P. Combris, G. Enderli, S. Issanchou, and J.F. Shogren. 2017. “French Consumers’ Attitudes and Preferences toward Wild and Farmed Fish.” *Marine Resource Economics* 32(1): 59–81.

Rubio, N., I. Datar, D. Stachura, D. Kaplan, and K. Krueger. 2019. “Cell-Based Fish: A Novel Approach to Seafood Production and an Opportunity for Cellular Agriculture.” *Frontiers in Sustainable Food Systems* 3(43): 1–13.

Shamshak, G.L., J.L. Anderson, F. Asche, T. Garlock, and D.C. Love. 2019. “US Seafood Consumption.” *Journal of the World Aquaculture Society* 50: 715–727.

Tveteras, S. 2015. “Price Analysis of Export Behavior of Aquaculture Producers in Honduras and Peru.” *Aquaculture Economics and Management* 19(1): 125–147.

UN Convention on the Law of the Sea (UNCLOS). 1982. Available online: https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf.

U.S. Department of Agriculture (USDA). 2020. *Food Availability (per Capita) Data System*. Available online: https://www.ers.usda.gov/webdocs/datafiles/50472/meat.xls?v=5661.

U.S. Department of Agriculture, Agricultural Marketing Service. 2021. “Electronic Code of Federal Regulations – PART 60—Country of Origin Labeling for Fish and Shellfish.” *Federal Register* 74: 2657–2707. Available online: https://www.ecfr.gov/current/title-7/part-60.

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Go FISH: U.S. Seafood Consumers Seek Freshness, Information, Safety, and Health Benefits

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Seafood Can Be an Efficient and Healthier Source of Protein

The United States will become the fourth most populous country in 2050, with 379 million people, while the world population is expected to reach 10 billion people (United Nations, 2019). In this context, agricultural research has focused on discovering strategies to ensure food production can meet this increasing food demand. This study evaluated ongoing changes in social aspects of demand for seafood as a source of protein by identifying individuals' preferences moved by the effect of interlinked scientific and technological development within boundaries of environmental sustainability on food production systems.

Seafood is a healthy source of animal protein, providing calcium and minerals, omega-3 and other beneficial fatty acids, and vitamins B12 and D (USDA and HHS, 2020). Seafood also has an environmental advantage in terms of resource use in relation to other animal protein production systems. With an efficient feed conversion rate (FCR), estimated as the proportion of feed intake by the weight gained by the animal, fish production has a lower environmental impact as less feed is required to produce a ton of fish (d'Orbcastel, Blancheton, and Aubin, 2009; Besson et al., 2014; Besson et al., 2016), between 1.0 and 2.4, compared to 6.0–10.0 in beef, 2.7–5.0 in pigs and 1.7–2.0 in chicken (Fry et al., 2018). This efficient FCR, along with high fertility rates, also contributes to a significantly lower greenhouse gas (GHG) emission intensity than ruminants, another important contribution of seafood aquaculture to environmental sustainability (MacLeod et al., 2020).

Seafood Consumers Are Looking for a Healthier Diet

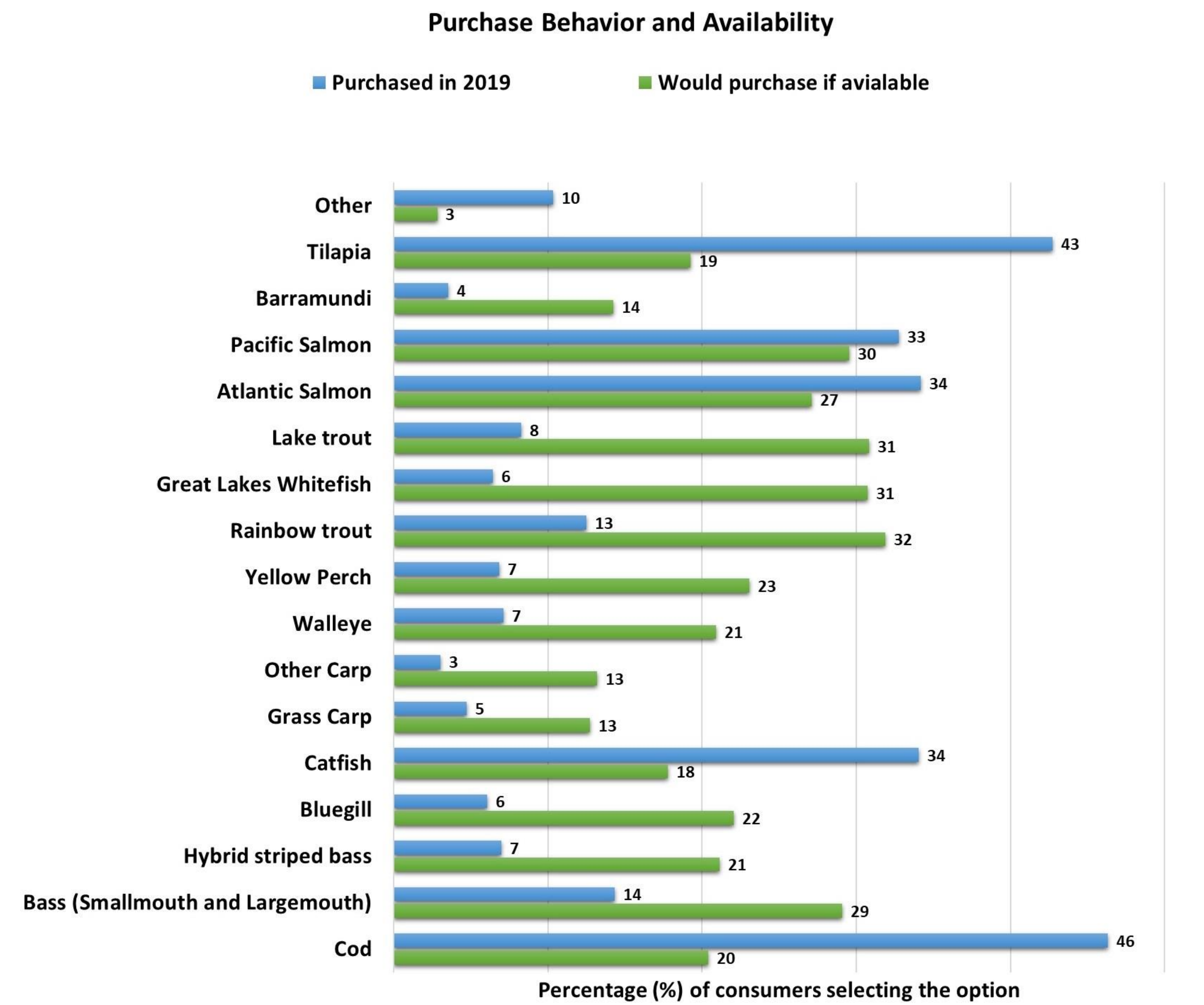
U.S. per capita seafood consumption is below the global average but has grown 25% since 1990, of which 10% happened in the last decade (National Marine Fisheries Service, 2021; USDA, 2021). Market reports credit this growing demand for seafood to consumers' increasing consciousness of the benefits of eating a healthier diet (Roberts, 2021). Although market researchers attribute the large increase in U.S. retail sales of seafood in 2020 to the closure of restaurants during the COVID-19 pandemic, sales have been steadily increasing for years. Retail sales grew from $14 billion in 2016 to $16 billion in 2019 and then soared to $19.8 billion in 2020 (Roberts, 2021). A major reason why consumers buy seafood is its perceived health benefit, especially compared to red meat; seafood is also considered tasty and a good source of protein (Murrary, Wolff, and Patterson, 2017; Averbook, 2018; Roberts, 2021).

Addressing an Increasing Seafood Consumer Demand

Despite the potential increase in demand from market trends that favor seafood consumption, U.S. seafood production—both from fisheries and aquaculture—struggles to grow as it faces supply-chain driven challenges (Hull, 2005), high production costs (Engle, van Senten, and Fornshell, 2019), and lower market prices induced by international producers with lower production costs. The United States runs a large seafood trade deficit, importing from 70% to 85% of the seafood it consumes (Engle, Quagrainie, and Dey, 2017; National Marine Fisheries Service, 2021).

This study provides insights into the U.S. seafood consumer demand to inform the industry about opportunities to expand the share of domestically produced seafood consumption. First, preferences for specific species are drawn, including popular species encountered in retail and other Midwest-caught or produced species, which take a smaller share of current markets but are still part of the U.S. consumers' culture and culinary tradition. Second, attitudes toward attributes and market claims which may benefit both fisheries and aquaculture industry are assessed. To that end, a

Figure 1. Percentage of Consumer Preferring Fish Species Available to them in 2019 and Hypothetical Choices If All Species Were Made Available



nationwide online survey of U.S. seafood consumers was distributed in the fall of 2020, using Qualtrics. Though the demographics of the final sample skew younger, more White, and lower on the income spectrum than the national average, it is nationally representative.

What Species of Seafood Are Consumers Looking For?

To elicit purchase behavior, consumers were first asked which species they purchased in 2019. Respondents chose from 16 species of finfish (Figure 1). Cod was the top ranked purchase, chosen by 46% of respondents, followed by tilapia (43%) and catfish (34%) and Atlantic salmon (34%). These results reflect the variety of species consumed but also emphasize that U.S. consumers of fish and seafood focus on only a few species (Shamshak et al., 2019). A second question explicitly asked what species consumers would have bought if all 16 listed species had been made available. An opportunity was identified here to expand smaller markets as consumers exhibited willingness to purchase Midwest species instead of tilapia, cod, or catfish if made available at their chosen market channel. Rainbow trout led the national list (Figure 1), as 32% of respondents requested the species, followed by the Great Lakes whitefish (31%), and lake trout (31%). Midwest-produced or caught species such as lake and rainbow trout, Great Lakes whitefish, yellow perch, walleye, and bluegill appear to have a greater demand than currently estimated by suppliers, indicating an underserved market for these species.

Seafood Consumption at Home and Away from Home

Restaurants are reportedly the primary outlet for seafood consumption in the United States, and those who order seafood at restaurants tend to have higher than average incomes (Engle, Quagrainie, and Dey, 2017; Love et al., 2020). In this study, 80% of respondents reported eating seafood both at home and away from home while equal proportions, 8%, ate seafood only at home or only in a restaurant. Individuals earning at least $75,000 were less likely to consume seafood at home, while those earning under $75,000 were less likely to eat seafood in a restaurant.

Traditional supermarkets served as the major outlet for seafood shoppers purchasing for home consumption, with 74% purchasing in store and 22% purchasing online or delivery sales. Seafood shoppers frequented mass merchandisers second as much, with 58% of those customers buying at the store and 16% choosing online and delivery. Given the growing trend in fisheries and aquaculture to seek direct-to-consumer sales, consumers were asked if they bought seafood from farmers' markets or food subscription and delivery services. About a third (34%) reported patronizing farmers' markets and 22% subscribed to such services.

The comparative lack of seafood consumption at home stems predominantly from perceived difficulty or uncertainty regarding seafood preparation but includes other factors such as the perceived expense of seafood or the smell of uncooked seafood, often associated with freshness of seafood. High prices observed in restaurants lead as the main reason respondents did not eat seafood in a restaurant.

Purchases of Fresh and Frozen Seafood

Alternative forms of seafood were presented to respondents when asked about their past year purchases, including fresh, frozen, or live, with value-added options such as breaded, fresh prepared, or smoked. Overall, consumption of fish was larger than shellfish or mollusks in this study (Table 1). Similar proportions of respondents purchased fresh and frozen fish, possibly reflecting consumers' acceptance of new flash-freezing technologies. Of the individuals who bought fish, 49% of respondents purchased frozen fillets and 48% purchased fresh fillets. Only 24% of respondents purchased a value-added option of either "frozen and breaded" or "fresh and prepared" fish, showing a preference for less value-added products (Surathkal et al., 2017). A clear preference for fresh was observed between individuals who bought shellfish, with 69% of respondents purchasing fresh and 61% of respondents purchasing frozen whole shellfish. In the case of shellfish sold as tails, frozen was purchased by 39% of respondents while 31% of respondents purchased fresh tails. Mollusks are also purchased fresh more frequently than frozen. Value-added options such as smoked or shelf stable, the least popular choice, represented less than 3% of their purchases.

