NATIONAL AQUACULTURE DEVELOPMENT PLAN: OVERVIEW

A Report by the

SUBCOMMITTEE ON AQUACULTURE

COMMITTEE ON ENVIRONMENT

of the

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

December 2024

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About this Document

The National Aquaculture Development Plan (NADP) guides national action to advance the Nation's interest in advancing aquaculture. This Overview of the NADP summarizes the three national strategic plans that comprise the NADP, how they interrelate to advance national interests, and the benefits, challenges, and continuing advances in domestic aquaculture. The strategic plans include:

- Strategic Plan for Aquaculture Research
- Strategic Plan to Enhance Regulatory Efficiency in Aquaculture
- Strategic Plan for Aquaculture Economic Development

For detailed discussion of the subject matter described in the Overview, readers are encouraged to refer directly to the strategies.

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Table of Contents

Abbreviations and Acronyms

AIE	Aquaculture Information Exchange
CDC	Centers for Disease Control and Prevention
DOI	U.S. Department of the Interior
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
FDA	U.S. Food and Drug Administration
FWS	U.S. Fish & Wildlife Service
FWSBAB	Federal Waters Shellfish Biotoxin Advisory Board
GFI	Guidance for Industry
HHS	U.S. Department of Health and Human Services
ISSC	Interstate Shellfish Sanitation Conference
NADP	National Aquaculture Development Plan
NIFA	USDA National Institute for Food and Agriculture
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NSF	National Science Foundation
NSSP	National Shellfish Sanitation Program
NSTC	National Science and Technology Council
OSTP	Office of Science and Technology Policy
SCA	NSTC Subcommittee on Aquaculture
USDA	United States Department of Agriculture

Introduction

The National Aquaculture Development Plan (NADP) guides national actions to advance aquaculture—the cultivation of aquatic animals and plants for commercial, recreational, or conservation purposes—to improve public health and nutrition, strengthen resilience in communities, grow a strong economy, and support a healthy planet.

The NADP comprises this overview and three strategic plans, summarized below, that address aquaculture research, economic development, and regulatory efficiency. The strategies build on the work of federal and state agencies, Tribes and Indigenous communities, universities, other ocean users, and aquaculture stakeholders to help guide and support the nation's interest in aquaculture development.

Aquaculture production in the United States advances national priorities by producing high-quality and nutritious food, recreational opportunities, good jobs, and economic development in rural, urban, and coastal areas. U.S. commercial aquaculture produces $2.27 billion in annual farmgate sales.[1] In addition, aquaculture production supports direct and indirect activities up and down the value chain (e.g., equipment, feeds, fish health services, transportation, food service, and retail/supermarkets).

Aquaculture contributes to conservation objectives through hatchery-reared juvenile fish and shellfish that are used by government agencies, industry, and their partners to conserve and restore more than 70 endangered or threatened species;[2] enhance commercial, recreational, and Tribal fisheries (e.g., Pacific salmon); restore ecologically important habitats (e.g., oyster and coral reefs); and mitigate climate change and other ecosystem stressors such as excess nutrients (e.g., through oyster reef and marsh grass restoration). Accordingly, the NADP explicitly recognizes that commercial and conservation aquaculture overlap and are interdependent.[3]

Climate change is driving the need for aquaculture-based actions by federal, state, and Tribal agencies and their partners as part of their food supply and security and biodiversity conservation strategies. Expanded domestic aquaculture will be an essential element of food systems designed to reduce and mitigate the effects of climate change.[4,5] As aquaculture provides over half the global seafood supply,[6] it will be an essential part of a climate-resilient, sustainable food strategy.[7] Aquaculture, when done in a

[1] USDA National Agriculture Statistics Service. 2022 Census of Agriculture. https://www.nass.usda.gov/Publications/AgCensus/2022/Full_Report/Volume_1,_Chapter_1_US/st99_1_002_002.pdf

[2] U.S. Fish and Wildlife Service. *2022 Fish and Aquatic Conservation Annual Report – Confluence: Connecting Partners and Conservation*. https://www.fws.gov/media/2022-fish-and-aquatic-conservation-annual-report

[3] The NADP uses the term "commercial aquaculture" to include the private sector production of aquaculture products for food and for other human uses, such as industrial products, aquarium fish, and stocking of fish fingerlings in private ponds for recreational fishing. The NADP uses the term "conservation aquaculture" to encompass the conservation, restoration, and enhancement uses of aquaculture typically pursued or implemented by public agencies. Products of conservation aquaculture include commercial or private sector activities, such as commercial and recreational fishing of species produced in a hatchery and released into the wild. For example, developing hatchery infrastructure and aquatic health management practices for conservation aquaculture benefits the recovery of threatened and endangered aquatic species and creates production technologies and scientific understanding that are transferrable to the commercial aquaculture sector—and vice-versa.

