

Opportunities for U.S. marine finfish aquaculture

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Abstract

Expanding aquaculture production in the United States affords opportunities to complement fisheries in meeting domestic demand for seafood. This access to safe, affordable, and healthy food choices is provided with minimal impacts on the environment and in concert with the many uses required of our water resources. The United States has a strong history of well-managed fisheries; however, with harvests near their maximum sustainable capacity, meeting current and future demands for seafood may best be accomplished through development of aquaculture. In fact, this is already happening, but mostly outside of the United States. Over 85% of the seafood Americans eat is imported, half is produced through foreign aquaculture; therefore, expanding aquaculture in the United States is a logical approach for reducing our \$16.8 billion seafood trade deficit along with other benefits of local production. This series of articles on the development of marine finfish species for commercial aquaculture production is a part of the effort to spur domestic growth in marine finfish aquaculture. The articles in this volume provide up-to-date scientific and technical knowledge needed to sustainably produce safe and nutritious fish that will lead to the creation of new economic opportunities through aquaculture in rural, urban, coastal, and inland communities.

KEYWORDS

aquaculture, finfish, marine, United States

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Why should the U.S. increase domestic marine finfish production?. But why marine finfish? We think there are several key reasons. Briefly:

- Americans eat more finfish than any other seafood product.
- Finfish provide a unique combination of nutritional benefits.
- Finfish aquaculture is a key part of a climate resilient food production system.
- Growth of marine finfish connects the coast to the heartland.

1 | AMERICANS EAT MORE FINFISH THAN ANY OTHER SEAFOOD PRODUCT

Shrimp is great, but Americans also like to eat fish. Based on data from the National Oceanographic and Atmospheric Administration's (NOAA's) annual report on seafood consumption¹ and analyzed by the National Fisheries Institute² for 2018, seven of the top 10 species consumed in the United States, accounting for 64% by weight, are finfish (Table 1). The top 10 seafood items consumed capture the majority of the seafood in the U.S. diet. In 2018, these 10 seafood categories made up 86% (6.3 of the 7.3 kg, or 13.8 of the 16.1 lbs, consumed per capita) of all the seafood Americans consumed. Further, if we apply some estimates of the ratio of farmed versus wild production, farmed finfish supplied about 28% of Americans' top 10 seafood consumption in 2018.

TABLE 1 Top 10 seafood categories consumed by Americans in 2018 estimates of the contribution of aquaculture

Species	Estimated U.S. consumption from farmed sources in 2016–2017 (%)	Mean annual per capita consumption (kg–lbs)	Aquaculture's share (kg–lbs)	Contribution over all (%)	Aquaculture portion contribution (%)
Shrimp	90	2.09–4.60	1.88–4.14	33.4	30.0
Salmon	61	1.16–2.55	0.71–1.56	18.5	11.3
Tuna	0	0.95–2.10	0.00–0.00	15.2	0.0
Tilapia	100	0.50–1.11	0.50–1.11	8.1	8.1
Pollock	0	0.35–0.77	0.00–0.00	5.6	0.0
Pangasius	100	0.29–0.63	0.29–0.63	4.6	4.6
Cod	0	0.28–0.62	0.00–0.00	4.5	0.0
Crab	0	0.24–0.52	0.00–0.00	3.8	0.0
Catfish	95	0.25–0.56	0.24–0.53	4.1	3.9
Clams	22	0.15–0.32	0.03–0.07	2.3	0.5
Total top 10		6.25–13.78	3.65–8.04	100	58
All finfish		3.78–8.34	1.74–3.83	61	28

Note: Data are from Fisheries of the United States, 2018 (<https://www.fisheries.noaa.gov/feature-story/fisheries-united-states-2018>); estimates on aquaculture's share of production are from NOAA data averaged over 2016 and 2017, and various trade publications, tempered with the professional judgment of the authors.

TABLE 2 Estimate of long-chain omega-3 fatty acid (EPA+DHA) dose contributed by the top 10 seafood items consumed in 2018 by Americans

Species	Estimated U.S. consumption from farmed sources in 2016–2017 (%)	Mean estimated contribution of EPA+DHA (g/year)	Aquaculture provided EPA+DHA (g/year)	Contribution over all (%)	Aquaculture portion contribution (%)
Shrimp	90	6.57	5.92	23.1	20.8
Salmon	61	14.18	8.65	49.8	30.4
Tuna	0	2.72	0.00	9.6	0.0
Tilapia	100	0.46	0.46	1.6	1.6
Pollock	0	1.63	0.00	5.7	0.0
Pangasius	100	0.51	0.51	1.8	1.8
Cod	0	0.40	0.00	1.4	0.0
Crab	0	1.13	0.00	4.0	0.0
Catfish	95	0.45	0.43	1.6	1.5
Clams	22	0.41	0.09	1.4	0.3
Total top 10		28.47	16.05	100	56
All finfish		20.36	10.04	72	35

