SUSTAINABILITY CONSIDERATIONS FOR THE EXPANSION OF US OPEN OCEAN AQUACULTURE

Preventing and Managing Disease

Environmental Defense Fund

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About the Project

EDF and partners are pursuing a science-based, inclusive approach to the development of aquaculture in the federal waters of the United States. EDF advocates for federally directed research to better understand potential offshore aquaculture impacts and steps needed to ensure aquaculture operations throughout the supply chain are sustainably designed and use best practices, which minimize risk. Well-regulated, responsible, and sustainable open-ocean aquaculture operations can drive new investment and jobs, support community resilience, increase U.S. food security, and address issues associated with climate crisis disruptions.

EDF is working to build support among ocean, coastal, and seafood stakeholders and policy makers to establish a rigorous, science-based environmental and social regulatory framework that provides a predictable environment for business investment, protects ocean health, and supports equitable outcomes for coastal communities and individuals working throughout the seafood industry.

To learn more about EDF’s U.S. aquaculture portfolio, contact Maddie Voorhees, EDF’s Climate Resilient Fisheries and Oceans program at *mvoorhees@edf.org* or visit *www.edf.org*.

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Sustainability Considerations for the Expansion of US Open Ocean Aquaculture: Preventing and Managing Disease

Executive Summary

As with terrestrial crop and livestock production systems, aquaculture, or the practice of farming seafood, contends with the risk of disease. More so than on land, the aquatic environment facilitates the spread of pathogens within farms and out to the surrounding environment. Disease burden is considered the major constraint to the growth of the aquaculture industry globally (Stentiford et al., 2012). Lost revenue due to aquaculture parasites alone has been estimated at up to 10 billion USD annually (Shinn et al. 2015). Additionally, the spread of diseases to wild populations and impacts of excess antibiotic use can threaten local biodiversity.

It is not fully understood how expanding U.S. aquaculture into the open ocean (i.e., federal waters or 3-200 nautical miles from the shore), will impact disease prevalence and treatment. On one hand, the open ocean environment simply has more space, allowing for healthier stocking densities and pen spacing, and reducing contact with wild animals and ecosystems. On the other hand, it is harder to access open ocean pens for health inspections and disease treatments, and the higher-energy environment increases the risk of escapes, which could be a pathway for transmitting diseases to wild populations.

Best practices for disease management involve a three-tiered approach: (1) having plans and protocols in place for cleanliness, disease identification, and disease response; (2) implementing proactive strategies to prevent disease, including optimal farm husbandry, vaccination, and selective breeding; and (3) treatment of disease with antibiotics or other therapeutics. Ideally, farms implement a combination of strategies tailored to the specific cultivated species and site.

A major challenge—and area of innovation—for disease management in aquaculture is developing alternative therapeutics to antibiotics. The rise of antimicrobial resistance due to mis- or overuse of antibiotics in human healthcare and food systems is a grave global health threat. In addition to risks of antibiotic-resistant genes transferring to pathogens that could infect humans, there are human health risks from potential contact with antibiotics or residues while administering medicines on farms or consuming treated fish. Researchers estimate that

over 70% of antibiotics administered via fish feed diffuse into the surrounding environment, where they can harm microbial biodiversity and be consumed by wild fish, with food safety implications for wild capture fisheries (Cherian et al., 2023).

Fortunately, emerging research in fish immune system function and pathogen virulence has led to innovative, targeted treatments that can rapidly address specific pathogens without risk of developing resistance. Furthermore, scholars and aquatic farmers are recognizing Indigenous and traditional practices that can improve fish health while providing ecological co-benefits.

Sustainability means minimizing disease and antimicrobial resistance in aquaculture—including as it expands into the open ocean. Therefore, the U.S. must set mandates and enforce regulatory protocols, building from widely available comprehensive guidelines and best practices. Such requirements will guide industry and provide assurances for ocean and human health. In addition, funding for coordinated and collaborative research, along with expanded capacity for qualified laboratory facilities and personnel, is urgently needed. Finally, expedited processes for vaccine and therapeutant licensing and approvals would encourage innovation and reduce costly delays in disease treatment.