Purchases of Wild-Caught and Farm-Raised Seafood

When asked whether the seafood they bought was farm-raised or wild-caught, on average per species, a third of

Table 1. Percentage of Respondents Choosing between Forms of Seafood When Purchasing Fish, Shellfish, and Mollusks

Forms of Product (average all species)		Fish	Shellfish (crustaceans)	Mollusks
Sample selection (*N* = 1,416)		99%	77%	37%
Frozen	Whole	27%	61%	36%
	Fillets	49%	—	—
	Breaded[a]	24%	—	—
	Tails	—	39%	—
Fresh	Whole	28%	69%	42%
	Fillets	48%	—	—
	Prepared[b]	24%	—	—
	Tails	—	31%	—
Live		2.2%	3.8%	10%
Smoked		2.4%	2.9%	7%
Shelf stable (cans/pouches)		1.7%	2.4%	6%

Notes: [a]Frozen breaded fish products include fish sticks or breaded fillets.
[b]Fresh prepared fish products include marinated or seasoned fillets or portions.

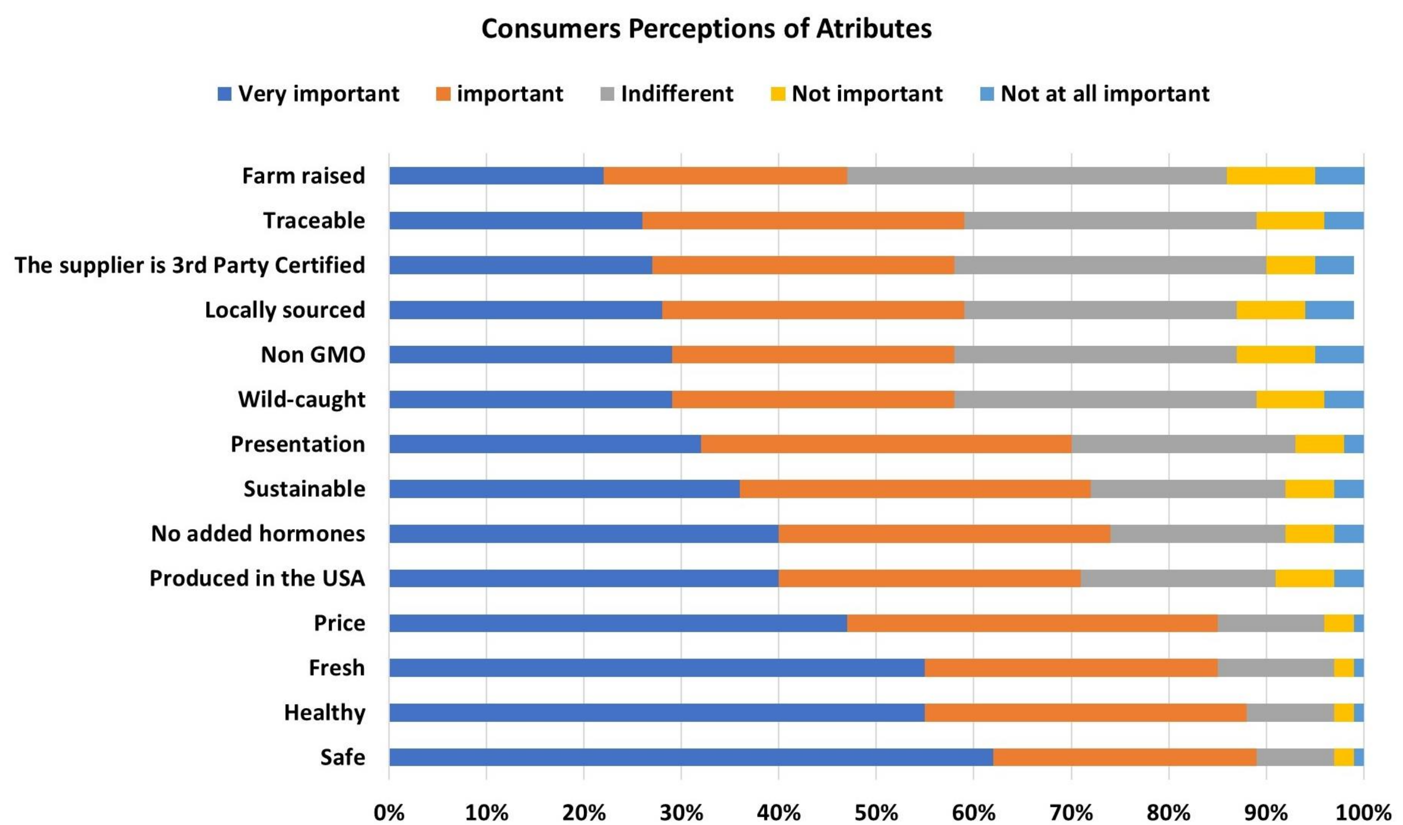
mollusks and shellfish consumers and a quarter of individuals who had bought finfish were uncertain. The percentage of consumers' wild-caught purchasing choice were consistently higher than farm-raised for all mollusks and shellfish, with an average between all species of 43% and 45%, respectively, compared with 25% of farmed mollusks and shellfish. The scenario for fish-purchasing choices differs between species. Hybrid striped bass, grass carp, and barramundi were more frequently chosen with the understanding that these are farm-raised. Cod, Pacific and Atlantic salmon, and walleye were bought as wild-caught almost twice as much as farm-raised, but a third of respondents were unsure, which could express indifference toward the production system, especially cod consumers (37%). Yellow perch, rainbow trout, bass (including smallmouth and largemouth), lake trout, and bluegill purchased by consumers were predominately wild-caught by about 10% more than farm-raised. Only a fifth to a quarter of respondents were uncertain about production systems for these species. Highest uncertainty, and possible indifference, was observed for tilapia (41%).

Consumers Attitude toward Seafood Attributes

Questions were designed in this study to not only identify consumers perceptions regarding attributes of seafood but also to untangle preferences between attributes (Figure 2). In particular, the question "How important are these attributes for you when choosing seafood?" was asked twice with two sets of attributes, combined to measure the importance consumers ascribe to labels of "wild-caught," "farm-raised," "3rd party certification," "non GMO," "no added hormones," "safe," and "presentation," separately from their personal values attributed to "fresh," "healthy," "sustainable," "produced in the USA," "locally sourced," "traceable," and how important "price" is when purchasing seafood.

At an aggregated level, consumers showed awareness about the importance of food safety guaranteed by a regulatory system they trust, along with maintaining a healthy diet and freshness. Specifically, 62% of participants ranked "safe" as a "very important" attribute when purchasing seafood. "Healthy" and "fresh" ranked second, each rated "very important" by 55% of respondents, but "healthy" had a small edge of 3% in "important" over "fresh." Next comes "price," with 47% selecting "very important." Another significant result unveiled here was the portion of individuals selecting U.S. production as "very important" (40%) or "important" (31%) when choosing seafood products. This may indicate the trust consumers place on American food safety control systems and institutions. "Farm-raised" was the least important attribute, with 22% choosing the "very important" options and also recorded the higher score of indifference to the claim, 39%, and the highest

Figure 1. Overall Percentage of Consumers Selecting "Very Important," "Important," "Indifferent," "Not Important," or "Not Important at All" in Relation to Selected Seafood Attributes



score for combined “not important” and “not important at all,” 14%. Less than 30% selected “very important” for “wild-caught” and “non-GMO” labels, as well as “locally sourced,” “supplier having a 3rd party certification,” and “traceable.”

Consumers Attitude toward Seafood Attributes by Demographics

A detailed look into demographics shows contrasting preferences between ethnic groups, gender, age, and household income levels.

Food safety was overall the most important attribute to all respondents, but particularly “very important” to women, Hispanic consumers, respondents earning between $25,000 and $50,000, and those 55–64 years old.

Healthy, the second most important attribute overall, ranked most important to the highest income bracket of “$150,000 or more,” individuals between 45 and 54 years old, and all ethnic groups, but more so to Hispanic and Black respondents.

Fresh is “very important” to consumers who are 45–54 years old and those in the highest income bracket, although lower-level income earners also find it “important” when choosing seafood. Respondents from all ethnic groups find freshness very important.

Price of seafood is a concern for most respondents, although the proportion of individuals indifferent or declaring price to be “not important” or “not important at all” increases as age decreases. About 2% more of women find price very important compared to men. Like freshness, price was very important to highest income earners. Within the ethnic groups, 54% of Hispanic respondents find “price” very important compared to lower levels of importance by Asian (43%) and Native American (33%) consumers.

Produced in the USA and locally sourced: Although an important attribute for some consumers (Fonner and Sylvia, 2014; Murray, Wolff, and Patterson, 2017), “localness” is neither well-defined nor well understood. To disentangle consumers’ perceptions toward local production from the trust associated with U.S. production, both market claims appeared on the same question. Overall, an excess of 10% valued the latter more. “Produced in the USA” was mostly considered very important by Black (48%) and Hispanic (42%) respondents. The youngest adults sampled, 18-to-24-year-olds, showed the highest level of indifference of any age group toward U.S. production. Opportunities to grow these segments include informing the public about the regulatory frameworks and how these institutions guarantee safe food for consumers. Locally sourced, on the other hand, is very important for Black (36%) and White (28%) consumers. Youngsters share a similarly high indifference to locally sourced claims (34%) with those aged 65 and higher (34%). Lower income earners place more value on the claim “produced in the USA,” while higher income earners value “locally sourced” claims more.

No added hormones claims resonated more with females, those in the 45–64 age bracket, higher income earners, and Black and Hispanic, but were least important to Native American respondents, about a third of 18-to-24-year-olds, those earning less than $25,000, and men.

Sustainable and third-party certification: Sustainable production is very important to almost 40% of individuals aged 35–44 and 45–54; men; individuals of Hispanic, Black, and White ethnicities and to half of those earning more than $150,000. These are also the groups that valued products with a third-party certification the most, although Black consumers, high income earners, and 35-to-44-year-olds rely more on the certification label than other ethnic groups.

Presentation was more important to females and to about 40% of high-income earners, people aged 35–44, and those within the Hispanic and Black ethnic groups. A higher combination of indifference and no importance was shown by lower income earners, both the youngest and the oldest groups, and the Native American and Asian groups.

Non-GMO was relatively unpopular in this sample but was of increasing importance as age increased up to 64 years old and more important as income increased. Women found the claim more important than men and among ethnic groups, about a third of Hispanic, Black, and Native American respondents found the non-GMO claim to be very important.

Traceable is a relatively new term to consumers, as processors have only recently made the feature available, which may explain the low importance given by consumers to an ability of track the source of their seafood. Only about a third of sampled consumers, predominantly 45-to-64-year-olds, high-income earners, and men, found it very important to be able to trace their seafood through the supply chain.

Wild-caught and farm-raised: Consumers attributed the least importance to claims of farm-raised and wild-caught production, with large segments reporting indifference or a lack of importance from production system labels. A small indifference to the farm-raised label was reported by the highest income earners and the highest by those age 65 years old or older. Although a third of 35-to-44-year-olds, very high-income earners, men, and Asian and Black consumers found it very important that their seafood be farm-raised. The youngest were indifferent about both farm-raised and wild-caught claims. Half of very high-income earners and about a third of male and individuals aged 35–44 found it very important that their seafood to be wild caught. Among ethnic groups, Native Americans and Hispanics valued most wild-caught as a characteristic of their seafood.

