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INVITED EDITORIAL

Refuting Marine Aquaculture Myths, Unfounded Criticisms, and Assumptions

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ABSTRACT

Sustainable domestic aquaculture development is a critical component to achieving greater U.S. seafood security in the future, yet detrimental allegations have corrupted public support. A variety of longstanding and inaccurate myths and assumptions directed at offshore aquaculture farming and its regulation have been foisted on the public. This paper refutes the most prevalent critiques by reviewing current policies, regulations, research and industry production practices. These criticisms include: inadequate regulatory oversight; portrayal of farms as being high density factories unconcerned by food waste, untreated discharge, use of antibiotic and antifungal treatments; entanglement of marine mammals; impacts on wild stocks and habitats; use of feed additives to pigment fish flesh; unsustainable use of fish meal in feed formulations; potential market disruption by producing cheap, low quality products; and commercial farms and commercial fishers cannot coexist as for-profit businesses. Marine aquaculture is not risk-free in terms of potential environmental, economic, social, and cultural impacts and challenges remain to achieve a sustainable industry. These challenges are well known and addressable by the U.S. and global research community. Current offshore farming realities bode well for the future: 1) there is a clear global imperative to sustainably produce more seafood to meet growing demand and the U.S. has the marine resources to become a major exporter, if U.S. law can be amended to grant offshore farmers a property right or security of tenure for sites in federal waters; 2) U.S. ocean farmers work within a very complex and effective legal, regulatory, science-driven environment to anticipate and mitigate potential impacts; 3) farm level management decisions and federal and state regulatory frameworks have worked together to bring about environmentally friendly siting, operational, and production outcomes, and 4) the farming community and its advocates in government, universities, and industry recognize it is essential to reach out to decision-makers and the interested public, as well as critics, with the latest research and empirical results to present an accurate picture of risks and rewards to development.

KEYWORDS
Aquaculture; science; regulation; policy; production practice

Introduction

A variety of tenacious myths and assumptions critical of marine aquaculture as practiced in the United States have persisted for decades (Goldberg and Triplett 1997) and have been presented as facts to the public and Congress (Knapp and Rubino 2016; Mail Buoy 2019). The reality is U.S. fish and shellfish farmers culture aquatic animals and plants within a very complicated and expensive legal, regulatory, husbandry and science-driven environment. We believe critics are unfamiliar with this environment or have erroneously assumed marine aquaculture-related environmental damage reported in other countries occurs in the United States. Our response to these pernicious myths, criticisms and assumptions does not lend itself to short, simple answers; although, we have worked to be as succinct as possible. The myths, unfounded criticisms and false assumptions we address include:

- Federal regulations, permitting and environmental review processes are inadequate to manage offshore fish farms
- Marine net pens or sea cages are factory farms that in US waters would contribute marine pollution caused by excess feed, untreated fish waste, antibiotics and antifoulants
- Offshore farms entangle marine animals

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- Farms displace marine animals from important habitats and farmers harm marine mammals
- Escaped farm-raised fish adversely impact wild fish stocks
- Fish feed includes colorants
- Fish meal and fish oil in fish feeds is unsustainable
- Farm-raised fish will displace US fisheries and are cheap and of low-quality
- American commercial fishing and marine finfish aquaculture cannot coexist

We are not touting global marine aquaculture as totally risk-free with no impacts to the abiotic or biotic environment or the socio-economics of wild fisheries (Clavelle et al. 2019; Theuerkauf et al. 2021) or there aren't significant challenges to sustainable expansion (Costello et al. 2020). We are arguing day-to-day farm-level management decisions and federal and state regulatory frameworks work together in the United States to bring about favorable siting and production outcomes. This synergism anticipates, mitigates or prevents the environmental effects falsely presented by critics. As an anecdotal example, the recent film *Seaspiracy* dramatized fishery and aquaculture issues in foreign nations and through omission implicitly acknowledges the success of U.S. private and public investment in fostering sustainable production practices and an efficient and effective regulatory framework.