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Environmental Defense Fund

Sustainability Considerations for the Expansion of US Open Ocean Aquaculture: Preventing and Managing Disease

Introduction

The Challenge of Disease in Aquaculture

Farmed seafood, or aquaculture, has become an integral component of the global food system, accounting for over half of the world's seafood production (FAO, 2024). As with terrestrial crop and livestock production systems, the risk of disease represents a major cost and potential environmental impact from farming seafood. Thousands of pathogens including bacteria, viruses, fungi, and parasites can cause disease in farmed aquatic species, and new diseases emerge each year (World Bank, 2014). Disease burden is considered the major constraint to the growth of the aquaculture industry globally (Stentiford et al., 2012). Lost revenue due to aquaculture parasites alone has been estimated at up to 10 billion USD annually (Shinn et al. 2015). According to a major insurer, disease accounted for 20% of total insurance losses in the salmon farming industry from 1992-2012 (World Bank, 2014).

In addition to risks and costs to farms, there is concern that diseases in aquaculture can impact wild ecosystems. In open pens, diseases and parasites are initially transmitted *from* wild *to* farmed fish. Pathogens and contamination can also occur through interactions with birds or other wildlife (Wright et al, 2023). In most fish farms, animals are kept in high concentrations that increase animal stress and rates of contact with other fish and reduce water quality, conditions that accelerate disease transmission within farms. (Fujita et al., 2023). It has been well-documented that pathogens and parasites are also transmitted back to local wild species, but it remains unclear if and when these transmission events have population-level effects on wild stocks (Fujita et al., 2023).

Disease in Open Ocean Aquaculture

Offshore farms, which do not yet exist in the U.S., may pose less risk of spreading disease and parasite infections simply because they are further from coastal animals and ecosystems (Fujita, et al., 2023). This reduces not only the spread of disease, but also the risks of coastal runoff, oil spills and Harmful Algal Blooms that can stress and sicken cultured species (Rhodes et al., 2023). The open ocean environment also has more space to maintain lower stocking densities and adequate distance between pen enclosures and farms. Based on limited studies, moving aquaculture enclosures further offshore may reduce parasite load and improve fish health (Kirchoff et al. 2016; Morro et al. 2022).

However, greater distances from shore create new risk profiles for farming aquatic species. It is more costly and takes longer to visit open ocean pens for disinfection, health inspections, and veterinary visits. Due to stronger waves and higher energy in the open ocean environment, farmed fish are more likely to escape pens in the open ocean than in the coastal or nearshore environment, and thus come into contact with wild species to spread disease (Fujita et al., 2023). Still, there is significant uncertainty around the impact of escaped individuals on local ecosystems, especially in offshore environments where farmed individuals may be less suited to survive or out-compete wild populations.

Risks of antibiotic misuse

Antimicrobial and antibacterial products are used to prevent and treat pathogen outbreaks in aquaculture, just like in terrestrial livestock cultivation. However, when excessively or indiscriminately used, aquaculture antibiotics contribute to the rise of antimicrobial resistance, a major global health threat. The FAO identified preventing and tackling antimicrobial resistance as a major sustainability challenge for the aquaculture sector (FAO, 2024). Globally, aquaculture uses around 13,600 tons of antibiotics annually, accounting for nearly 6% of total antimicrobial usage (Wright et al., 2023).

Overuse of antibiotics in aquaculture carries human health risks because genes for antimicrobial resistance could be transferred to pathogens that infect humans, or resistant zoonotic pathogens (able to be transmitted from animals to humans) could directly infect people via consumption of or contact with infected fish (Cherian et al., 2023; Wright et al., 2023). Additionally, consuming antibiotic residues in farmed fish could cause adverse drug interactions. Farm workers who administer antibiotics in dust aerosols have also reported developing drug allergies or other health impacts (Cherian et al., 2023).