[4] Costello et al. 2020. *The future of food from the sea*. High Level Panel for a Sustainable Ocean Economy. www.oceanpanel.org/future-food-sea

[5] Froehlich, HE, et al. 2021. Securing a sustainable future for US seafood in the wake of a global crisis. Marine Policy 124: 104328. https://www.sciencedirect.com/science/article/pii/S0308597X20309751

[6] FAO 2022. State of the World Fisheries 2022. Rome (Italy): FAO. https://www.fao.org/publications/home/fao-flagship-publications/the-state-of-world-fisheries-and-aquaculture/en

[7] Costello et al. 2020. The future of food from the sea; Nature 588(7836): 95-100. Doi:10.1038/s41586-020-2016-y; Golden, CD., et al. 2021. Aquatic foods to nourish nations. Nature 598: 315-320.

sustainable way, can be one of the most environmentally efficient ways to produce food; it optimizes the use of feed and space, has a low carbon footprint, and often supports ecosystem health.[8,9,10]

Aquaculture can also pose risks that need to be addressed, as it has the potential to create environmental damage or disrupt rather than complement existing economic activities.[11,12,13,14]The NADP outlines specific actions federal agencies are taking to address the challenges and opportunities posed by aquaculture, actions that understand and mitigate potential environmental impacts, food safety, domestic manufacturing, and the resilience of the U.S. seafood industry.

Summary of the Aquaculture Strategic Plans

The three national strategic plans that comprise the NADP describe how federal agencies are advancing aquaculture to support public health and nutrition, resilient communities, a strong economy, and a healthy planet through the interrelated components of research and science, economic development, and regulatory efficiency. The strategic plans describe cutting-edge scientific, technical, operational, and policy actions and tools to generate significant benefits from aquaculture while minimizing negative impacts to people and the environment and providing for the restoration and promotion of healthy aquatic ecosystems. The strategic plans serve as companion documents that encourage specific opportunities for critical research, aim to support public and private investment, and increase the efficiency, effectiveness, and predictability of federal aquaculture management, in collaboration with state, Tribal, academic, private sector, and other partners.

Strategic Plan for Aquaculture Research (released February 2022)

This strategic plan communicates federal priorities for research and technology development that will facilitate development and uses of domestic aquaculture. The plan is foundational for supporting a science-based industry that increases seafood availability, creates jobs, and provides economic and recreational opportunities while also providing for the restoration and promotion of healthy aquatic ecosystems. Federal aquaculture research programs benefit the American people, including current and future generations. The plan identifies critical objectives for the following strategic goals that will support U.S. aquaculture development through federal agency and interagency research, science, and technology coordination over a five-year term: (1) develop economic growth while promoting healthy aquatic ecosystems; (2) improve aquaculture production technologies and inform decision-making; and (3) uphold animal well-being, product safety, and nutritional value. These strategic goals guide federal agencies, with public and private sector partners, in building an interagency collaborative and multidisciplinary research framework to address the nation's aquaculture priorities. Agency activities related to this plan are subject to the availability of appropriations and must be consistent with domestic and international legal obligations.

[8] Rust, MB. et al. 2014. Environmental performance of marine net-pen aquaculture in the United States. Fisheries 39(11): 508-524. https://www.tandfonline.com/doi/full/10.1080/03632415.2014.966818

[9] Froehlich, HE., et al. 2018. Comparative terrestrial feed and land use of an aquaculture-dominant world. PNAS 115(20): 5295-5300. https://www.pnas.org/content/115/20/5295

[10] Gephart, JA, et al. 2021. Environmental performance of blue foods. Nature 597: 360-365.

[11] Stentiford GD, et al. 2020. Sustainable aquaculture through the One Health lens. Nature Food 1, 468-474. https://www.nature.com/articles/s43016-020-0127-5

[12] Clavelle T, et al. 2019. Interactions and management for the future of marine aquaculture and capture fisheries. Fish and Fisheries, 20(2): 368-388. https://onlinelibrary.wiley.com/doi/abs/10.1111/faf.12351

[13] Price, CS, Morris JA. 2013. Marine cage culture and the environment: twenty-first century science informing a sustainable industry. NOAA-NCOSS Technical Memorandum NOS-NCCOS-211. U.S. Department of Commerce. https://www.noaa.gov/stories2013/pdfs/2013_PriceandMorris_MarineCageCultureandTheEnvironment(5).pdf

[14] Shumway, S. ed. 2011. Shellfish Aquaculture and the Environment. John Wiley and Sons. https://onlinelibrary.wiley.com/doi/book/10.1002/9780470960967

Strategic Plan to Enhance Regulatory Efficiency in Aquaculture (released February 2022)

This strategic plan outlines actions that federal agencies are undertaking and plan to implement to improve efficiency, predictability, and timeliness, and reduce the costs of reviewing, approving, monitoring, and enforcing permits and other regulatory requirements for commercial aquaculture ventures. The plan describes key interagency and federal-state aquaculture regulatory issues, as well as science and technology needs for facilitating more efficient state and federal aquaculture management actions. The plan's strategic goals are as follows: (1) improving efficiencies in aquaculture permitting and authorization programs; (2) implementing a national approach to aquatic animal health; and (3) refining, developing, and disseminating tools for aquaculture regulatory management. Actions undertaken to further these goals will help federal agencies build an interagency collaborative regulatory framework to meet the nation's aquaculture priorities through coordination with the NSTC. These goals will also help to ensure all aquaculture facilities continue to meet all applicable environmental, public health, and other federal requirements. These proposed actions will be undertaken in the context of environmental stewardship, human health, animal well-being, and other federal requirements, and will be implemented within agencies' existing statutory authorities and budgetary resources.