Conclusion

Worldwide, research focuses on sustaining sufficient supply of nutritious food to a fast-growing population. Fish emerges as an efficient use of resources in production of animal protein given its efficient feed conversion ratio (FCR) and low greenhouse gas (GHG) emission intensity compared to other sources of protein. Growing consumer awareness regarding nutritional value and health attributes of seafood, acceptance of new seafood preservation technologies, and increasing trust in environmental responsibility and food safety standards have contributed to a sharp increase in per capita seafood consumption worldwide. These trends are also observed in the United States, where consumption per capita has grown quickly. Despite its potential to expand, the U.S. seafood industry remains a commodity business with low profit margins. Consequently, demand is met through imports. This study aimed to identify demand for domestically produced and culturally important species and highlighted current market trends that favor attributes of seafood to offer opportunities to expand current markets.

Three main opportunities for the industry were identified in this study: to target underserved markets for species traditionally raised or caught in the North Central region, such as lake and rainbow trout, Great Lakes whitefish, yellow perch, walleye, and bluegill; to design labels with detailed information about food safety measures taken in production and healthy contents of their product; and to target fresh fillet markets while effectively operating the supply chain to access additional markets. An opportunity for the small-scale producer is to target least-offered species that are still sought by consumers, possibly through specialty seafood outlets and adopting alternative marketing mechanisms, such as the development of processing facilities for distributing high valued (demand-driven) direct-to-consumer seafood.

For More Information

Averbook, M. 2018. *Fish and Shellfish, US – November 2018*. Mintel Group.

Besson, M., H. Komen, J. Aubin, I.J.M. de Boer, M. Poelman, E. Quillet, C. Vancoillie, M. Vandeputte, and J.A.M. van Arendonk. 2014. “Economic Values of Growth and Feed Efficiency for Fish Farming in Recirculating Aquaculture System with Density and Nitrogen Output Limitations: A Case Study with African Catfish (*Clarias gariepinus*)”. *Journal of Animal Science* 92(12): 5394–5405.

Besson, M., J. Aubin, H. Komen, M. Poelman, E. Quillet, M. Vandeputte, J.A.M. van Arendonk, and I.J.M. de Boer. 2016. “Environmental Impacts of Genetic Improvement of Growth Rate and Feed Conversion Ratio in Fish Farming under Rearing Density and Nitrogen Output Limitations.” *Journal of Cleaner Production* 116: 100–109.

d’Orbcastel, E.R., J-P. Blancheton, and J. Aubin. 2009. “Toward Environmentally Sustainable Aquaculture: Comparison between Two Trout Farming Systems Using Life Cycle Assessment.” *Aquacultural Engineering* 40(3): 113–119.

Engle, C.R., K.K. Quagrainie, and M.M. Dey. 2017. *Seafood and Aquaculture Marketing Handbook,* 2nd ed. Hoboken, NJ: Wiley-Blackwell.

Engle, C.R., J. van Senten, and G. Fornshell. 2019. “Regulatory Costs on U.S. Salmonid Farms.” *Journal of the World Aquaculture Society* 50: 522–549.

Fonner, R., and G. Sylvia. 2014. “Willingness to Pay for Multiple Seafood Labels in a Niche Market.” *Marine Resource Economics* 30(1): 51–70.

Fry, J.P., N.A. Mailloux, D.C. Love, M.C. Milli, and L. Cao. 2018. “Feed Conversion Efficiency in Aquaculture: Do We Measure It Correctly?” *Environmental Resource Lett*ers 13: 024017.

Hull, B.Z. 2005. “Are supply (driven) chains forgotten?”, *International Journal of Logistics Management, The*, 16(2): 218-236.

Love, D.C., F. Asche, Z. Conrad, R. Young, J. Harding, E.M. Nussbaumer, A.L. Thorne-Lyman, and R. Neff. 2020. “Food Sources and Expenditures for Seafood in the United States.” *Nutrients* 12(6): 1810.

MacLeod, M.J., M.R. Hasan, D.H.F. Robb, and M. Mamun-Ur-Rashid. 2020. “Quantifying Greenhouse Gas Emissions from Global Aquaculture.” *Scientific Reports* 10: 11679.

Murray, G., K. Wolff, and M. Patterson. 2017. “Why Eat Fish? Factors Influencing Seafood Consumer Choices in British Columbia, Canada.” *Ocean & Coastal Management* 144: 16–22.

National Marine Fisheries Service. 2021. *Fisheries of the United States, 2019*. Washington, DC: U.S. Department of Commerce, NOAA Current Fishery Statistics No. 2019.

Roberts, W. Jr. 2021. *Fish and Shellfish, US – February 2021*. Mintel Group.

Shamshak, G.L., J.L. Anderson, F. Asche, T. Garlock, and D.C. Love. 2019. “US Seafood Consumption.” *Journal of the World Aquaculture Society* 50: 715–727.

Surathkal, P., M.M. Dey, C.R. Engle, B. Chidmi, and K. Singh. 2017. “Consumer Demand for Frozen Seafood Product Categories in the United States.” *Aquaculture Economics & Management* 21(1): 9–24.

U.S. Department of Agriculture and U.S. Department of Health and Human Services (USDA and HHS). 2020. *Dietary Guidelines for Americans, 2020-2025*, 9th ed. Available online: http://www.dietaryguidelines.gov.

U.S. Department of Agriculture, Economic Research Service (USDA-ERS). 2021. *Food Availability (Per Capita) Data System*, by Linda Kantor and Andrzej Blazejczyk. Available online: https://www.ers.usda.gov/data-products/food-availability-per-capita-data-system/.

United Nations. 2019. *World Population Prospects 2019: Highlights*. United Nations, Department of Economic and Social Affairs, Population Division ST/ESA/SER.A/423.

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Voices from the Industry: Aquaculture Producers in the Midwestern United States

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JEL Classifications: Q10
Keywords: Aquaculture producers, Qualitative research, USDA North-Central Region

Aquaculture in the Midwest: Promise and Stagnation

The promise of Midwest aquaculture lies in the region's history and status as a major agricultural center within the United States. The twelve states in the USDA North-Central Region (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin) compose about 22% of the country's land but contain about 33% of the country's farms, 32.5% of the country's farmland, and 39.1% of the market value of agricultural crops in the United States (U.S. Department of Agriculture, 2019a). Given this agricultural prowess, there is reason to believe that the region could be a strong aquaculture producer as well, leveraging the experience and efficiencies of the existing agriculture industry. However, despite the strong regional agriculture and despite the fact that the North-Central Region states are home to approximately 21% of the U.S. population (U.S. Census Bureau, 2019), the region has only about 16% of the foodfish aquaculture farms in the United States, which collectively represent about 1.4% of annual U.S. farmed foodfish sales, a number that has been flat or even decreasing over the last 20 years (U.S. Department of Agriculture, 2019b) (Figures 1–2).

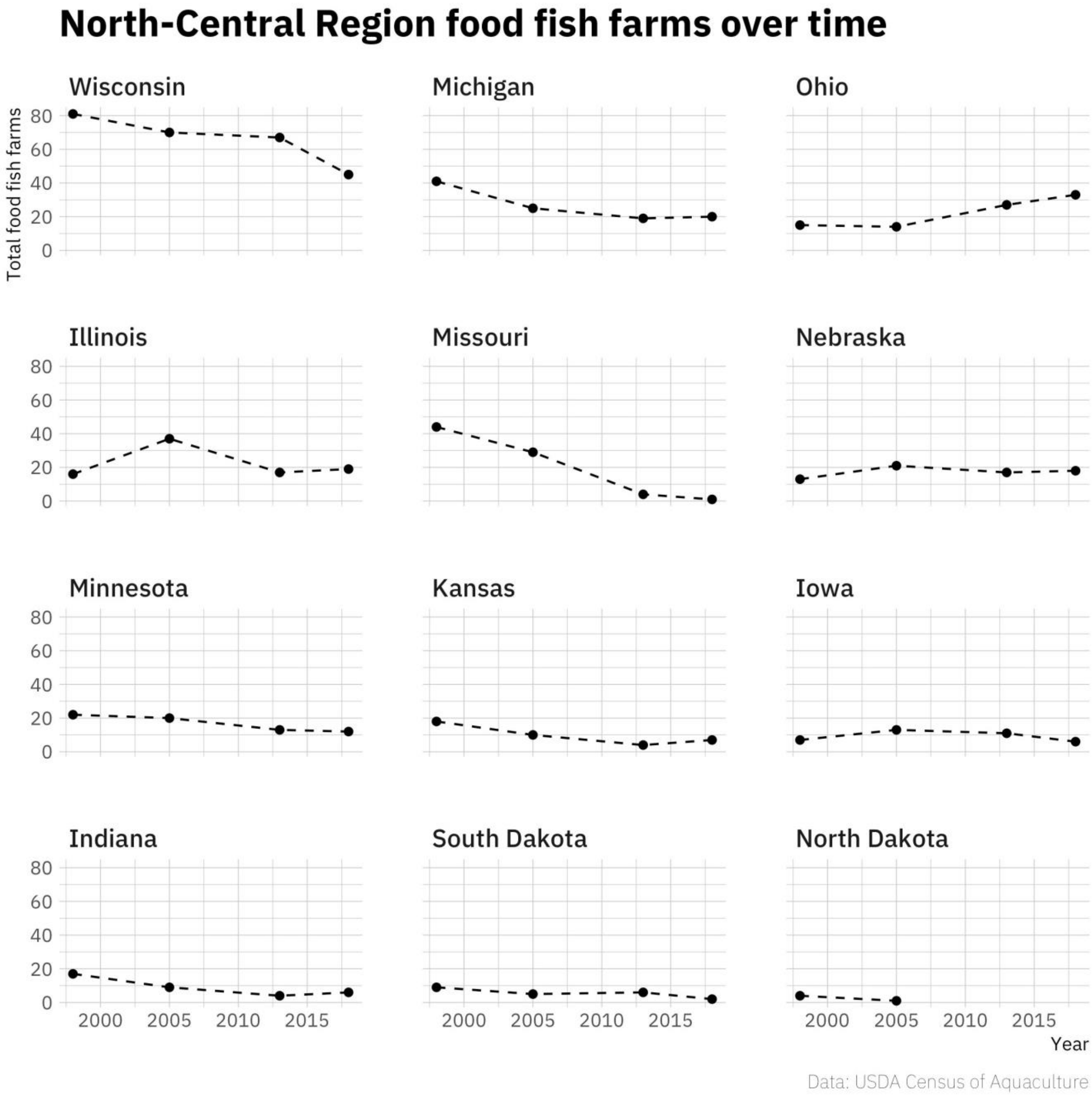
Several factors likely contribute to the relatively soft Midwestern local-sourced foodfish market. First, Midwestern consumers eat less seafood than residents of coastal areas (U.S. Environmental Protection Agency, 2014) and therefore may be less likely to demand locally produced seafood. The reasons for this are not exactly clear and have not been studied extensively; anecdotal speculation includes sociocultural differences in the Midwest palate, a culinary culture that is more focused on farmed livestock such as beef, or the chicken-or-egg problem of a lack of sources of seafood leading to less seafood consumption and vice versa. Second, the Midwest has historically relied on wild-caught seafood, both locally caught and imported. Third, seafood produced in the Midwest often has to compete with cheaper, imported seafood, which may suppress demand. And finally, the Midwest may produce less foodfish than expected because other aquaculture markets (e.g., baitfish or pond-stocking) are relatively more lucrative.

Regardless, a stagnant Midwestern foodfish aquaculture industry has national implications given the large and growing trade deficit in edible seafood (Figure 3), the second-largest natural resources trade deficit behind oil (National Marine Fisheries Service, 2021). A Midwestern population that ate more locally produced farmed and wild-caught seafood might reduce that deficit over time.

Against this backdrop—and against a backdrop of increasing feed, fuel, and other expenses—aquaculture producers are working to grow and market their products to maintain or increase their market share and profitability. How do producers do that in this region? How do they meet the challenge of setting prices and marketing their food? How do they view regulation? The answers to these questions can help policy makers, regulators, and land grant universities be more responsive to aquaculture producers' needs.

To begin to explore these questions, we interviewed 30 aquaculture producers across the Midwest region as part of our work with the Great Lakes Aquaculture Collaborative and the Eat Midwest Fish projects. We used our professional networks to identify and select the 30 producers to represent a diverse range of production methods, species produced, and geographic locations. As part of these qualitative interviews, we asked producers about their pricing, business expansion plans, and their thoughts about regulators and regulations. These interviews took place in late 2019 and January 2020, before the COVID-19 pandemic affected the region.