Antibiotic use in aquaculture may carry greater risk to surrounding ecosystems compared to terrestrial agriculture because the aquatic environment spreads residues more widely. Researchers estimate that over 70% of antibiotics administered via fish feed end up diffusing into the surrounding environment, either because fish miss the feed, or they excrete out excess drugs. These excess antibiotics can harm plankton and zooplankton that form the foundation of marine food webs and alter the natural surrounding microbial communities. Wild fish may also consume antibiotic residues, with food safety implications for wild capture fisheries (Cherian et al., 2023).

As aquaculture expands globally, emerging pathogens and antimicrobial resistance are growing concerns. Helpfully, the need for alternative strategies has both spurred novel approaches to pathogen control, and shined a light on traditional and Indigenous practices that reduce outbreak risks.

Methods to Prevent or Manage Pathogens

In general, prevention of disease is far less costly than containment and treatment. The worst and most costly case would be pre-harvest culling of animals to limit spread of disease (Rhodes et al., 2023). Effective disease management requires a combination of strategies from the three tiers of intervention described below: protocols and plans for disease management, proactive strategies to prevent disease, and therapeutics to treat disease (Wright et al., 2023). The below prevention and management techniques are broadly applicable across finfish, shellfish, and seaweed, although each of these sectors would require tailored biosecurity protocols (Rhodes et al., 2023).

Comprehensive Protocols for Disease Management

Detecting and Monitoring Pathogens

Effective management requires rapid detection and diagnosis of pathogens in aquaculture systems. Regular health monitoring and documentation by on-site staff, paired with regular inspections by a certified health professional, are key to early detection and containment of disease. The United States Department of Agriculture (USDA) offers voluntary standards (see below section on Current Sustainability Guidelines for Disease Management), but the U.S.

currently has no requirements for professional health inspections nor guidance for determining and maintaining aquaculture organism health (Rhodes et al. 2023).

Traditional diagnostic methods include visual diagnosis by an animal health professional based on animal symptoms or examination of blood or tissue samples in a laboratory setting (Bohara et al., 2023). For open ocean facilities, the time required to bring veterinary personnel to facilities and awaiting laboratory results may delay critical responses to prevent outbreaks. Furthermore, the U.S. lacks sufficient laboratory facilities qualified to work with aquaculture samples to support the growing industry (Rhodes et al., 2023). Newer innovations, such as on-farm sensors, cameras and drones, artificial intelligence (AI), genetic sequencing of pathogens and cultured species, biosensors, and CRISPR have enabled disease detection within minutes of an outbreak, and support targeted therapies (Bohara et al., 2023).

Biosecurity protocols

Practical and effective biosecurity plans are fundamental for preventing the introduction and spread of pathogens in aquaculture. Ideally, a team of animal health experts, aquaculture professionals, and licensed veterinarians would develop this plan (UC Davis, 2024). Per best practices put forth by the National Oceanographic and Atmospheric Administration (NOAA; Rhodes et al., 2023), a biosecurity plan should:

1) Train staff to identify and assess disease and other health hazards. Disease response protocols should provide clinical signs for recognizing diseases and include appropriate response for all major diseases that are prevalent for a given cultured species and location (Wright et al., 2023). Biosecurity training plans should promote awareness of likely pathogens and their routes of introduction, spread, and release. For example, transport of animals from hatcheries to open ocean grow-out sites is a critical activity mechanism with potential to spread disease because of the interface with nearshore or land-based components of the animal's life cycle (Rhodes et al., 2023).

2) Describe actions to prevent and mitigate disease risks. General biosecurity protocols for disease prevention include personal protective equipment (e.g., gloves, boots, masks); disinfection foot baths; area restrictions; quarantine procedures for sick animals; and standard procedures for cleaning and disinfecting equipment (Wright et al., 2023). Traditionally, disinfecting agents are broad-spectrum biocidal products such as benzalkonium chloride, hydrogen peroxide, and iodine. In pens that interface with the ocean surface and risk contamination with birds and other wildlife, methods to reduce contamination and disease transmission include placing netting or fencing around pen perimeters, putting mesh covers or screens over the pen surface, and installing wildlife deterrents like sound devices, bright lights, or even scarecrows (Wright et al., 2023). Data collection and monitoring, such as logging health records and documenting animal movements and husbandry practices, enables farm and veterinary personnel to make informed health decisions (Rhodes et al. 2023).