Strategic Plan for Aquaculture Economic Development (released December 2024)

This strategic plan outlines actions that federal agencies will undertake to support a robust, resilient, globally competitive, and environmentally sustainable domestic aquaculture sector. Effective implementation of this plan will require a significant amount of public-private collaboration with a diverse set of stakeholders. The plan supports both the viability and expansion of existing aquaculture operations and encourages new entrants by addressing needs across the seafood supply chain and diverse production systems. The proposed actions serve as points of intersection between climate-smart food production, private-public partnerships, blue economy, healthy aquatic ecosystems, community resilience and health, workforce development, working waterfronts, urban and rural development, and seafood supply chains.

The aquaculture industry encompasses a broad variety of practices, species, and operational structures, so this plan offers a number of approaches that acknowledge and support this diversity. There is no one-size-fits-all approach to aquaculture development; therefore, the plan includes a wide range of actions tailored to the specialized needs of diverse aquaculture operations to assist in industry growth. The plan outlines four strategic goals to guide interagency collaborative efforts, coordinated through the SCA, to meet the nation's aquaculture priorities: (1) increase aquaculture engagement, communications, and literacy; (2) support infrastructure and workforce development; (3) encourage industry investment and growth; and (4) expand market opportunities for U.S. aquaculture products. These goals are informed by and will advance cross-cutting themes to: (1) enable aquaculture and communities to be climate-ready; (2) advance equitable economic development of the domestic aquaculture industry; and (3) contribute to healthy aquatic ecosystems.

The plan outlines objectives under each goal that federal agencies have identified to implement over the next five years within their existing statutory authorities and budgetary resources. Numerous federal and non-federal programs have mission areas that intersect with the goals and objectives of this plan. Some programs and initiatives are specific to aquaculture, but many others have a broader scope for which aquaculture entities are relevant and eligible. Effective implementation of this plan will require coordinated efforts among existing and new federal and non-federal participants, including states, Tribes, and the private sector.

Aquaculture Opportunities, Challenges, and Advancements

The three strategic plans describe how federal agencies are working with state and Tribal partners, as well as with the aquaculture community, to focus national strengths to foster sustainable aquaculture development and uses. Since the original NADP was published more than 40 years ago, global aquaculture production has substantially increased and now supplies over half of the world's seafood.[15]

The United States has ideal resources to become a world leader in the aquaculture production of fish, mollusks, crustaceans, algae, and other products and in using aquaculture for conservation. It possesses expansive aquatic and land resources suitable for aquaculture; a strong regulatory framework, advanced technology and scientific research; and one of the largest seafood markets in the world.

Using aquaculture as a tool to produce food and to restore species and habitats can provide a variety of economic, social, and environmental benefits. At the same time, if developed without modeling, monitoring, and mitigation, aquaculture can pose environmental and social risks, such as excess nutrients impacting marine ecosystems and conflicts between user groups.[16,17,18,19] To advance the benefits of aquaculture while also mitigating the risks, federal agencies and their partners are working to expand efforts to address ongoing and emerging challenges to the expansion of commercial aquaculture and the uses of aquaculture for conservation and enhancement. The benefits and challenges posed by aquaculture are further outlined in the sections below.

To address and minimize the risks posed by aquaculture, commercial and conservation aquaculture are subject to over two dozen federal and additional state environmental, health, and social laws and regulations designed to protect the environment, public health, and other social objectives.[20] These regulatory requirements are among the reasons the U.S. aquaculture community has made great strides in using science-based techniques to improve the environmental performance of U.S. commercial and conservation aquaculture production (described in the subsections below).

For the commercial aquaculture industry, incorporating environmental, safety, and social considerations has generated gains in efficiency, food safety, and sustainable production. However, meeting the numerous federal and state environmental and other requirements also comes with significant costs[21] and loss of market share to imported aquaculture products. These regulatory costs often cannot be passed on to consumers in the form of higher prices because of competition from similar lower-priced imported products from countries where producers are not subject to the standards required of U.S. producers. While some U.S. consumers may save money by purchasing low-cost imported seafood, some of that seafood may be creating environmental and social costs in other parts of the world that are not accounted for in the U.S. supermarket price of imported seafood products.[22]

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[15] Aquaculture is Agriculture: USDA's Role in Supporting Farmers of Fish, Shellfish, and Aquatic Plants. https://www.usda.gov/sites/default/files/documents/aquaculture-agriculture-colloquim.pdf