Figure 1. USDA North-Central Region Food Fish Farms over Time as Reported in the USDA Census of Aquaculture



Notes: Nonrespondents are not accounted for in these data.

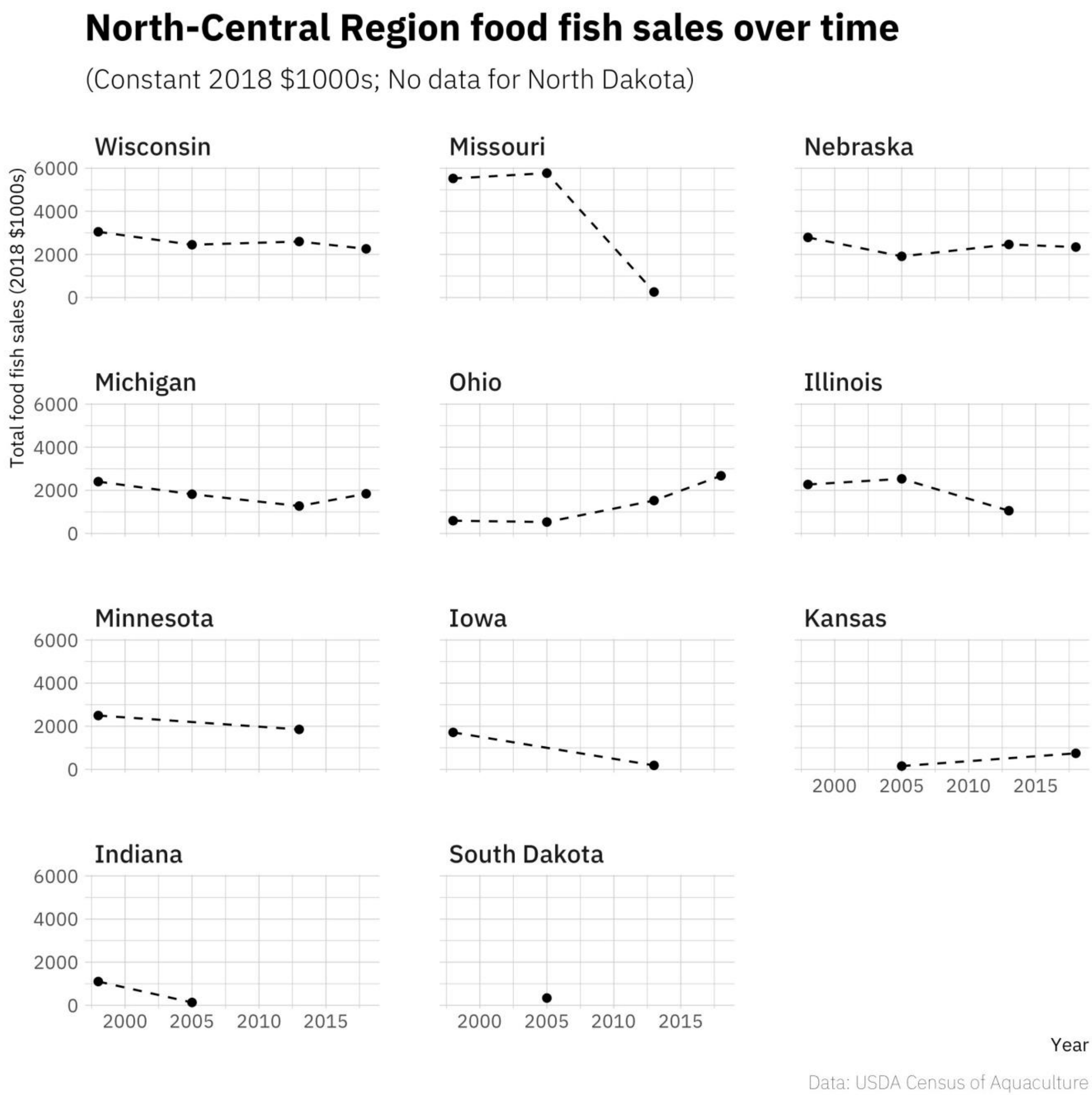
After interviewing the producers, we transcribed the interviews and coded them using *inductive coding*, a process of examining the interview responses for emergent themes without a predefined notion of what those themes might be (Miles, Huberman, and Saldana 2014). Inductive coding allows researchers to remain open to and consider the potential nuances and multiple meanings of the responses before categorizing them.

Our findings are detailed below. It is important to remember that these are qualitative interviews within a specific region, so the goal of our study was not to draw general conclusions about all aquaculture producers. However, by forgoing the need to generalize we can focus on specific frames and themes that fill out the larger story, adding richness and nuance to our understanding of the producers' experiences.

Producers Generally Sell on Farms and in Restaurants

Most of the producers we interviewed sold their fish locally or within a narrow region. When asked to identify their *most important* sales channel (see Table 1), in-

Figure 2. USDA North-Central Region Food Fish Farm Sales over Time as Reported in the USDA Census of Aquaculture



Notes: Nonrespondents are not accounted for in these data.

person, on-farm sales were listed by five producers, restaurants by four, grocery stores by three, and ethnic markets and fish haulers by two each, with other channels (live markets, farmers' markets, processors, etc.) mentioned by zero or one producer. When asked why the channels they chose were most important, the answers were consistent: money. As one producer put it, their most important channel is the one that "pays the bills every week," although another producer indicated that the potential brand-recognition benefits of selling at a farmers' market were important, too.

Producers Use a Variety of Pricing Strategies

Pricing is a consistent challenge for small businesses across industries, and Midwestern aquaculture is no different. One producer expressed their frustration with the challenges of setting a sustainable price succinctly: "Our pricing is awful." We asked producers to describe how they priced their products in the marketplace, first as an open-ended question. After transcribing and reviewing their answers, we found the following common

Figure 3. US Edible Seafood Trade Deficit over Time

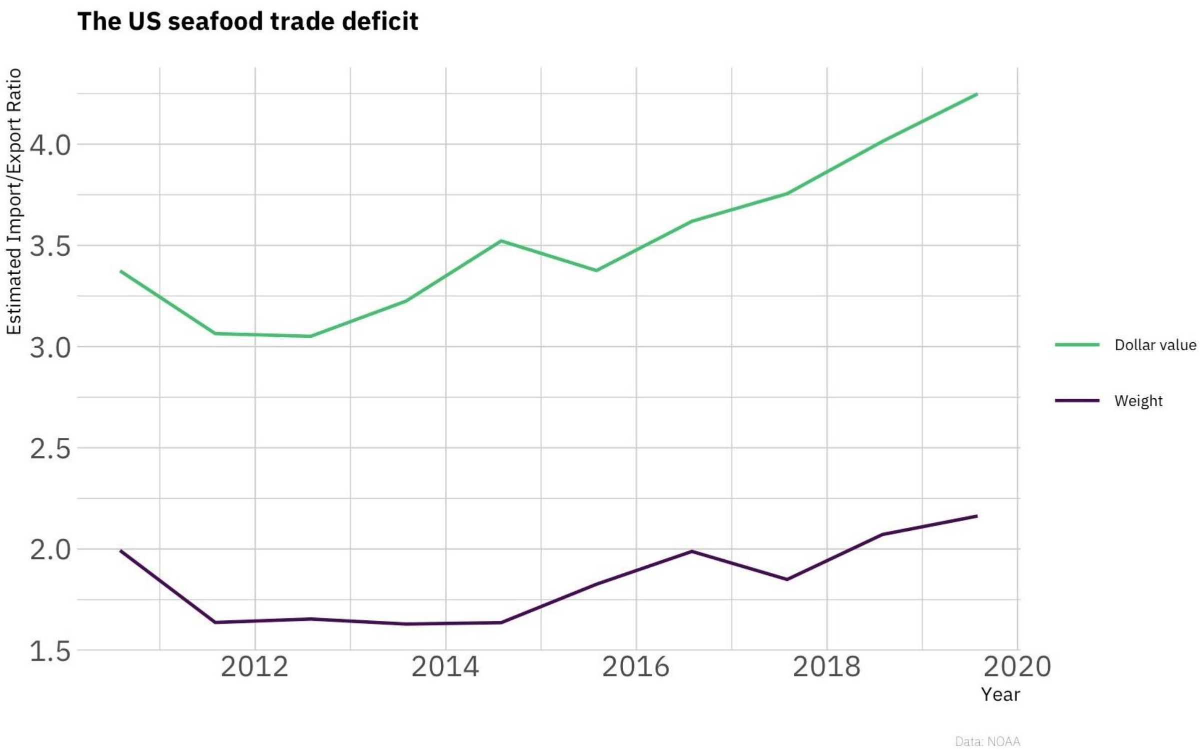


Table 1. Sales Channels Mentioned by Aquaculture Producers

Channel	Total mentions (of 30 producers)
In-person, on-farm	17
Restaurant	12
Ethnic markets/grocery stores	4
Grocery stores	4
Live markets	3
Farmers' markets	2
Fish haulers	2
Family and friends	1
Online	1
Distributors	1

themes (note that since these were open-ended interviews, not every producer gave a "codeable" response, so the number of mentions will not add up to 30):

Price based on prevailing market (mentioned by five producers): This theme indicates a producer who prices their product primarily to be in line with existing market prices, based either on conversations with customers/distributors or by looking at the markets. This is often an imprecise process, as described by an Ohio producer, who said, "You hear what (fish) are going for up at Lake Erie, you kind of look on restaurant menus and just get a feel for what people are already paying and try to be somewhere in that area."

Price as a premium product (four producers): Many producers perceive and price their product as premium compared to the market, either because of freshness, local origin, traceability, or perceived environmental quality of fish raised in the United States compared to other parts of the world. For example, a producer told us that, "I put a small premium (on the prevailing price) because what they were getting is not a similar product in terms of the quality of the water. And this is especially true for tilapia overseas: they often are not in high water quality situations, with very polluted waters…and essentially sewage coming out of some other farm."

One producer explicitly mentioned using the premium price as a signal of quality: "There's a tagline from Stella [Artois], which is a beer that I love… 'Reassuringly Expensive.' And that's where I want to be."

Price as low as possible (two producers): This describes a producer who prices their fish as low as they can while preserving profitability. As one producer phrased it, "[Our species of fish] is becoming commoditized a little bit and it's becoming an item that is almost like ground beef… we want to be the cheapest on [our fish]."