In the above transport example, carefully disinfecting the “well boats” that transport animals and equipment among facilities, designing delivery and inspection routes that go from healthiest to unhealthiest fish, and prohibiting discharge of ballast water would all be key components of a biosecurity protocol (Rhodes et al., 2023).

3) Define how risk management is communicated. Site-specific Standard Operating Procedures (SOPs) for all personnel and visitors should be in place for routine activities and disease response (Rhodes et al. 2023). Personnel should have regular training to understand biosecurity principles and implement SOPs. Biosecurity plans should be accessible on-site and reviewed and updated regularly (Rhodes et al. 2023). Farms can simplify and speed disease response times by implementing “syndromic disease response protocols,” where groups of diseases that appear similar are subject to the same initial response actions (e.g., quarantine procedures) while additional testing is done to identify the specific pathogen (Wright et al., 2023). Additionally, aquaculture facilities should be familiar with federal and state pathogen reporting requirements (Wright et al., 2023).

Proactive Strategies to Prevent Disease

Optimal Farm Design and Good Husbandry

Farm design and management decisions and good animal husbandry practices are key to supporting healthy and resilient animals that can resist pathogen onset, and preventing outbreaks from spreading to the wild ecosystem and species. Best practices for farm siting include selecting locations further offshore, in areas with higher water flow, and with wider spacing between farms and pens. Good husbandry practices such as minimizing stress (such as from crowding or improper handling), optimizing environmental conditions for species-specific needs (e.g., temperature, dissolved oxygen, turbidity, pH, access to natural habitats), maintaining a nutritious diet, and implementing routine veterinary checks help support overall animal health and strengthens immunity (Wright et al., 2023; UC Davis, 2024).

Additionally, the practice of fallowing, leaving a pen and associated equipment empty for one or more growing seasons, is effective at reducing disease and pathogen load (Rhodes et al. 2023; Fujita et al. 2023). For salmon in temperate zones, at least 4 weeks is recommended and up to 3-6 months for known disease outbreaks (Rhodes et al. 2023).

Vaccination and Dietary Supplements

Vaccines, which prepare the immune system to fight a specific disease, are highly effective against prominent pathogens, and are also safe and economical. Vaccines can only be used in finfish; shellfish and invertebrates lack adaptive immune systems (Rhodes et al. 2023). Vaccines can be administered orally during feeding, by immersion of the fish in a vaccine solution, or by direct injection. These administration methods are in order of both efficacy and difficulty/ time intensity (Wright et al., 2023).

There are 7 USDA-approved and commercially available vaccines for use in aquaculture. Five are for bacterial or viral infection in salmonids, and 2 are for catfish. These vaccines can be used for other finfish species and have reduced antibiotic use, but more research and vaccine development are urgently needed (Wright et al., 2023). An emerging innovation is the development of “autogenous” vaccines, which are developed *in situ* and thus adapted/targeted to the specific pathogen affecting a specific farm and cultured species. These vaccines can be more effective, more adaptive, and more rapidly developed to respond more quickly to pathogen outbreaks (Wright et al., 2023).

In addition to vaccines, dietary supplements have been shown to enhance immune system function and increase overall health, which improves resilience to disease. A robust body of aquaculture research indicates that prebiotics and probiotics improve microbiome gut health in farmed fish, which indirectly boosts the immune system and provides various additional benefits (Wright et al., 2023). Nascent research on immunostimulants—compounds intended to directly enhance the immune system —also appears promising (Wright et al., 2023).

Stock and Genomic Selection for Disease Resistance

Animal agriculture has employed selective breeding for disease resistance (among other valued traits) in both terrestrial and aquatic animals for decades. Further advances in breeding and genetics could improve the overall health and resilience of animals in aquaculture systems and reduce the need for antimicrobials. For most aquatic species, researchers are in the early stages of understanding their genetics. An exception is freshwater catfish (*Ictalurus* spp.) with selective breeding experiments dating back to the 1960s. However, advances in genomics have reduced the cost of genome sequencing, allowing researchers to identify and understand how genetics influence disease susceptibility and resistance. Once researchers identify specific genetic markers associated with disease susceptibility or resistance, they must then uncover how to select for those desired markers and develop breeding programs that reliably accomplish this selection (Wright et al., 2023).