[16] Stentiford GD, et al. 2020. Sustainable aquaculture through the One Health lens. Nature Food 1, 468-474. https://www.nature.com/articles/s43016-020-0127-5

[17] Clavelle T, et al. 2019. Interactions and management for the future of marine aquaculture and capture fisheries. Fish and Fisheries, 20(2): 368-388. https://onlinelibrary.wiley.com/doi/abs/10.1111/faf.12351

[18] Price, CS, Morris JA. 2013. Marine cage culture and the environment: twenty-first century science informing a sustainable industry. NOAA-NCOSS Technical Memorandum NOS-NCCOS-211. U.S. Department of Commerce. https://www.noaa.gov/stories2013/pdfs/2013_PriceandMorris_MarineCageCultureandTheEnvironment(5).pdf

[19] Shumway, S. ed. 2011. Shellfish Aquaculture and the Environment. John Wiley and Sons. https://onlinelibrary.wiley.com/doi/book/10.1002/9780470960967

[20] See the *Strategic Plan to Enhance Regulatory Efficiency in Aquaculture*: https://www.ars.usda.gov/sca/Documents/2022%20NSTC%20Subcomittee%20on%20Aquaculture%20Regulatory%20Efficiency%20Plan_Final%20508%20compliant.pdf; Tucker and Hargreaves, eds. 2008. Environmental Best Management Practices for Aquaculture. Ames (IA): Wiley-Blackwell; Shumway, S.E. Ed. 2011. Shellfish aquaculture and the environment. Ames (IA): Wiley-Blackwell.

[21] Engle, CR, Stone, NM. 2013. Competitiveness of U.S. aquaculture within current U.S. regulatory framework. Aquac Econ Manag. 17(3): 251-280.

[22] Engle, CR, Stone, NM op. cit.; Van Senten, J. et al. 2020. Regulatory costs on Pacific coast shellfish farms. Aquac Econ Manag. doi.org/10.1080/13657305.2020.17811293; Hegde S. et al. 2022. Cost of regulations on US catfish farms. J World Aquac Soc. 54(1): 32-

Federal agencies are working with each other, state agencies, Tribes, and industry to improve the coordination, timeliness, and functioning of the federal aquaculture regulatory system and research and development programs. For example, a 2020 series of listening sessions hosted by USDA entitled "Aquaculture is Agriculture" provided stakeholders an opportunity to communicate 35 recommendations on how to strengthen domestic aquaculture.[23] Several federal agencies also work together to promote fair international trade by seeking to prevent the imports of seafood products that do not meet U.S. standards. In addition, federal partnerships with industry, state, and academic partners on aquaculture science and on research and development have produced notable advancements in the sustainability and efficiency of commercial aquaculture production (see examples in sections below).[24]

The use of aquaculture as a tool or technique for conservation, restoration, or enhancement of species and habitats has also been refined during the past 40 years. Government agencies and their partners, as well as industry, use hatchery-reared stock to conserve and restore endangered or threatened species, enhance commercial and recreational fisheries, restore ecologically important habitats (e.g., through oyster reef and marsh grass restoration), and mitigate climate change and other ecosystem stressors such as excess nutrients.

The following sections outline the benefits, challenges, and advances in commercial and conservation aquaculture.

The benefits of commercial aquaculture include:

- ***Nutrition:*** Seafood is one of the best sources of nutrients essential for human well-being; studies show beneficial associations with infant brain development and other health benefits.[25] U.S. federal dietary guidelines recommend an increase in annual seafood consumption from the current consumption of 19.2 pounds per capita to 26 pounds per capita.[26]
- ***Business, jobs, and economic resilience:*** As noted above, U.S. aquaculture produces $2.27 billion in annual farmgate sales.[27] In addition, aquaculture production supports direct and indirect activities up and down the value chain (e.g., equipment, feeds, fish health services, transportation, food service, and retail/supermarkets). For instance, the United States is a major producer of agricultural fish and shrimp feed ingredients (e.g., soy and corn) that are exported around the world.
- ***Food security:*** The Department of Homeland Security recently identified the high U.S. reliance on seafood imports as a key national economic and food supply vulnerability. DHS recommended

53.; Van Senten J, Engle CR. 2017. The costs of regulations on US baitfish and sportfish producers. J World Aquac Soc. 48: 3503-17.; Anderson JL, Asche F, Garlock, T. 2019. Economics of Aquaculture Policy and Regulation. Ann Rev of Resource Econ. 11Z: 101:123.

[23] Aquaculture is Agriculture: USDA's Role in Supporting Farmers of Fish, Shellfish, and Aquatic Plants. https://www.usda.gov/sites/default/files/documents/aquaculture-agriculture-colloquim.pdf

[24] See the *Strategic Plan to Enhance Regulatory Efficiency in Aquaculture*: https://www.ars.usda.gov/sca/Documents/2022%20NSTC%20Subcomittee%20on%20Aquaculture%20Regulatory%20Efficiency%20Plan_Final%20508%20compliant.pdf; Tucker and Hargreaves, eds. 2008. Environmental Best Management Practices for Aquaculture. Ames (IA): Wiley-Blackwell; Shumway, S.E. Ed. 2011. Shellfish aquaculture and the environment. Ames (IA): Wiley-Blackwell.