Note: Data on fatty acid composition for each seafood category are from Mozaffarian, D., and Rimm, E. (2006). Fish intake, contaminants, and human health: Evaluating the risks and benefits. *Journal of the American Medical Association*, 296(15), 1885–1899 and the USDA National Nutrient Database for Standard Reference 28 Software v.3.8.5.12017-06-28.

2 | AMERICANS ARE NOURISHED BY FINFISH

The 2015–2020 Dietary Guidelines³ suggested Americans should increase their seafood intake to 113 g (4 oz) per week (5.9 kg/year) to 227 g (8 oz) or more per week (>11.8 kg/year), and 227 to 340 g/week (11.8–17.7 kg/year) is recommended for pregnant or breastfeeding women. This guidance is reinforced in the 2020–2025 Dietary Guidelines⁴ but adds new recommendations for children. While it is clear that the unique health-promoting properties of seafood are complex, many information points to the importance of healthy long-chain omega-3 fatty acids (ecosapentaenoic acid and docosahexaenoic acid, EPA+DHA) that are found only in seafood. Table 2 builds on the data from Table 1 and adds information on the content of EPA+DHA in the top 10 seafood items to calculate an annual per capita dose of these healthy fats by source. We estimate that in 2018, finfish accounted for 72% of the EPA+DHA that Americans consumed from the top 10 list. Aquaculture produced finfish accounted for about half of this and there is much scope to increase this contribution. Recommendations for EPA+DHA consumption range from 250 to 500 mg/day (91–182 g year⁻¹ person⁻¹) for healthy adults up to 1,000 mg/day (365 g year⁻¹ person⁻¹) for those with heart conditions. The top 10 seafood items contributed only about 78 mg day⁻¹ person⁻¹ (28.47 g year⁻¹ person⁻¹) in 2018. Increasing finfish aquaculture generally, and using marine and freshwater finfish aquaculture as a natural way to produce a functional food high in omega-3 fatty acids, is likely our best hope to get to the EPA+DHA levels needed for the nation's health. In fulfilling this recommendation in the context of a rapidly growing global population,⁵ it is imperative that the United States expands domestic aquaculture production to do our part to establish global nutritional security.

3 | FINFISH AQUACULTURE IS A KEY PART OF A CLIMATE RESILIENT FOOD PRODUCTION SYSTEM

A recent high-level panel⁶ was commissioned to look at the role of the ocean in adding resiliency to food security under conditions of climate change. The overall conclusions were that the oceans were more than just a victim of climate change, rather in many ways they could provide solutions. One white paper produced by this group that focused on food security provided this headline conclusion:

“Under optimistic projections regarding alternative mariculture feed innovations and uptake, the ocean could supply over six times more food than it does today (364 million metric tons of animal protein). This represents more than two-thirds of the edible meat that the FAO estimates will be needed to feed the future global population.”

The authors also concluded:

“Significantly expanding fed mariculture (i.e., mariculture of species that rely on feed inputs for nutrition, such as finfish and crustaceans) in a sustainable way is possible but will require major innovations in feed so production is not limited by capture fisheries.”

Looking at this report, it is clear that they make a good case that finfish aquaculture will play a major role in the sustainable production of food from animals of all types. In one scenario examined in this report (fig. 4, scenario 4), the potential for finfish aquaculture is projected to be much greater than the headline finding reported above, with potential to far exceed FAO's projected world needs for all sources of animal protein well into the future, if feed is no longer constrained by fishmeal and fish oil. We argue that this is already the case. A decade ago, NOAA and U.S. Department of Agriculture (USDA) asked the question if fishmeal and oil was going to constrain future growth in fed aquaculture⁷ and we issued our findings in a report called the *Future of Aquafeeds*.⁸ The relevant main finding from that report is:

“Fish meal and fish oil are not nutritionally required for farmed fish to grow.”

The bottom line from that joint initiative is that we are not constrained by inputs from the wild capture fishery. Fishmeal and oil from wild sources are increasingly being decoupled from finfish aquaculture not only technically but also economically. A decade after the *Future of Aquafeeds*, we are now seeing this happening with the private sector exploding in both the adaption of traditional non-marine-based feedstuffs and the development of new feedstuffs targeted specifically for aquaculture.