Biocides and Therapeutics to Prevent and Treat Disease

Traditional Antimicrobials

Antimicrobial products can be split into two functional groups: biocides for cleaning and therapeutics for disease treatment. Due to a troubling rise in antimicrobial resistance, these are considered the last line of defense and should be carefully and appropriately used.

Biocides for disinfection and disease prevention (e.g., bleach) kill a broad spectrum of life forms and must be applied sparingly and carefully. Assessment of the most likely materials or equipment that transmit pathogens (called fomites) can help prioritize biocide decontamination efforts to avoid excessive application (Rhodes et al., 2023).

Antimicrobial products for disease treatment, including antibiotics, are generally more selective. They are safe for use in production fish and effective at controlling specific pathogens once detected. The U.S. Food and Drug Administration (FDA) has approved three antibiotics available for use in aquaculture: oxytetracycline, florfenicol, and sulfadimethoxine/ormetoprim. All require a prescription or veterinary feed directive by a licensed veterinarian (Wright et al., 2023).

Hydrogen peroxide and chloramine-T, often used as surface disinfectants, are also approved by the FDA for treating some bacterial diseases and do not require prescription (although veterinarian consultation is advisable). Copper sulphate and potassium permanganate are approved for use in aquaculture for certain parasites and bacterial or fungal infections (Wright et al., 2023).

Novel Antimicrobials with Reduced or No Risk of Antimicrobial Resistance

To reduce antibiotic resistance, researchers are developing innovative alternative treatments, leveraging recent research into fish immune system function and pathogen virulence to develop even more targeted therapies. These approaches can transform aquaculture disease management (Wright et al, 2023). However, approval processes for new medicines and therapeutics are extremely slow (Rhodes et al., 2023).

Antimicrobial peptides, which are naturally produced in fish immune systems, provide a rapid, broad-spectrum response to a diverse array of pathogens. They represent promising alternatives to antibiotics because they are highly effective, do not cause resistance, and biodegrade so do not remain in animal tissues or the environment (Wright et al., 2023).

Antivirulence therapies use compounds that target the specific pathways by which pathogens cause disease—such as secreting toxins or adhering to host cells. Unlike traditional antibiotics that indiscriminately kill both pathogens and beneficial microbes, antivirulence therapies only target pathogens that could be virulent. This significantly lessens the risk of spurring antimicrobial resistance. Both antimicrobial peptides and antivirulence therapies are abundant in nature, and research into their applicability in aquaculture is promising (Wright et al., 2023).

Biological control agents, such as bacteriophages (viruses that infect and kill specific bacteria) and beneficial microbes, can also control disease-causing pathogens naturally (Richards, 2014). For example, "biofloc" technology utilizes bacteria that consume nutrient waste in pens to maintain water quality and suppress pathogen proliferation within aquaculture systems. These bacteria then can also be used as protein-rich feed for some cultured species (Crab et al., 2012).

Traditional, Indigenous, and Nature-Based Management Practices

Indigenous aquaculture systems have existed for millennia, and continue to provide examples of sustainable, holistic management techniques (*Indigenous Aquaculture Collaborative*, n.d.). These systems prioritize ecosystem health and foster synergistic relationships between cultured species and the systems within which they grow, which promotes overall health (Stentiford et al., 2020). Nature-based aquaculture management practices, including integrated-multitrophic aquaculture—wherein multiple species of different trophic levels are grown synergistically together, are seeded in these Indigenous aquaculture principles.

Integration of certain native and adapted aquatic vegetation can reduce fish stress by providing shade and habitat and provide refuge for beneficial organisms while enhancing water quality, oxygenation, and ecosystem balance. These integrated practices can optimize the nutrient balance and reduce the pathogens in the wastewater and sediments, thereby reducing the risk of disease outbreaks (Tom et al., 2021). For example, establishment of constructed wetlands or biofiltration systems utilizing aquatic plants can remove excess nutrients and pollutants from aquaculture effluents (Gorito et al., 2022; Pérez, 2021).