[25] Gephart JA et al. 2020. Scenarios for global aquaculture and its role in human nutrition. Rev Fish Sci Aquac. 29(1):122-138; Hibblen JR et al. 2019. Relationships between seafood consumption during pregnancy and childhood and neurocognitive development: Two systematic reviews. Prostaglandins Leukot Esst FattyAcids. 151:14-36. Doi:10.1016/j.plefa.2019.10.002; Love DC et al. 2017. Fisheries, food, and health in the USA: The importance of aligning fisheries and health policies. Agric Food Secur. 6:16 doi: 10.1186/s400066-017-0093-9.

[26] USDA and U.S. Department of Health and Human Services. 2020. Dietary Guidelines for Americans, 2020-2025. 9th Edition. https://www.dietaryguidelines.gov/sites/default/files/2021-03/Dietary_Guidelines_for_Americans-2020-2025.pdf

[27] USDA. 2022 Census of Agriculture. https://www.nass.usda.gov/Publications/AgCensus/2022/Full_Report/Volume_1,_Chapter_1_US/st99_1_002_002.pdf

increased production of domestic aquaculture as one of six key national priorities to support domestic food system resilience.[28]

- ***Equity, environmental justice, and social benefits:*** Aquaculture offers opportunities for jobs, professional development, and investments not historically available in underserved and underrepresented rural and coastal communities.
- ***Climate resilience:*** Aquaculture can be used as a tool to help farmers adapt to climate change. For example, hatchery and larval rearing methods can be adjusted to improve animal survival through the most vulnerable parts of a life cycle. Organisms can also be selectively bred for adaptation to changing climate conditions, and site and species selections can be made to improve long-term resilience.
- ***Environmental benefits:*** Certain types of commercial aquaculture can help to improve water quality in coastal areas (e.g., water filtration, nutrient adsorption, and enhanced denitrification by farmed shellfish, as well as nutrient assimilation by farmed seaweed), habitat provisioning services provided by inland aquaculture ponds (e.g., for migratory birds) and by marine aquaculture gear (e.g., to juvenile fish), and the potential stabilization and armoring of shorelines against wave energy (e.g., using shellfish beds and oyster reefs).

The challenges to commercial aquaculture include:

- ***Aquatic animal health:*** Advances in aquatic health management practices, drugs and vaccines, and genetics are needed to reduce risks of disease outbreaks and climate-induced stress in farmed aquatic animals and potential transfer effects on wild stock.[29] Pathogens and parasites from the aquatic environment can infect farmed fish and shellfish. There is an ongoing need for research and surveillance to know what pathogens are present and to design aquatic health management and biosecurity practices to keep cultured animals healthy.
- ***Feed ingredients:*** Feed can amount to up to 70% of the cost of raising fish or crustaceans (fed aquaculture). Thus, research to improve the sourcing, availability, and nutritional composition of feedstuffs is critical to a sustainable expansion of aquaculture and hatchery rearing of species for restoration or enhancement. Finfish and shrimp aquaculture production in the past relied on fish meal and fish oil sourced from wild fish to provide essential nutrients for fed species. With limits to the harvest of forage fish, such as anchovy and menhaden, the aquaculture industry is turning to other feed ingredients, such as fish processing trimmings, new agricultural crop derivatives, algal oil, insect meal, bacterial protein, and other ingredients to meet the needs of a growing industry.[30,31]
- ***Other environmental effects:*** Waste discharge, interactions with wild populations, and potential entanglement with endangered or threatened species are among the potential negative environmental effects of aquaculture.[32] Science-based approaches to siting, designing,

[28] U.S. Department of Homeland Security. Threats to Food and Agricultural Resources (2021). https://www.dhs.gov/sites/default/files/publications/threats_to_food_and_agriculture_resources.pdf

[29] See the *National Strategic Plan for Aquaculture Research*: https://www.ars.usda.gov/sca/Documents/2022%20NSTC%20Subcomittee%20on%20Aquaculture%20Research%20Plan_Final%20508%20compliant.pdf

[30] Barrows, FT, et al. 2008. Report of the plan products in aquafeed strategic planning workshop: An integrated interdisciplinary research roadmap for increasing utilization of plant feedstuffs in diets for carnivorous fish. Rev. Fish Sci. 16: 449-455. Rust, M.B., et al. 2011. The Future of Aquafeeds. NOAA/USDA Alternative Feeds Initiative. NOAA Technical Memorandum NMFS F/SPO-124.