The NOAA/USDA Alternative Feeds Initiative also found:

“Farming of fish is a very efficient way to produce animal protein and other human nutritional needs. Farmed fish use their feed very efficiently. For example, farmed Atlantic salmon can convert approximately one kilogram of feed (dry) into one kilogram of flesh (wet). In contrast, the feed conversion of poultry is 3-5:1, and pork is 8:1. Fish need fewer calories because they are cold-blooded and they do not need to support their weight.”

4 | GROWTH OF MARINE FINFISH CONNECTS THE COAST TO THE HEARTLAND

That same NOAA/USDA Alternative Feeds Initiative report found:

“Plants produce the vast majority of protein and edible oils in the world, accounting for 94 percent of total protein production and 86 percent of total edible oil production. Plants also make up a substantial proportion of diets for carnivorous fish (e.g., 50-60 percent of a typical salmon diet), and that proportion is increasing. It is likely that plants will deliver the bulk of amino acids and fats to diets for farmed fish in the future due to abundance, the potential for increased production, and low cost. Research to increase the use of sustainable plant products in feeds for aquatic organisms will help to increase the importance of agriculture to aquaculture and vice versa. This area of research would be as important to farmers as to aquaculturists and may represent a significant opportunity for American farmers.”

This projection from a decade ago turned out to be true and the growth of marine aquaculture is increasingly tied to agriculture. No other segments of aquaculture have as strong ties to terrestrial agriculture as feeds for the aquaculture production of seafood. However, this exchange goes both ways. The economic importance of feed from the heartland for the fish farming industry is obvious; however, the products of fish farmers can also benefit our nation's terrestrial farmers. This is because inland communities consume less seafood and benefit less from the health-giving aspects gained by seafood consumption than coastal communities. Increasing the tie between inland and coast through the finfish aquaculture industry benefits both communities.

5 | BRINGING IT ALL TOGETHER

In 2017, the status of many marine finfish species was described in the *U.S. Country Report*⁹ for the FAO's *State of the World's Aquatic Genetic Resources for Food and Agriculture*.¹⁰ In March 2017, Florida Atlantic University Harbor Branch Oceanographic Institute, USDA ARS, and NOAA hosted a *Marine Fish Aquaculture Scoping Workshop*¹¹ in Ft. Pierce, Florida. The objectives were: (a) identify critical needs for research and knowledge gaps in current technologies for the production of marine food fish and (b) develop short-term and long-term goals for meeting the needs of the U.S. aquaculture industry. This workshop included 26 experts from academia, government, and industry and led to a national survey pulling together information from 76 respondents to assess 18 marine finfish species identified by workshop participants (<https://www.fau.edu/hboi/aquaculture/status-of-marine-fish.php>). Survey results were used to develop a special session at Aquaculture America 2019 entitled, "Status of Marine Finfish Species for US Aquaculture"¹². In this session, experts described the status of readiness for each of the 18 species and identified research priorities for removing barriers to commercialization. A follow-up session at Aquaculture America 2020 entitled "Status of US Marine finfish: Capacity, Resources and Partnership Opportunities to Advance US Aquaculture"¹³, provided an overview of U.S. infrastructure, research expertise and extension capacity for supporting marine finfish aquaculture development. The series of articles in this *Journal of the World Aquaculture Society* volume resulted from these earlier meetings and summarizes the readiness of each of these species for commercialization in terms of closing the lifecycle, meeting nutrient requirements at all stages of the lifecycle, managing fish health and well-being, and establishing breeding programs to provide domesticated stocks that thrive in net pen or recirculating aquaculture production systems. We need to support efforts to prepare many of these species among others for aquaculture production and to continue to support the development of marine finfish aquaculture through federal research, education, and extension programs.

Our efforts to support the expansion of marine finfish aquaculture focus on developing culture methods; however, it is important to note that the growth of this industry is primarily limited by regulatory and policy constraints and negative consumer perceptions of aquaculture. Specifically, Knapp and Rubino¹⁴ identified the following top challenges for marine finfish aquaculture.

- Marine aquaculture is relatively small, diverse, and (with a few exceptions) unproven.
- Marine waters are public resources.
- Some Americans fear potential negative effects of marine aquaculture without offsetting benefits.
- Aquaculture faces significant social opposition.
- The governance system for leasing and regulation hinders the development of U.S. marine aquaculture.