Medicinal plants have been used for centuries in traditional medicine and aquaculture practices. Probiotics, natural immunostimulants such as herbs, spices, and seaweeds, and plant-based oils with antimicrobial properties, including, garlic, oregano, and neem, can be incorporated into aquafeed formulations or added directly to the water to improve disease resistance and overall health (Dawood et al., 2021; Gupta et al., 2021; Ng et al., 2023; Tadese et al., 2022; Van Hai, 2015).

Co-cultivation of cleaner fish, such as lumpfish (*Cyclopterus lumpus*), or cleaner wrasses can reduce parasites, such as sea lice, with lower environmental impacts and health impacts for cultured species. However, additional species bring additional pathogen potential and biosecurity needs (Rhodes et al., 2023).

Needs and Barriers for Managing Disease and Parasites in Open Ocean Aquaculture

Challenges remain for developing and promoting best practices for preventing and managing disease and parasites in aquaculture, both open ocean and nearshore. The following recommendations build from a 2022 NOAA-hosted stakeholder workshop (Rhodes et al., 2022):

- **Increase coordinated research and implementation of biosecurity and disease management.** Currently, there is little support for health and disease research including breeding programs, diet research, and basic research about pathogen dynamics. More partnerships among academia and industry, and funding and incentives for those partnerships, are needed. For example, NOAA and the Department of Health and Human Services could collaborate with industry to identify priority native species and diseases for pharmaceutical, vaccine, and antimicrobial research.
- **Expand availability of qualified personnel** for developing and implementing biosecurity plans, or training aquaculture staff on biosecurity and disease diagnosis and response.

- **Expand testing capacity (i.e., qualified laboratory facilities) and staff.** Research and development investment is needed to develop low-cost, rapid diagnostic methods that can be used on-site.
- **Expedite the pace of vaccine and therapeutant development and licensing**, including INAD (investigational new animal drug) approval, which remains slow.
- **Establish consistent aquaculture disease regulation**. Mandatory federal disease and biosecurity programs are needed, along with enforcement. These should include standards for interpreting and acting on positive lab findings.
- **Develop an indemnification program for aquaculture losses**. No such program currently exists, requiring growers to shoulder all financial risks. For open ocean aquaculture specifically, this can be because there are too many unknowns and no historical data to conduct actuarial risk assessments.

Current Sustainability Guidelines for Disease Management

A variety of national and international organizations have released principles, guidelines, and standards to support aquatic animal health in aquaculture, with prominent examples given below. It would be considered best practice for all aquaculture operations to develop customized protocols for pathogen prevention, response, and treatment that are specific to the species being reared and the local context and risks (see section on "Biosecurity Protocols;" Wright et al., 2023).

- USDA's Comprehensive Aquaculture Health Plan and Standards (CAHPS) provides training and guidance for national disease reporting, laboratory and testing standardization, surveillance, response, biosecurity, data management, and education and training.
- The American Fisheries Society (AFS) Fish Health section reference document, the AFS Blue Book, details the pathology and diagnostic methods for common aquaculture diseases. Additionally, AFS published a Guide to Using Drugs, Biologics, and Other Chemicals in Aquaculture.

- The Food and Agriculture Organization (FAO) developed Technical Guidelines on Health management for responsible movement of live aquatic animals to assist countries in reducing the risk of introduction and spread of transboundary aquatic animal diseases.
- The Best Aquaculture Practices (BAP) certification program, operated under the Global Seafood Alliance, developed a Biosecurity Area Management Standard that offers further insights into how to develop a suitable system for offshore aquaculture in the U.S.
- The World Organization for Animal Health Aquatic Animal Health Code Chapter on biosecurity for aquaculture establishments established guidance and principles for developing biosecurity protocols.
- The US East Coast Regional Shellfish Seed Biosecurity Program created guidelines and voluntary standards for bivalves and shellfish
- Ocean Best Practices and Swansea University compiled best practices and SOPs for temperate seaweed monoculture based on pilot farms in the EU and UK.

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