[31] See the *National Strategic Plan for Aquaculture Research*: https://www.ars.usda.gov/sca/Documents/2022%20NSTC%20Subcomittee%20on%20Aquaculture%20Research%20Plan_Final%20508%20compliant.pdf

[32] Gephart, JA, et al. 2021. Environmental performance of blue foods. Nature 597: 360-365; Price CS, and Morris JA. 2013. Marine cage culture and the environment: twenty-first century science informing a sustainable industry. NOAA Technical Memorandum NOS-NCCOS-164. Washington (DC): NOAA; Shumway SE, ed. 2011. Shellfish aquaculture and the environment. Ames (IA): Wiley-Blackwell.

monitoring, regulation, and management of aquaculture facilities, along with farmer training, can help improve U.S. aquaculture's environmental performance.[33] In some cases, aquaculture operations, such as shellfish farms, provide habitat for aquatic species and filter excess nutrients, thereby enhancing water quality.

- ***User conflicts, social license, and regulatory costs:*** Several documented constraints—including a complicated regulatory system, potential environmental and social effects, and competing and conflicting uses of land and public waters—have limited the development of U.S. commercial aquaculture.[34] Actions noted in the research, regulatory, and economic development thematic plans of the NADP aim to alleviate these constraints and to address the potential negative social and economic effects of aquaculture.
- ***Climate change:*** Aquaculture is an important component of food systems designed to mitigate the effects of climate change.[35] Aquaculture production can also be negatively affected by changes in climate, as warmer waters may cause stress in animals or support new vectors for pathogens causing mortalities. More frequent and extreme storm events may damage aquaculture operations and working waterfronts.
- ***Workforce development:*** Aquaculture operations, and the U.S. seafood industry overall, are having difficulty attracting a sufficient number of skilled employees willing to perform the work required. Although federal guest worker programs provide some support, workforce development and training programs are needed to encourage new entrants into the aquaculture and seafood industry workforce (e.g., high school, community college, technical school, and university educational programs).

Advances in commercial aquaculture include:

- Producing fish feeds made from non-traditional ingredients has decoupled the growth of fed aquaculture (fish and shrimp) from dependence on fish meal and fish oil derived from small pelagic fish known as forage fish.[36] Feeds for carnivorous fishes such as salmonids are now also produced using fish processing trimmings, soy, algae, insect meal, and other ingredients, thereby reducing reliance on fish meal and oil while maintaining successful production metrics.
- The split-pond production system for catfish, which uses 20% of a pond for fish grow-out and the remaining 80% for oxygen production and waste treatment, increases feeding efficiencies and improves water quality.[37] In addition, reproductive technologies have facilitated the use of hybrid catfish that exhibit improved performance in these systems over purebred strains.
- USDA and NOAA are collaborating with universities and private companies to develop regional oyster strains better adapted to local conditions and stresses caused by climate change.
- Scientific developments that have contributed to domestic and global aquaculture production advances include development of fish, mollusk, and crustacean strains that are pest- and pathogen-resistant or -tolerant; enhanced pond, recirculating, and offshore production designs

[33] Naylor et al. 2021. A 20-year retrospective review of global aquaculture. Nature 591(551-563).
[34] National Research Council. 1992. Marine aquaculture: Opportunities for growth. Washington (DC): National Academy Press; U.S. Commission on Ocean Policy. 2004. An ocean blueprint for the 21st Century, U.S. Commission on Ocean Policy. Washington CDC): U.S. Ocean Commission; Engle CR, Stone NM. 2013. Competitiveness of U.S. aquaculture within current U.S. regulatory framework. Aquac Econ Manag. 17(3):251-290; Rubino, M. C. (2022). Policy Considerations for Marine Aquaculture in the United States. *Reviews in Fisheries Science & Aquaculture*, *31*(1), 86–102. https://doi.org/10.1080/23308249.2022.2083452.
[35] Costello et al. 2020. The future of food from the sea. Nature 588(7836):95-100.
[36] Barrows, FT, et al. 2008. Report of the plan products in aquafeed strategic planning workshop: An integrated interdisciplinary research roadmap for increasing utilization of plant feedstuffs in diets for carnivorous fish. Rev. Fish Sci. 16: 449-455. Rust, M.B., et al. 2011. The Future of Aquafeeds. NOAA/USDA Alternative Feeds Initiative. NOAA Technical Memorandum NMFS F/SPO-124.
[37] Kumar, G. et al. 2016. Costs and risks of catfish split-pond systems. J of the World Aquac Soc. 47(3): 327-340. Cheatham M. et al. 2023. Economic risk of commercial catfish production practices. Aquac Econ & Mang. https://doi.org/10.1080/13657305.2023.2181463

and systems; and performance improvements resulting from genetic selection and aquatic animal health science.[38]

- Significant improvements in the environmental performance of aquaculture in recent years in the United States have helped to optimize the use of land, feed, and water on aquaculture farms and produce protein with a small environmental footprint. For example, the majority of catfish farms (the largest part of U.S. aquaculture) discharge water intermittently and rely on treating wastewater naturally in the production ponds. Advances in site selection and siting tools, efficient feeds, aquatic health management (which greatly reduces the need for therapeutants), escape prevention, and research on gear types to prevent entanglement of other marine life have all contributed to improved environmental practices that meet federal and state performance standards.[39]