Furthermore, Lester et al. 2018¹⁵ also identified the following limitations to expanding U.S. marine finfish aquaculture.

- Barriers to entry include regulatory and permitting systems that are highly fragmented across multiple state and federal agencies;

- Our framework for offshore permitting is not clear, is lengthy in time and expensive with uncertain outcomes;
- There is an unmet need for spatial planning that identifies off-shore areas for aquaculture development that are productive and profitable while minimizing environmental, social and economic impacts; and
- Consumers and political leaders have not yet viewed aquaculture as a responsible and sustainable solution for meeting global demands for animal protein.

Although this series of articles focuses on culture methods, there are ongoing efforts within the federal government to address all the limitations to expanding domestic production of marine finfish. Federal aquaculture activities are coordinated under the National Science and Technology Policy Council's Subcommittee on Aquaculture (SCA), who supports science-based expansion of domestic aquaculture and is considering updating the *1983 National Aquaculture Development Plan*.¹⁶ If the plan is updated, it will include strategic plans for research, regulatory efficiency, and economic development. Aquaculture science is critically important for informing the development of policies that:

- sustain aquaculture production while maintaining healthy and productive freshwater, coastal, and marine ecosystems;
- protect special aquatic areas;
- rebuild overfished wild stocks;
- restore populations of endangered species;
- restore and conserve freshwater, coastal, and marine habitat;
- balance competing uses of aquatic environments;
- create employment and business opportunities in inland and coastal communities; and
- enable the production of safe and sustainable seafood.

These efforts to strategically expand marine finfish aquaculture have long been supported by teams of government agencies, universities, and entrepreneurs aiming to advance aquaculture, and the series of meetings that resulted in this volume reflect that continued commitment.

Aquaculture aligns well with the USDA Agriculture Innovation Agenda¹⁷ goals for creating a comprehensive U.S. Agriculture innovation strategy to align public and private research efforts, integrate the latest innovative conservation technologies and practices, and improve USDA data collection and reporting. More specifically, aquaculture is relevant to all five themes of the USDA Science Blueprint¹⁸ including: (a) Sustainable Agriculture Intensification, (b) Agricultural Climate Adaptation, (c) Food and Nutrition Translation, (d) Value Added Innovations, and (e) Agricultural Science Policy Leadership. USDA programs that can support the development and expansion of a responsible marine finfish aquaculture industry are:

- Intramural research supported through Component 5 of the Agricultural Research Services National Action Plan for Aquaculture: Developing Marine Finfish Seedstocks.¹⁹
- Extramural research, education, and extension supported by the National Institute of Food and Agriculture²⁰ including capacity building formula funds, competitive programs with broad eligibility such as the Agriculture and Food Research Initiative and Small Business Innovation Research, and aquaculture specific programs such as the Aquaculture Research specialty program and the Regional Aquaculture Centers.
- The National Agricultural Statistics Service produces the Census of Aquaculture²¹ every 5 years, which expands on the data collected about aquaculture collected from the Census of Agriculture²² and provides a comprehensive picture of the aquaculture sector at the state and national levels.

Supporting the responsible development and expansion of responsible marine finfish aquaculture is also a stated priority for the Department of Commerce supported by the following programs:

- The NOAA's National Marine Fisheries Service (NMFS) intramural regional Fisheries Science Centers focus on enduring industry and regulatory science needs. NMFS also provides extramural funding²³ to support industry development through the Saltonstall-Kennedy Grant Program, Small Business Innovative Research, and other grant programs.
- NOAA Sea Grant provides grants and extension services that support the development of sustainable marine and Great Lakes aquaculture to help coastal communities maintain a safe and sustainable local seafood supply.
- NOAA National Ocean Service National Centers for Coastal Ocean Service programs specialize in understanding the environmental interactions of aquaculture with marine and human ecosystems. Interdisciplinary scientists focus on coastal planning to address conflicts among ocean uses, to inform and support public outreach and education efforts, and to increase awareness of the environmental, economic, and social opportunities aquaculture that can provide coastal communities.

Although the federal sector supports a fairly comprehensive aquaculture research portfolio, several critical gaps remain. The 2021 National Strategic Plan for Aquaculture Research (in preparation) will highlight current interagency investments in aquaculture research, especially highlighting investments in genetics, nutrition, health, production systems, food safety, and product quality. However, the plan will also provide an opportunity to identify important areas that are not adequately addressed. This would include:

- Economic and marketing research on the competitiveness of U.S. aquaculture products, and their economic and social values in comparison to imported products
- Long-term, commercial scale demonstration projects for offshore aquaculture that evaluate commercial feasibility, environmental impacts, and new technologies.
- Long-term, commercial scale demonstration projects for land-based, closed-containment systems that evaluate commercial feasibility, environmental impacts, and new technologies.
- Supporting a robust Extension workforce, who is able to facilitate technology transfer and inform research needs and priorities.