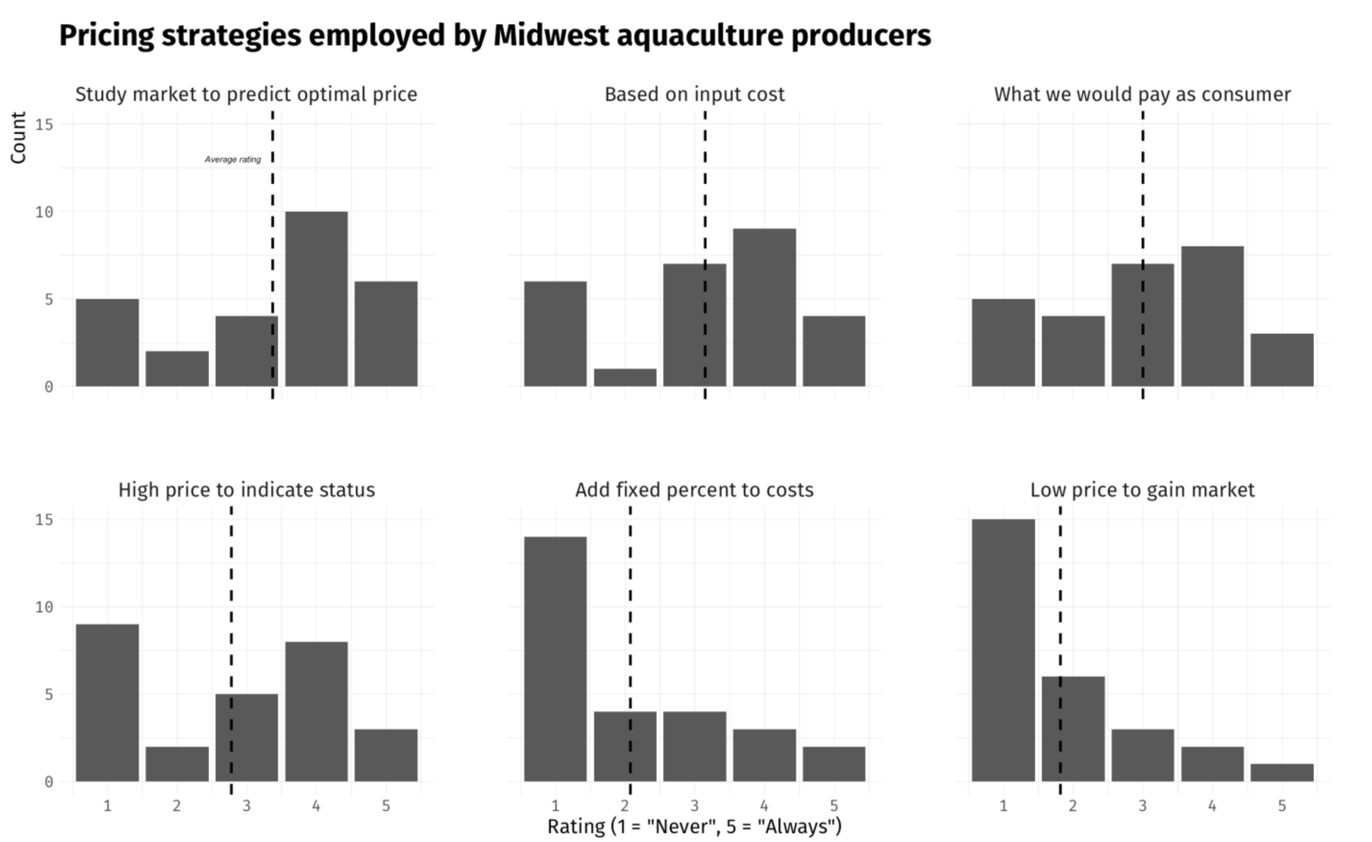
Price compared to other proteins (two producers): Two producers explicitly mentioned their fish as competing with other, nonfish sources of protein, which they consider when pricing: "At the end of the day, you know, you're not just competing against the tuna or the swordfish in the (seafood) case, you're competing with the protein choices that are further down the aisle: chicken and beef and pork. And so you're competing for people's protein. You have to try to keep an eye on protein prices are in general."

After the open-ended question about pricing, we asked a more standardized version, wanting to know how often the producers use each of the following pricing strategies:

- We charge a low price designed to gain market share.
- We set prices based on how much we would want to pay if we were the consumer.
- We add a fixed percentage to our costs to establish a price.
- We study the market to try to predict what price will produce optimal results.
- We set a high price in order to establish the status of our brand.
- We set prices based on the cost of our ingredients and other inputs.

The full results can be found in Figure 4. The highest-rated strategies were "We study the market to try to predict what price will produce optimal results" (average rating of 3.37/5) and "We set prices based on the cost of

Figure 4. Producer Pricing Strategies



our ingredients and other inputs” (average rating of 3.33/5). The lowest-rated strategy was “We charge a low price designed to gain market share” (average rating 1.81/5), though several producers rated that strategy highly.

Producers Are Generally Optimistic about Business Expansion

Despite aquaculture’s mixed history in the Midwest, most of the producers that we talked to were trying to expand their business in the near-term, with only seven of 30 indicating that they were not. Of those who indicated that they were looking to expand, the most common themes included:

Expanding to meet demand and increase profits (four producers): Many people who said they were expanding said they were doing so to meet demand and increase profitability. As one producer said, “We’re expanding so I can sell more [product]…we’re struggling now to where we can’t keep up [with demand].”

Expanding to diversify product line/revenue streams (three producers): This theme describes expanding to diversify their production either to protect their businesses from catastrophe: “I’d like to put in another pond; that way, I have two options, and if one pond failed, the other would provide some of the need.” Other producers indicated they were diversifying the types of products they sell or markets they’re selling into: “We are thinking of increasing the number of tanks of fish to be able to have a continuous supply of [processing-plate sized] food fish.”

Expanding with skill growth (three producers) A final business expansion theme that was raised multiple times is producers who were expanding as their skill and experience increased, as put succinctly by one smaller producer: “We finally started keeping more fish alive; the plan is to keep growing the farm until it can become a primary source of income.”

Producers who either were not expanding their business or who expressed concerns about their business expansion plans raised two consistent themes:

Regulatory concerns (four producers): Producers were concerned either with regulations making expansion too risky or that regulations limiting their ability to acquire new land to expand. Sometimes, this was a specific concern, such as expressed by one producer, who investigated expansion “after the Food Safety Modernization Act, and it was not economically feasible.” Other times, this was a more general concern about the “regulatory environment,” as one producer put it.

Capital concerns (two producers): Producers indicated that expansion was either economically infeasible (“It was it was basically we’re talking about an extra $50–60,000 of investment, just for the fish to be able to keep the 40–50,000 fish that they needed to keep to make it worth my time.”) or that they did not have access to sufficient cash or credit to expand.

Producers Are Concerned about Regulation

We asked the producers for their thoughts on their primary regulator and why they trusted or distrusted them. The responses fit into one of five themes, two that were related to higher levels of trust and three that were related to lower levels of trust. Common themes related to higher levels of trust included:

Smooth processes and lack of conflict (four producers): Producers had not had any “run-ins” with the regulators, either on an interpersonal level or by bumping up against restrictive regulations. This theme is exemplified by a producer who said, “I have a lot of faith in [the regulator]: They’ve been very easy to work with and very accommodating.”

Perceived competence and legitimacy (two producers): Some producers indicated that the regulators were doing important, legitimate work in a competent manner: “When they inspect a facility, and they see what we’re doing, they’re putting their stamp of approval on the product… I have complete faith that when they do their inspection and pass me when they see our fish… They’re signing off on the whole deal that we’re doing what we should be doing and we’re doing it right.”

Common themes related to lower levels of trust included:

Regulators influenced by exogenous concerns (four producers): Some producers expressed concern that regulators do not have the best interests of the industry at heart and the producers perceive regulators as balancing other interests, too. It is unsurprising that producers feel this way, as regulators typically have responsibility for larger domains than just aquaculture (e.g., a water regulatory agency may primarily be concerned with water quality and quantity and only be concerned with aquaculture to the extent that it affects water quality). However, in this theme, producers indicated that the regulators balanced these interests in a way that the producers disagree with. This may be represented as “politics” or “money” or other potential users of the resource. This theme is exemplified by a quote from one producer, who said, “When you start making regulations because of politics [as opposed to] what’s good for the species or what’s good for aquaculture… that makes no sense to me.”

Increasing regulatory burden (three producers): Regulators increase the regulatory burden over time, potentially with regulations that do not make sense to the producers: “Their culture is to always seek higher levels of regulations. They’re ‘always, always, always’ institutions… every single renewal cycle, [we] end up arm wrestling over something new, that they want us to do, despite the fact that there are no identified issues, problems, violations, you name it, there [haven't been] any problems to address on our farm."

In addition, several producers specifically called out the Food Safety Modernization Act as an onerous regulation that challenged their business and damaged their relationship with regulators.

Lack of relevant knowledge (one producer): Regulators lack the detailed knowledge of aquaculture production that the producers consider essential to effectively regulate the industry: "Lack of industrial knowledge… I talked to my local health department and they didn't know what aquaculture even was."

Conclusion: There Is No Single Midwest Aquaculture Market

Despite the historical challenges of the Midwestern aquaculture market, most of the producers we interviewed were generally optimistic about the future of their businesses, as reflected in the large number that are planning to expand in the next several years. This might reflect a change in business conditions compared to the past: The Midwestern aquaculture market has seen significant private and federal investment in recent years, which may lead to industry growth. The optimism could also be a sign of survivorship bias: The producers who are still in the market are those who run stronger businesses and, consequently, have more reason to be optimistic about future success. This could also reflect a biased sample or the natural optimism of business owners and farmers. Regardless, there is clearly more work to be done here to understand the nature and concerns of those who are or are not planning to expand their businesses: In future investigations we will attempt to tease out what factors cause producers to want to expand or not expand.

Despite their optimism on business expansion, many producers expressed concern about actual or potential regulatory burden. However, several producers expressed appreciation for straightforward regulators and regulatory processes that feel reasonable and considered as opposed to arbitrary and overly harsh. Many of the producers were concerned about regulators who were influenced by politics or exogenous concerns. Trust seems to coincide with a perception that regulators understand aquaculture and that the regulations are reasonable. However, trust in natural resources systems is complicated and multidimensional (Stern and Coleman, 2015) and there is a clear need to better understand the drivers of trust in aquaculture. In addition, there are likely state-by-state and regulator-by-regulator factors that influence producers' perceptions of and trust in the regulatory process. Our data do n0t have that level of granularity, but this is worth investigating in the future.

These qualitative interviews and the quotes we included above tell an important story about the Midwest aquaculture market: There is no single Midwest aquaculture market and no one way of doing business. Each of the producers we interviewed had a unique set of challenges and market conditions and are doing their best to succeed under these conditions. These are largely small businesses without the same support, distribution, and consulting infrastructure that larger agricultural operations might have. As one producer put it, "Small farmer aquaculture in this country is in a state of its chaos… We're doing business without written agreements… Things are done on a handshake. Our pricing is awful. We have regulators… telling us what we can't do. You know, and in many cases, it's preventing us from being profitable." This attitude was not universally held, and many producers expressed optimism about their businesses and the industry, but this perspective is evidence that when it comes to the Midwest aquaculture market, many significant challenges remain.

For More Information

Love, D.C., F. Asche, Z. Conrad, R. Young, J. Harding, E.M. Nussbaumer, A.L. Thorne-Lynam, and R. Neff. 2020. "Food Sources and Expenditures for Seafood in the United States." *Nutrients* 12: 1810.

Miles, M.B., A.M. Huberman, and J. Saldana. 2014. *Qualitative Data Analysis: A Methods Sourcebook*. Thousand Oaks, CA: Sage.

National Marine Fisheries Service. 2021. *Fisheries of the United States 2019*. Washington, DC: U.S. Department of Commerce, NOAA Current Fishery Statistics No. 2019.

Stern, M.J., and K.J. Coleman. 2015. "The Multidimensionality of Trust: Applications in Collaborative Natural Resource Management." *Society & Natural Resources* 28(2): 117–132.

U.S. Census Bureau. 2019. *American Community Survey 1-Year Estimates Census Reporter Profile Page for Midwest Region.* Washington, DC: U.S. Census Bureau.

U.S. Department of Agriculture. 2019a. *2017 Census of Agriculture, Volume 1 Geographic Area Series Part 51.* Washington, DC: U.S. Department of Agriculture, National Agricultural Statistics Service.

U.S. Department of Agriculture. 2019b. *2018 Census of Aquaculture, Volume 3*. Washington, DC: U.S. Department of Agriculture, National Agricultural Statistics Service.

U.S. Environmental Protection Agency. 2014. *Estimated Fish Consumption Rates for the U.S. Population and Selected Subpopulations (NHANES 2003-2010.* Washington, DC: U.S. Environmental Protection Agency EPA-820-R-14-002.

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Regulatory Landscape of the U.S. Aquaculture Supply Chain

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JEL Classifications: Q21, Q22, Q27
Keywords: Aquaculture, RegData, Regulatory restrictions, Supply chains

Introduction

Laws regulating food systems are complex, overlapping, and decentralized. They are complex because the laws must account for the delicate intricacies and objectives of a supply chain; overlapping because the legislation regulating food production, safety, and distribution are constructed through amendments to decade-old statutes; and decentralized because they involve local, state, and federal policy makers who grant enforcement jurisdiction to multiple agencies. While these regulations are often written to encourage ethical business practices, protect consumers, workers, and the environment, and promote animal welfare, they may hinder industry growth, prevent innovation, and generate higher consumer prices (Malone and Lusk, 2016; Mullally and Lusk, 2018; Chambers, Collins, and Krause, 2019).