The benefits of conservation aquaculture include:

- ***Commercial fisheries:*** Hatchery stock is used to supplement the commercial catch of Pacific salmon species. Salmon hatcheries provide an average of 34% of the total common-property harvest of the salmon caught in Alaska,[40] and around 70 to 90% of the catch in the Pacific Northwest (California, Oregon, and Washington).[41]
- ***Recreational fisheries:*** The National Fish Hatchery System[42] operated by the U.S. Fish and Wildlife Service (FWS) supports recreational fisheries by directly stocking sport fish into public waterways. This stocking supports $1.2 billion in economic output annually, provides 12,000 jobs, and generates $88 million in federal tax revenue. For example, U.S. freshwater lakes and rivers stocked with trout fingerlings from state, Tribal, and private hatcheries provide recreational opportunities for millions of anglers.
- ***Recovery of threatened and endangered species:*** The National Fish Hatchery System propagates 46 species of fish and 27 species of mollusks listed under the Endangered Species Act.[43] Propagation activities are conducted in accordance with recovery plans and range from providing genetic refuge in a captive environment (e.g., delta smelt and woundfin) to integrated stocking programs that provide demographic and genetic support to natural populations (e.g., razorback sucker, Gila trout, and pallid sturgeon). NOAA also works with FWS and other partners to restore endangered and threatened marine and anadromous species, such as white abalone, certain coral species, Atlantic salmon, and several Pacific salmon species.
- ***Mitigation:*** Dams and other infrastructure projects can reduce habitat connectivity and alter ecosystems, resulting in negative impacts on recreational and commercial fisheries and imperiled

[38] See the *National Strategic Plan for Aquaculture Research*: https://www.ars.usda.gov/sca/Documents/2022%20NSTC%20Subcomittee%20on%20Aquaculture%20Research%20Plan_Final%20508%20compliant.pdf

[39] Gephart, JA, et al. 2021. Environmental performance of blue foods. Nature 597: 360-365; Asplin I. et al. 2020. Working group on environmental interaction of aquaculture. ICES Scientific Reports 2(112). Copenhagen (Denmark): International Council for the Exploration of the sea. Doi:10.17895/ices.pub.7619.; Price CS, and Morris JA. 2013. Marine cage culture and the environment: twenty-first century science informing a sustainable industry. NOAA Technical Memorandum NOS-NCCOS-164. Washington (DC): NOAA; Shumway SE,. ed. 2011. Shellfish aquaculture and the environment. Ames (IA): Wiley-Blackwell;.Price CS, et al. 2017. Protected species and marine aquaculture interactions. NOAA Technical Memorandum. NOAA NCCOS 211. Washington (DC): NOAA.

[40] Evenson DF et al. 2018. Salmon hatcheries in Alaska: a review of the implementation of plans, permits, and policies designed to provide protection for wild stocks. Special publication No. 18-12. Alaska Department of Fish and Game.

[41] Knapp, G, Roheim, CA, Anderson JL. 2007. The Great Salmon Run: Competition between Wild and Farmed Salmon. Washington (DC): TRAFFIC North America World Wildlife Fund; Marine Fisheries Advisory Committee. 2020. A Vision for Salmon and Steelhead: Goals to Restore Thriving Salmon and Steelhead to the Columbia River Basin. Phase 2 report of the Columbia Basin Partnership Task Force of NOAA's Marine Fisheries Advisory Committee. https://www.fisheries.noaa.gov/vision-salmon-and-steelhead-goals-restore-thriving-salmon-and-steelhead-columbia-river-basin

[42] U.S. Fish & Wildlife Service. National Fish Hatchery System. https://www.fws.gov/program/national-fish-hatchery-system

[43] 2022 Fish and Aquatic Conservation Annual Report – Confluence: Connecting Partners and Conservation. https://www.fws.gov/media/2022-fish-and-aquatic-conservation-annual-report

nongame populations. Captive propagation and release are used to help mitigate some of the negative impacts of federal infrastructure projects on inland and anadromous fishes.

- ***Subsistence fisheries:*** The FWS stocks cultured fish on Tribal lands, and this fulfills Tribal trust responsibilities by supporting subsistence fisheries and food sovereignty for 60 Tribes. The National Broodstock Program also provides eggs to support Tribal hatchery programs, which enables Tribes to conduct conservation aquaculture.
- ***Habitat restoration:*** Oyster spat, corals, and marsh grass produced in hatcheries and nurseries are out-planted to restore oyster and coral reefs and marsh habitat around the United States.[44] The restored habitats provide a variety of ecological services (e.g., fishery spawning and nursery habitat, water quality improvements, and nutrient and carbon sequestration) and coastal storm water protection.