USDA and NOAA aquaculture programs work together and separately to emphasize the importance of establishing partnerships as being critical to the success of expanding domestic aquaculture, whether inter-federal agency, partnerships with academic institutions, non-profit organizations, state, tribal or local governments, or public-private partnerships that demonstrate the possibilities for aquaculture and transfer emerging technologies to the industry. The partnership that will be the most critical for expanding domestic marine aquaculture is the broad relationship between federal agencies and their stakeholders. Stakeholders, including farmers, industries that support farming (feed suppliers, fish health services, manufacturers of aquatic systems and technologies) and the allied organizations that represent them and the federal sector must engage to: (a) support science-based policy making, participate in formal rule making and legislative processes affecting aquaculture research and policy and (b) help direct the federal research portfolio through communication on research needs and priorities, participating in programmatic reviews, and collaborating to establish effective technology transfer. This *Journal of World Aquaculture* volume is an outcome of such a partnership. It would not have been possible without the contribution of many from the federal government, academia, and the private sector.

As is evident from this journal issue, the U.S. capacity for innovation and technology development will enable the use of science-based approaches to expand responsible use of the nation's natural resources for food production and develop a globally competitive, science- and technology-driven sector that meets increasing demands for aquatic products that are affordable and meet high standards for safety, quality, nutrition, and environmental stewardship while providing new opportunities for profitability and economic growth.

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ENDNOTES

- ¹ Fisheries of the United States, 2018 (<https://www.fisheries.noaa.gov/feature-story/fisheries-united-states-2018>).
- ² National Fisheries Institute, 2019 (<https://aboutseafood.com/about/top-ten-list-for-seafood-consumption/>).
- ³ <https://health.gov/our-work/food-nutrition/2015-2020-dietary-guidelines>
- ⁴ <https://www.dietaryguidelines.gov/>
- ⁵ <http://www.fao.org/3/a-i6583e.pdf>
- ⁶ Costello, C., Cao, L., Gelcich, S., Cisneros, M. A., Free, C. M., Froehlich, H. E., ... Thilsted, S. H. (2019). *The future of food from the sea*. Washington, DC: World Resources Institute. Retrieved from www.oceanpanel.org/future-food-sea.
- ⁷ <https://www.fisheries.noaa.gov/noaa-usda-alternative-feeds-initiative>
- ⁸ Rust, M. B., Barrows, F. T., Hardy, R. W., Lazur, A., Naughten, K., & Silverstein, J. (2011). The Future of Aquafeeds: Report to the NOAA/USDA Alternative Feeds Initiative. NOAA Technical Memorandum NMFS F/SPO-124, 103 p.
- ⁹ <https://www.ars.usda.gov/news-events/news/research-news/2017/usda-agency-led-group-profiles-us-aquaculture-for-world-report/>
- ¹⁰ <http://www.fao.org/aquatic-genetic-resources/home/en/>
- ¹¹ <http://www.fau.edu/hboi/aquaculture/status-of-marine-finfish.php>
- ¹² <https://www.was.org/MeetingAbstracts/SessionAbstracts/AQ2019/24>
- ¹³ <https://www.was.org/MeetingAbstracts/SessionAbstracts/AA2020/68>
- ¹⁴ <https://www.tandfonline.com/doi/full/10.1080/23308249.2015.1121202>
- ¹⁵ <https://www.pnas.org/content/115/28/7162>
- ¹⁶ <https://www.govinfo.gov/content/pkg/CZIC-sh34-f4-1984/html/CZIC-sh34-f4-1984.htm>
- ¹⁷ <https://www.usda.gov/aia>
- ¹⁸ <https://www.usda.gov/sites/default/files/documents/usda-science-blueprint.pdf>
- ¹⁹ <https://www.ars.usda.gov/animal-production-and-protection/aquaculture/>
- ²⁰ <https://nifa.usda.gov/program/aquaculture>
- ²¹ https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Census_of_Aquaculture/index.php
- ²² <https://www.nass.usda.gov/Publications/AgCensus/2017/index.php>
- ²³ <https://www.fisheries.noaa.gov/national/aquaculture/aquaculture-funding-opportunities-and-grants#noaa-competitive-grants-programs-for-aquaculture>

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