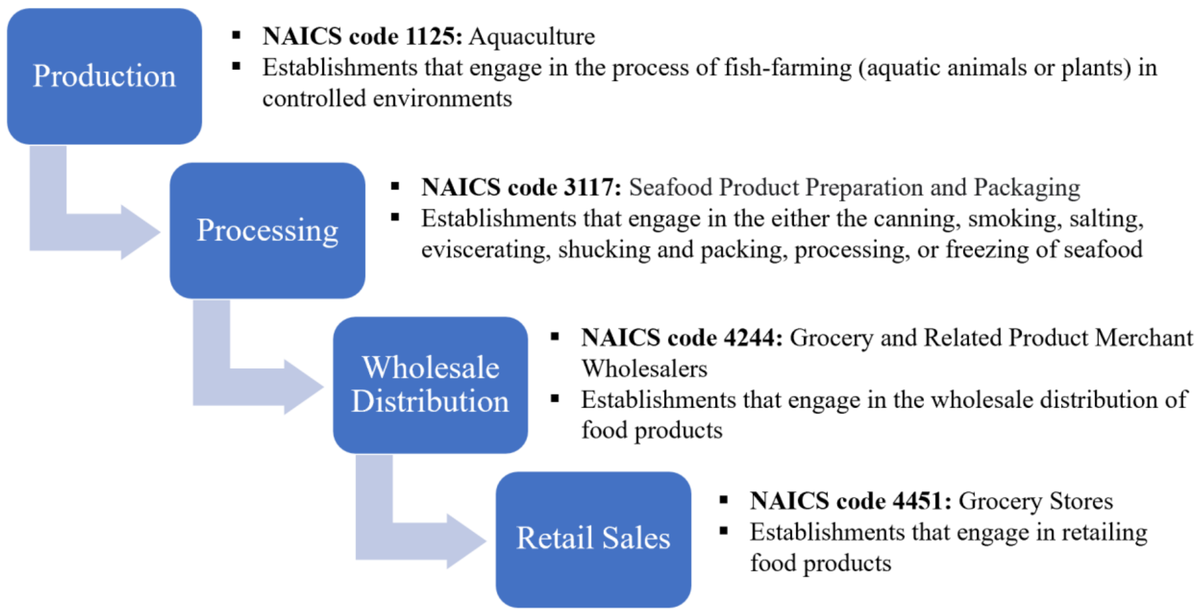
The first major food policy initiatives in the United States were introduced in the early twentieth century after the publication of Upton Sinclair's notorious book *The Jungle* (Fortin, 2017). The Pure Food and Drug Act of 1906 and the Meat Inspection Act of 1906 addressed the need to protect consumers from illness, fraud, and other accounts of malpractice. After advancements in refrigeration technology, improvements in transportation, and a rise in the standard of living, the Pure Food and Drug Act of 1906 was quickly outdated, and it was replaced by the Food, Drug, and Cosmetic Act (FD&C) of 1938.[1] The FD&C of 1938, along with the Meat Inspection Act of 1906, still serve as the foundation of modern-day food law. Of course, the number of food regulations have increased tremendously over the last century, but the restrictiveness of these constraints may not be distributed evenly across different food supply chains. For instance, recent studies have suggested that the U.S. aquaculture industry—a nascent industry compared to the U.S. beef, pork, and poultry industries—may be "over-burdened" by regulations, resulting in higher production costs and slower market growth rates (Abate, Nielsen, and Tveterås, 2016; Knapp and Rubino, 2016; van Senten and Engle, 2017). Relatedly, Staples et al. (2021) examine the number of restrictive words in federal law matched to industries across various U.S. protein supply chains (cattle, hog and pig, poultry, sheep and goat, and aquaculture) from 1970 to 2019. Though simply counting the number of restrictive words cannot be considered a complete measure of regulatory burden, the study notes that regulatory restrictions have grown steadily across all protein industries and that the total regulatory language constraining the aquaculture industry is greater than that of the other protein sources studied. This article extends previous examinations of aquaculture regulations by tracing the development of U.S. aquaculture supply chain regulatory restrictions and discussing the factors that could be driving the recent growth in regulations.

We present quantitative data on federal and state aquaculture regulatory restrictions using Mercatus Center RegData 3.2, mirroring Staples et al. (2021). This database counts each instance that a binding federal restriction—specifically, the words "shall," "must," "may not," "prohibited," or "required"—appears in the *United States Code of Federal Regulations* (CFR) and weights the restriction by the probability that it applies to a given industry. The measure of industry relevance is generated using a machine-learning algorithm trained on the lexigraphy of industry-specific texts, and thus the total regulatory restrictions for a given industry is the equal to the probability-weighted sum of regulatory restrictions using the industry's specific weighting matrix.[2] Here, we assume that the aquaculture supply chain is represented by a four-step process proxied using the industry's corresponding North American Industry Classification System (NAICS) code: (i) production; (ii) processing; (iii) wholesale distribution; and (iv) retail sales. Our aquaculture supply chain and the four-digit NAICS code corresponding to each stage of the supply chain are presented in Figure 1.

[1] For more information on the evolution of U.S. food law, see Fortin (2017).

[2] For details on the methodology of calculating measures of regulatory restrictions, see McLaughlin and Sherouse (2019).

Figure 1. Aquaculture Supply Chain and Corresponding Four-Digit North American Industry Classification System (NAICS) Code with NAICS Code Description



The federal data span the CFR from 1970 to 2019, allowing us to address the relative changes in the aquaculture supply chain regulatory constraints over the past half-century. Upon presentation of recent trends, we discuss large-scale food policy initiatives and environmental regulations that may be driving the increase in aquaculture regulatory restrictions in recent years. We then analyze heterogeneity across state supply chains using 2020 state-level RegData before concluding with a discussion of recent legislation pertaining to the future of the aquaculture industry.

Aquaculture Regulatory Restrictions

Although federal statutes receive significant media attention after they are passed by Congress and signed into law by the president, the regulations enforcing these statutes take several years to codify into the CFR. Once a bill is signed into law, the agency with presiding jurisdiction over the statute will publish their initial interpretation of the law in the *Federal Register*, serving as an interim rule to inform the public and industry stakeholders about the proposed regulations. After a period for public comment, the initial ruling is revised, the agency responds to comments, and the final ruling and enforcement dates are announced in the *Federal Register*. At this point, the final regulations are codified in the CFR.

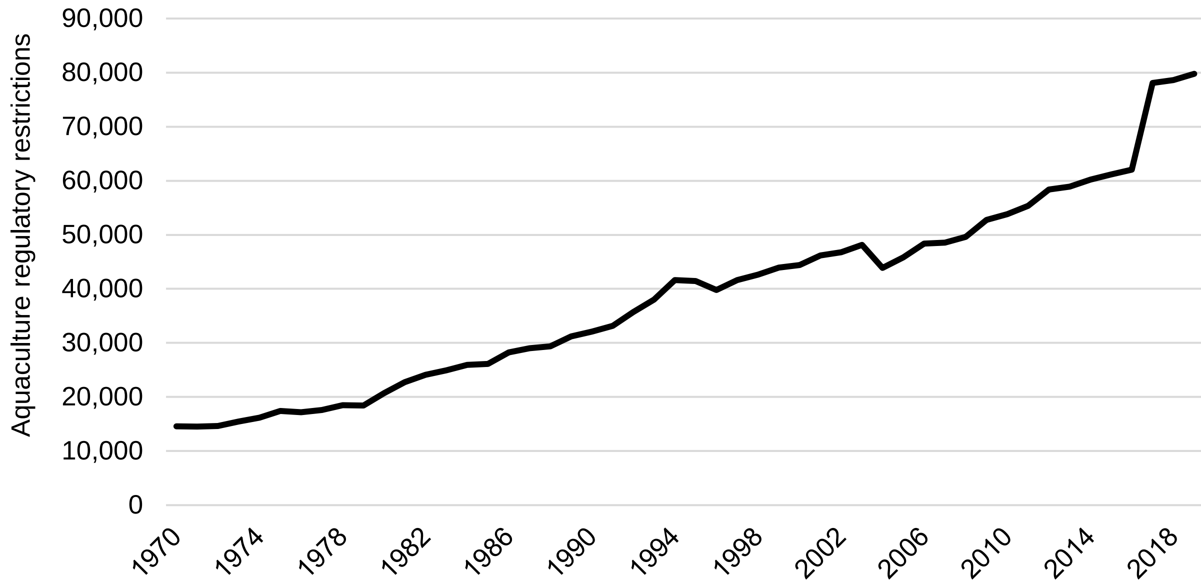
For most food products, including aquaculture, the Food and Drug Administration (FDA) has authority to monitor and enforce regulations stemming from the FD&C Act of 1938. Interestingly, cattle, hog and pig, and poultry production fall under the jurisdiction of the U.S. Department of Agriculture (USDA), not the FDA. While the overarching goals of these federal agencies are similar, and they sometimes work in conjunction with one another, this separation and complexity in regulatory oversight means that industries involved in protein production, processing, distribution, and retail can be subject to different regulations.[3]

Note also that the regulatory jurisdiction need not fall entirely on one agency. Indeed, the overlapping framework may be intentional in an effort to mitigate regulatory loopholes and capture decentralized expertise. For example, in addition to regulation from the FDA, the aquaculture industry is regulated by the USDA, the Environmental Protection Agency, the National Oceanic and Atmospheric Administration, and the U.S. Fisheries and Wildlife Service (FAO, 2021b). These relationships among agencies are often leveraged to establish certification and food safety training programs, such as the Seafood Hazard Analysis and Critical Control Points (HACCP) Alliance (Association of Food and Drug Officials, 2021).

In addition to the decentralized structure of monitoring and enforcement, state and local legislators can pass laws on food policy provided that they do not interfere with interstate commerce (lest they be deemed unconstitutional) (Fortin, 2017; Sumner, 2017). As such, food establishments—whether involved in the

[3] For instance, amendments made to the FD&C Act will directly affect the aquaculture industry but will not directly affect the other meat industries; amendments made to USDA-FSIS policies (e.g., via the Federal Meat Inspection Act) will affect the beef, pork, and/or poultry industries but will not directly affect the aquaculture industry.

Figure 2. U.S. Aquaculture Production (NAICS 1125) Regulatory Restrictions, 1970—2019



Note: The graph presents direct and indirect aquaculture regulatory restrictions for NAICS 1125 (Aquaculture). The four-digit industry code "comprises establishments primarily engaged in the farm raising and production of aquatic animals or plants in controlled or selected aquatic environments" (Office of Management and Budget, 2017). The figure does not include regulatory restrictions across processing, wholesale distribution, or retail sales.

production, processing, distribution, or retailing—must have a rich understanding of the federal, state, and local laws constraining their operation. With respect to aquaculture, this decentralized process is unique relative to other developed nations with comprehensive aquaculture industries, such as Norway, which has a centralized approach that was built to streamline the aquaculture licensing and permitting process (Engle and Stone, 2013).