The challenges of conservation aquaculture include:

- ***Environmental effects of hatchery-produced stock:*** While hatchery stock can be an important component of species recovery and restoration plans or can supplement important commercial and recreational stocks, the release of hatchery stock comes with environmental risks.[45] For example, scientists have long been aware that release of salmon species to supplement wild stocks to meet commercial, recreational, Tribal, or endangered species needs may negatively affect the survival of remaining stocks of wild salmon (by interbreeding with or outcompeting wild salmon for food). Although a variety of protocols based on scientific research are in place to guide hatchery programs and to separate wild from hatchery stock, additional research is required to reduce the genetic risks.[46]
- ***Climate change:*** Climate change may put additional stress on endangered and threatened aquatic species, putting new demands on species conservation and restoration programs.
- ***Habitat restoration:*** While a variety of federal, state, and private efforts are underway around the country to restore habitats with hatchery stock, the need for habitat restoration may greatly exceed the current resources available to these hatchery-based restoration efforts.

Advances in conservation aquaculture:

- Advances continue to be made in using hatcheries to restore threatened and endangered aquatic species, such as some trout species, Pacific and Atlantic salmon species, white abalone, corals, turtles, and queen conch. For example, genetics protocols for hatchery-reared stock used to restore endangered stocks have been refined by private and public aquaculture research facilities to reduce potential negative effects of releasing hatchery-raised stocks on wild populations. These efforts by hatcheries include developing and adopting genetic techniques to facilitate pedigree-based genetic management programs, which minimizes inbreeding risks and maximizes genetic diversity and effective population sizes in rare populations.[47] For example, the use of advanced pedigree-based genetic management approaches, like those used in the Atlantic Salmon and

[44] Bricker SB et al. 2017. Role of shellfish aquaculture in the reduction of eutrophication in an urban estuary. Environ Sci Technol. 52(1):173-183; Theraukauf SJ et al. 2022. Habitat value of bivalve shellfish and seaweed aquaculture for fish and invertebrates: pathways, synthesis and next steps. Rev Aquacult. 14(1):54-72.

[45] Lorenzen, K., Leber, K. M., & Blankenship, H. L. (2010). Responsible approach to marine stock enhancement: an update. *Reviews in Fisheries Science*, *18*(2), 189-210.

[46] Al-Chokhachy, R., Heki, L., Loux, T., & Peka, R. (2020). Return of a giant: coordinated conservation leads to the first wild reproduction of Lahontan Cutthroat Trout in the Truckee River in nearly a century. *Fisheries*, *45*(2), 63-73.

[47] Fisch KM, et al. 2015. Fish hatchery genetic management techniques: Integrating theory with implementation. N American J of Aquac. 77(3):343-357. O'Reilly, P.T. and Kozfkay, C.C., 2014. Use of microsatellite data and pedigree information in the genetic management of two long-term salmon conservation programs. *Reviews in fish biology and fisheries*, *24*, pp.819-848.

Lahontan Cutthroat Trout recovery programs, is assisting conservation aquaculture programs to reduce genetic risks.[48]

- The FWS released 124 million fish from 70 species into public waterways in 2022,[49] in addition to 1 billion individuals of more than 77 species released by state agencies supported by federal grants. These fish support the recovery of listed species under the Endangered Species Act and restoration of at-risk sport fishes, help mitigate the impacts of infrastructure projects on aquatic habitats, provide commercial and recreational fishing opportunities, and support Tribal harvests.
- The FWS Aquatic Animal Drug Approval Partnership program has facilitated the Food and Drug Administration (FDA) approval of multiple drugs for use in aquaculture.[50] In addition, the FWS Fish Technology Centers have conducted extensive applied aquaculture research to support captive propagation.

Conclusion

The NADP aims to support a globally competitive, science and technology–driven aquaculture sector that meets increasing demands for aquatic products that are affordable and meet high standards for safety, quality, nutrition, human health, and environmental stewardship while providing new opportunities for economic growth.

The three strategic plans that comprise the NADP and describe federal actions toward accomplishing these goals will be periodically reviewed and revised with engagement from federal and non-federal participants, including Tribes, states, the private sector, and the public. Updates, information, and opportunities for engagement will be posted to the Subcommittee on Aquaculture website.[51]

[48] O'Reilly, P. T., & Kozfkay, C. C. (2014). Use of microsatellite data and pedigree information in the genetic management of two long-term salmon conservation programs. *Reviews in fish biology and fisheries*, *24*, 819-848.
[49] 2022 Fish and Aquatic Conservation Annual Report – Confluence: Connecting Partners and Conservation. U.S. Fish and Wildlife Service. https://www.fws.gov/media/2022-fish-and-aquatic-conservation-annual-report
[50] Aquatic Animal Drug Approval Partnership Program. U.S. Fish and Wildlife Service. https://www.fws.gov/program/aquatic-animal-health/aquatic-animal-drug-approval-partnership
[51] Subcommittee on Aquaculture. https://www.ars.usda.gov/SCA/