Federal Regulatory Restrictions

Figure 2 presents regulatory restrictions relating specifically to aquaculture production (NAICS 1125) over the past 50 years, while Table 1 presents a decade-by-decade analysis of the regulatory restrictions across the entire supply chain: aquaculture production (NAICS 1125) → processing (NAICS 3117) → wholesale distribution (NAICS 4244) → retailer (NAICS 4451). Our approach allows us to estimate the total number of *direct* and *indirect* regulatory constraints in each sector. For our purposes, direct regulatory restrictions refer to constraints that bind the aquaculture producer, processor, wholesale distributor, or retailer themselves, while indirect regulatory restrictions are constraints that affect the inputs of each individual segment of the aquaculture supply chain.[4]

Since 1970, aquaculture supply chain regulatory constraints have increased by approximately 400%. The aquaculture supply chain is now subject to nearly 170,000 regulatory restrictions, with the majority of growth coming from constraints imposed on the production stage of the supply chain (NAICS 1125). Regulatory restrictions imposed on the production of aquaculture now account for 47% of all aquaculture supply chain regulatory restrictions, while processing, wholesale distribution, and retail sales account for the remaining 11%, 19%, and 23% of restrictions, respectively. Importantly, the growth in regulatory restrictions on aquaculture production has largely been through increased direct regulatory constraints. From 1970 to 2019, the percentage of direct regulations in aquaculture production (NAICS 1125) increased from 47% to 61%. In other words, while both direct and indirect regulatory restrictions have increased over time, a larger share of the recent regulatory language may have affected the actions and behaviors of the producer or production facility (*direct* restrictions) compared to the inputs to production (*indirect* restrictions).

There are several potential explanations for the increase in total aquaculture supply chain regulatory constraints. First, an increasing body of federal law and complex, interconnected global economy could explain the growth

[4] Indirect regulatory restrictions are calculated using input–output commodity weights from the Bureau of Economic Analysis (BEA) to weight the regulatory restrictions that apply to each. industry that produces the inputs required by that industry's supply chain. For further discussion of the construction of direct and indirect regulatory restrictions, see Malone and Chambers (2017); Chambers, Collins, and Krause (2019); and Staples, Chambers, and Malone (2021).

Table 1. Aquaculture Supply Chain Regulatory Restrictions from 1970—2019

Year		1970	1979	1989	1999	2009	2019
Aquaculture (NAICS 1125)	**Direct**	6,852	8,276	17,240	24,902	32,435	48,843
	Indirect	7,711	10,149	13,958	19,035	20,331	30,930
	Total	14,563	18,425	31,198	43,936	52,766	79,773
Processing (NAICS 3117)	**Direct**	1,330	1,573	1,625	2,040	2,629	3,815
	Indirect	3,525	5,650	8,176	10,660	12,011	15,422
	Total	4,855	7,223	9,802	12,700	14,640	19,237
Wholesale Distribution (NAICS 4244)	**Direct**	555	1,130	2,235	2,648	4,612	5,027
	Indirect	5,175	10,763	15,954	19,011	21,948	26,704
	Total	5,730	11,893	18,189	21,659	26,560	31,732
Retail sales (NAICS 4451)	**Direct**	3,034	3,904	5,521	7,220	7,896	11,839
	Indirect	5,099	10,087	14,962	17,816	20,253	26,903
	Total	8,133	13,991	20,483	25,037	28,149	38,742
Total Regulatory Restrictions		33,281	51,532	79,670	103,332	122,116	169,484

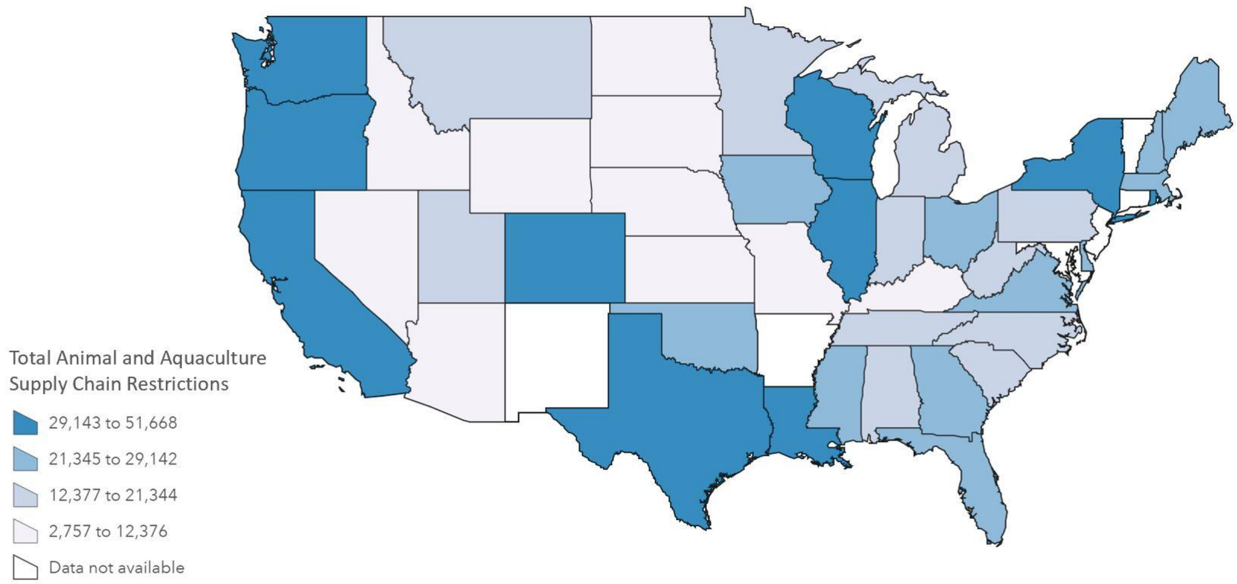
Notes: Aquaculture was modeled using NAICS sector 1125 (Aquaculture); Processing used NAICS sectors 3117 (Seafood Product Preparation and Packaging); Wholesale distribution used NAICS sector 4244 (Grocery Wholesalers); and Retail Sales used NAICS sector 4451 (Grocery Stores).

in regulatory restrictions. Indeed, during this time frame, the Obama administration passed the Food Safety Modernization Act (FSMA) of 2011. The FSMA is considered to be the most significant piece of food law reform since the establishment of the FD&C Act of 1938 (Fortin, 2017). Comprised of seven key rules, the FSMA of 2011 addressed issues of sanitation, adulteration, voluntary third-party certification programs, etc. (Thatte, 2019). Calling attention to Figure 2, we see that aquaculture production experienced a 26% year-over-year (YoY) increase in regulatory restrictions from 2016 to 2017. Over the 50-year period analyzed here, the 26% YoY change from 2016 to 2017 represents the largest shift in regulatory burden on the industry, with the second largest YoY change being a 12% increase from 1979 to 1980. The 26% increase in regulatory restrictions for aquaculture production in 2017 aligns with the codification of two key FSMA rules with implications on protein production: Mitigation Strategies to Protect Food Against Intentional Adulteration (21 CFR 11; 21 CFR 121, Food and Drug Administration, 2016a) and Sanitary Transportation of Human and Animal Food (21 CFR 1; 21 CFR 11, Food and Drug Administration, 2016b). This fact lends credence to the methodology employed while simultaneously demonstrating how large-scale legislative reform transform the regulatory landscape for an entire sector of the economy. Indeed, Staples et al. (2021) report that all protein sources (cattle, hog and pig, poultry, goat and sheep, aquaculture, and other animals) saw approximately a 25% YoY increase in regulatory restrictions from 2016 to 2017.

Second, the literature suggests that stringent U.S. aquaculture regulatory frameworks are often imposed due to concerns regarding effluent discharge and waste disposal (Boyd, 2003; Engle, van Senten, and Fornshell, 2019; van Senten et al., 2020). The discharge of excess nutrients, antibiotics, and organic fecal waste from fish production pose undesirable challenges to the environment (Read and Fernandes, 2003). As such, recent environmental policy—particularly related to water quality—may disproportionately impact the aquaculture industry relative to other protein producers. Maintaining premium water quality through water and waste management strategies can be expensive for the producer (Engle and Valderrama, 2002; Engle and Stone, 2013; Ahmad et al., 2021).

Finally, disease propagation from farmed aquatic animals to wild species through either water discharge or escapements is also a concern. Interaction between farmed fish and wild stocks can result in potential genetic dilution and the spread of disease from the former to the latter (Wirth and Luzar, 1999; Noga, 2010). Bacteria resistance through the widespread use of antibiotics in fish production can also damage wild fish stocks if the necessary precautions are not taken to limit escapements. Anxieties over food safety and fish health have also induced agencies to limit the availability of veterinary products in aquaculture production (Engle and Stone, 2013). For this reason, U.S. aquaculture producers face additional costs securing vital antibiotics and pharmaceutical products to control the spread of aquaculture-related diseases, making it difficult for them

Figure 3. Regulatory Restrictions across the Animal and Aquaculture Production Supply Chain by State



to compete with farmers in developing countries where the use of antibiotics is unregulated. Producers not only control disease outbreaks, but they must also have their fish sampled and water tested to conform to regulatory policies, leading to costs in product, time, labor, and lab testing.

Concerns regarding burdensome regulation for aquaculture have been prominently highlighted in an emerging line of literature on the impact of regulatory structures on aquaculture growth (Engle and Stone, 2013; Abate, Nielsen, and Tveterås, 2016; Engle, 2016). While rigorous empirical studies are needed, preliminary evidence points toward the increasingly stringent regulatory environment impacting the profitability and growth of the aquaculture industry. For instance, Engle and Stone (2013) stressed that the stringency of the regulatory framework governing U.S. aquaculture has increased in recent times, both in number and complexity. The evolving regulatory framework has generated higher production costs (van Senten and Engle, 2017; Engle, van Senten, and Fornshell, 2019; van Senten et al., 2020), increased transaction costs from market participation (Engle and Stone, 2013; Knapp and Rubino, 2016; van Senten and Engle, 2017; Engle, van Senten, and Fornshell, 2019), and created stakeholder confusion and risk over enforcement and future regulatory barriers (Wirth and Luzar, 1999; Rioux, 2011; Osmundsen, Almklov, and Tveterås, 2017).

State-Level Regulatory Restrictions

Federal laws are not the only constraints on the aquaculture supply chain. For example, several empirical studies have documented the costs of state-level aquaculture regulations on the industries' overall growth and dynamism (van Senten and Engle, 2017; Engle, van Senten, and Fornshell, 2019; van Senten et. Al, 2020). Some such regulations include the ban on Atlantic Salmon production in net pens off the Washington coast and the ban on commercial finfish aquaculture production in Alaska (Knapp and Rubino, 2016; Anderson, Asche, and Garlock, 2019).
Figure 3 uses State RegData to estimate the number of regulatory restrictions imposed across animal and aquaculture supply chains (producer → processor → wholesale distribution → retailer) at the state level. Unfortunately, the data are limited to the three-digit NAICS level, so we present data from NAICS code 112 (Animal Production and Aquaculture).[5,6] As such, the analysis speaks more to spatial heterogeneity in protein supply chain regulatory restrictions across states than to aquaculture supply chains itself.

State regulatory restrictions associated with animal and aquaculture supply chains range from 2,757 restrictions (South Dakota) to a high of 51,668 (California), with a mean of 21,817 and median of 20,589. Figure 3 suggests regulatory restrictions tend to be associated with the population size and the economic activity in a state, meaning that states with relatively large

[5] Using the three-digit NAICS code 112 implies that our measure for the production stage of the supply chain now includes cattle ranching (NAICS 1121), hog and pig farming (NAICS 1122), poultry and egg production (NAICS 1123), sheep and goat farming (NAICS 1124), aquaculture (NAICS 1125), and other animal production (NAICS 1129).

[6] All stages of the animal and aquaculture supply chains are aggregated at the three-digit level due to data limitations. We use NAICS 112: Animal Production and Aquaculture for production; NAICS 311: Food Manufacturing for processing; NAICS 424: Merchant Wholesalers, Nondurable Goods for wholesale distribution; and NAICS 445: Food and Beverage Stores for retail sales.

economies generally have more regulatory restrictions than smaller states (e.g., California versus Mississippi). Nevertheless, the figure also reveals large variation in regulatory restrictions at the state level demonstrating differences in the regulatory environment of protein supply chains across state lines. We do not find a clear pattern suggesting that states with more regulatory restrictions in animal production and aquaculture tend to have less aquaculture production. In fact, of the top-five leading aquaculture producers (Mississippi, Washington, Louisiana, Virginia, California) (Hyink and Melstrom, 2021), three (California, Washington, and Louisiana) were ranked among the top ten in total regulatory restrictions across the animal and aquaculture supply chain; Virginia (14th) and Mississippi (22nd) ranked in the top half. This is not to say that regulations have no bearing on production but instead that "over-burdened" likely hinges on the particulars of individual regulations rather than the number of overall restrictions. In other words, while the total number of regulatory constraints provides a proxy for regulatory burden, the restrictiveness of each regulation must be addressed in future studies.

Parting Thoughts

Although additional empirical studies that causally isolate the impacts of aquaculture regulations are needed, there is substantial anecdotal and observational evidence that suggest an increasingly stringent regulatory environment for aquaculture operations in the United States. Could more and relatively faster growth in regulatory restrictions explain the current sluggishness in U.S. aquaculture production? It depends. Between 1980 and 2016, U.S. aquaculture output increased 165%, from 168,000 tonnes to 445,000 tonnes (FAO, 2021a). This is faster than some animal industries—including cattle, which increased 25% between 1970 and 2018 (USDA, 2021)—but slower than others, including poultry, which increased nearly 500% between 1960 and 2006 (MacDonald, 2008). Further, while some countries have experienced unprecedented growth in their aquaculture production volumes, U.S. aquaculture production peaked in 2004 at 600,000 tonnes (FAO, 2021a); environmental regulatory restrictions are commonly cited as a limiting factor to the industry's development (Engle and Stone, 2013; van Senten et al., 2020). As such, more work must be done on the qualitative components of aquaculture restrictions. That is, future studies should examine the restrictiveness and economic burden that a specific piece of legislation places on the aquaculture industry (e.g., legislation related to effluent discharge, water quality, or waste disposal).

The negative impacts caused by the COVID-19 pandemic have created an opportunity for policy makers and regulators to re-evaluate the regulatory environment for aquaculture farms (van Senten, Engle, and Smith, 2021). Indeed, the Trump administration signed Executive Order (EO) 13921 in May of 2020 to deregulate the aquaculture industry. By removing "outdated" regulatory barriers and streamlining the permitting process, EO 13921 seeks to expand production opportunities for the aquaculture industry (e.g., use of net pens in federal waters) (Douglas, 2020; Exec. Order No. 13921, 2020). Following its implementation, the USDA (2020) held a six-part virtual *Aquaculture Is Agriculture Colloquium* in which they engaged with stakeholders on a variety of topics, including environmental management, technological innovation, and marketing. In summarizing the colloquium and describing how the agency plans to assist the industry moving forward, the USDA (2020) writes,

> The greatest constraints to the growth of U.S. aquaculture have been the inappropriate application of a regulatory environment designed for terrestrial agriculture and the lack of a comprehensive economic development plan. These constraints have prevented many segments of U.S. aquaculture from expanding to meet growing local demand for their products and competing effectively against imported products. In addition, some states regulate U.S. aquaculture using a framework designed for terrestrial agriculture, while other states regulate U.S. aquaculture using a framework designed for public-sector management of natural resources. Neither approach is useful for supporting or promoting the expansion of U.S. aquaculture (pg. 2).

Ultimately, food law remains complex, overlapping, and decentralized, and we hope this conversation can lend itself to further discussion on the current regulatory landscape of the aquaculture industry and spark ideas on potential mechanisms to grow the U.S. aquaculture industry.

For More Information

Abate, T.G., R. Nielsen, and R. Tveterås. 2016. Stringency of Environmental Regulation and Aquaculture Growth: A Cross-Country Analysis. *Aquaculture Economics & Management* 20(2): 201–221.

Ahmad, A., S.R.S. Abdullah, H.A. Hasan, A.R. Othman, and N.I. Ismail. 2021. "Aquaculture Industry: Supply and Demand, Best Practices, Effluent and Its Current Issues and Treatment Technology." *Journal of Environmental Management* 287: 112271.

Anderson, J.L., F. Asche, and T. Garlock. 2019. "Economics of Aquaculture Policy and Regulation." *Annual Review of Resource Economics* 11: 101–123.

Alexander, K.A., T.P. Potts, S. Freeman, D. Israel, J. Johansen, D. Kletou, M. Meland, D. Pecorino, C. Rebours, M. Shorten, and D.L. Angel. 2015. "The Implications of Aquaculture Policy and Regulation for the Development of Integrated Multi-Trophic Aquaculture in Europe." *Aquaculture* 443: 16–23.

Association of Food and Drug Officials. 2021. *Seafood HACCP Alliance*. Available online: https://www.afdo.org/training/sha/ [Accessed September 21, 2021].

Boyd, C.E. 2003. "Guidelines for Aquaculture Effluent Management at the Farm-Level." *Aquaculture* 226(1–4): 101–112.

Chambers, D., C.A. Collins, and A. Krause. 2019. "How Do Federal Regulations Affect Consumer Prices? an Analysis of the Regressive Effects of Regulation." *Public Choice* 180(1): 57–90.

Douglas, L. 2020, May 8. "Trump's Executive Order Seeks Controversial Overhaul of Seafood Industry." *Food & Environment Reporting Network* Available online: https://thefern.org/ 2020/05/trumps-executive-order-seeks-controversial-overhaul-of-seafood-industry/.

Engle, C.R. 2016. "Sustainable Growth of Aquaculture: The Need for Research to Evaluate the Impacts of Regulatory Frameworks." *Journal of the World Aquaculture Society* 47(4): 461–463.

Engle, C.R., and N.M. Stone. 2013. "Competitiveness of US Aquaculture Within the Current US Regulatory Framework." *Aquaculture Economics & Management* 17(3): 251–280.

Engle, C.R., J. van Senten, and G. Fornshell. 2019. "Regulatory Costs on US Salmonid Farms." *Journal of the World Aquaculture Society* 50(3): 522–549.

Engle, C.R., and D. Valderrama. 2002. "The Economics of Environmental Impacts in the United States." In J.R. Tomasso (ed.), *Aquaculture and the Environment in the United States*. Baton, Rouge, LA: U.S. Aquaculture Society, pp. 240–270.

Executive Office of the President. 2020, May 12. "Executive Order 13921: Promoting American Seafood Competitiveness and Economic Growth." *Federal Register* 85: 28471–28477.

Food and Agriculture Organization of the United Nations. 2021a. *FishstatJ – Software for Fishery and Aquaculture Statistical Time Series*. Available online: http://www.fao.org/ fishery/statistics/software/fishstatj/en [Accessed September 21, 2021].

Food and Agriculture Organization of the United Nations. 2021b. *National Aquaculture Legislation Overview: United States of America.* Available online: http://www.fao.org/fishery/legalframework/nalo_usa/en [Accessed September 21, 2021].

Food and Drug and Administration. 2016a. "Mitigation Strategies to Protect Food against Intentional Adulteration: 21 CFR 11; 21 CFR 121." *Federal Register* 81: 34165–34223.

Food and Drug and Administration. 2016b. "Sanitary Transportation of Human and Animal Food: 21 CFR 1; 21 CFR 11." *Federal Register* 81: 34165–34223.

Fortin, N. 2017. "Introduction to Food Regulation." In N. Fortin (ed.), *Food Regulation: Law, Science, Policy, and Practice*. Hoboken, NJ: Wiley, pp. 3–20.

Hyink, J., and R. Melstrom. 2021. *Summary of Aquaculture in the United States*. Chicago, IL: Loyola University Chicago Institute of Environmental Sustainability ENVS-2201-01.

Knapp, G., and M.C. Rubino. 2016. The Political Economics of Marine Aquaculture in the United States. *Reviews in Fisheries Science & Aquaculture* 24(3): 213–229.

MacDonald, J. 2008. *The Economic Organization of U.S. Broiler Production*. U.S. Department of Agriculture, Economic Research Service, Economic Information Bulletin EIB-38.

Malone, T., and D. Chambers. 2017. “Quantifying Federal Regulatory Burdens in the Beer Value Chain.” *Agribusiness* 33(3): 466–471.

Malone, T., and J.L. Lusk. (2016). “Brewing Up Entrepreneurship: Government Intervention in Beer.” *Journal of Entrepreneurship and Public Policy* 5(3): 325–342.

McLaughlin, P.A., and O. Sherouse. 2019. “Regdata 2.2: A Panel Dataset on US Federal Regulations.” *Public Choice* 180(1): 43–55.

Mullally, C., and J.L. Lusk. 2018. “The Impact of Farm Animal Housing Restrictions on Egg Prices, Consumer Welfare, and Production in California.” *American Journal of Agricultural Economics* 100(3) 649–669.

Noga, E.J., ed. 2010. *Fish Diseases: Diagnosis and Treatment*, 2nd ed. Ames, IA: Wiley-Blackwell.

Office of Management and Budget. 2017. *North American Industry Classification System, 2017*. Available online: https://www.census.gov/naics/reference_files_tools/2017_NAICS_Manual.pdf [Accessed September 21, 2021].

Osmundsen, T.C., P. Almklov, and R. Tveterås. 2017. “Fish Farmers and Regulators Coping with the Wickedness of Aquaculture.” *Aquaculture Economics & Management* 21(1) 163–183.

Read, P., and T. Fernandes. 2003. “Management of Environmental Impacts of Marine Aquaculture in Europe.” *Aquaculture* 226(1–4): 139–163.

Rioux, D. 2011. “United States Shellfish Growers Perception of Risk.” In R. Stickney, R. Iwamoto, and M. Rust (eds.) *Interactions of Fisheries and Fishing Communities Related to Aquaculture: Proceedings of the Thirty-Eighth U.S.-Japan Aquaculture Panel Symposium*. Silver Spring, MD: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, pp. 10–20.

Staples, AJ., D. Chambers, and T. Malone. 2021. “How Many Regulations Does It Take to Get a Beer? The Geography of Beer Regulations.” *Regulation & Governance*.

Staples, A.J., D. Chambers, R.T. Melstrom, and T. Malone. 2021. “Regulatory Restrictions across U.S. Protein Supply Chains.” *Journal of Agricultural and Applied Economics*.

Sumner, D.A. 2017. “Economics of US State and Local Regulation of Farm Practices, with Emphasis on Restrictions of Interstate Trade.” *Annual Review of Resource Economics* 9: 13–31.

Thatte, D. 2019, October 17. “The Food Safety Modernization Act in a Nutshell.” *Manufacturing Innovation Blog*. Available online: https://www.nist.gov/blogs/manufacturing-innovation-blog/food-safety-modernization-act-nutshell.

U.S. Department of Agriculture. 2019. *Food Availability (Per Capita) Data System: Red Meat, Poultry, and Fish*. Washington, DC: U.S. Department of Agriculture, Economic Research Service. Available online: https://www.ers.usda.gov/data-products/food-availability-per-capita-data-system/ [Accessed September 21, 2021].

U.S. Department of Agriculture. 2020. *Aquaculture Is Agriculture Colloquium: USDA's Role in Supporting the Farmers of Fish, Shellfish, and Aquatic Plants*. Washington, DC: U.S. Department of Agriculture. Available online: https://www.usda.gov/sites/default/files/ documents/aquaculture-agriculture-colloquim.pdf.

U.S. Department of Agriculture. 2021. *Since 1970, Increasing Cattle Weights Have Fueled Growth of U.S. Beef Production as Cattle Used Have Decreased*. Washington, DC: U.S. Department of Agriculture. Available online: : https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartid=93225 [Accessed September 21, 2021].

van Senten, J., and C.R. Engle. 2017. “The Costs of Regulations on US Baitfish and Sportfish Producers.” *Journal of the World Aquaculture Society* 48(3): 503–517.

van Senten, J., C.R. Engle, B. Hudson, and F.S. Conte. 2020. “Regulatory Costs on Pacific Coast Shellfish Farms.” *Aquaculture Economics & Management* 24(4): 447–479.

van Senten, J., C.R. Engle, and M.A. Smith. 2021. “Effects of COVID-19 on US Aquaculture Farms.” *Applied Economic Perspectives and Policy* 43(1): 355–367.

Wirth, F.F., and E.J. Luzar. 1999. “Environmental Management of the US Aquaculture Industry: Insights from a National Survey.” *Society & Natural Resources* 12(7): 659–672.

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