The United States is a minor player in producing farm-raised seafood

The United States is not a world leader in sustainable aquaculture production by volume or value no matter how seafood imports and exports are counted (Gephart et al. 2019).[1] We are in the thoughtful and rigorous development of regulatory and nonregulatory production practices, animal nutrition and health management (Schwarz et al. 2017; Stickney and McVey 2002; Tomasso 2002; Tucker and Hargreaves 2008; Shumway 2011), the efficient processing and distribution of high-quality, wholesome foods (Boyd et al. 2020) and a significant contributor to the development of technological innovation (Kumar and Engle 2016). A recent analysis of global marine aquaculture potential concluded with a statement that is very relevant to U.S. aquaculture by highlighting the unlimited potential of the United States to be a global leader in sustainability, technology and production (internal citations deleted) (Gentry et al. 2017, 1320) (emphasis added):

> *Given the significant potential for marine aquaculture, it is perhaps surprising that the development of new farms is rare. Restrictive regulatory regimes, high costs, economic uncertainty, lack of investment capital, competition and limitations on knowledge transfer into new regions are often cited as impediments to aquaculture development.* In addition, concerns surrounding feed sustainability, ocean health and impacts on wild fisheries have created resistance to marine aquaculture development in some areas. While ongoing and significant progress has been made in addressing sustainability issues with marine aquaculture, continued focus on these issues and dedication to ensuring best practices will be a crucial element shaping the future of marine aquaculture. Both the cultural and economic dimensions of development and the management and regulatory systems are critically important to understanding realistic growth trajectories and the repercussions of this growth. *Our results show that potential exists for aquaculture to continue its rapid expansion, but more careful analysis and forward-thinking policies will be necessary to ensure that this growth enhances the well-being of people while maintaining, and perhaps enhancing, vibrant and resilient ocean ecosystems.*

All forms of producing food incur environmental consequences. Systematic comparisons between production methods are difficult due to a lack of comparable quantification of the inputs (e.g., energy, water, fertilizers, feeds, pesticides, antibiotics), potential effects (e.g., greenhouse gas emissions, water use and quality, biodiversity loss, habitat or wild species displacement), different production systems, local environments, production intensity, and farm management. To satisfy an estimated global population of 9 billion people by 2050, animal production is expected to increase by 40% to 50%. Nations could trade globally to acquire farm-raised seafood without restriction, adopt a nationalist perspective protecting and supporting domestic production or impose sustainability restrictions for either case (Gephart et al. 2020). Comparing crop land increases under different scenarios of increasing animal protein, Froehlich et al. (2018, 3) estimated significantly less land conversion under any scenario of increased aquaculture production. They note:

> Shifting diets to more cultured seafood has comparatively lower impact on feed and land use, but does not eliminate such pressures and could result in other environmental and dietary shortcomings. Current aquaculture technology and best practices can help reduce some negative effects, including pollution

[1]Gephart et al. (2019, 9144) argue 62 to 65% of the seafood consumed in the United States is provided by other countries contrary to the widely cited 80 to 90%. They also note "Globally, more than half of all seafood is farmed, but the United States contributes less than 1%."

> and disease, but do not negate stresses that can arise from improper planning and weak oversight, such as escapes and habitat degradation.

As we will present, the United States has the will, investment, infrastructure, education and complex regulatory framework to reduce the effects of negligent planning, siting, and production. What is disappearing with increasingly complex regulations is the ability to innovate. As Asche and Smith (2018, 5–6) concluded (emphasis added):

> …innovations in technology, policy, and markets can alleviate potential scarcities arising from ecological conditions, the challenge for conservation and continued expansion of seafood production to address food security is how to promote the types of innovation that address these issues. In other words, *the primary risk to the oceans is not insufficient conservation but rather stifled or unproductive innovation. Productive innovations, including in policy, are ones that enable conservation, food production, and the creation of economic value.*
>
> Aquaculture regulations also highlight limitations on innovation and seafood production. Despite abundant coastline and habitat for farming fish, *U.S. production has been limited by the regulatory environment, and U.S. capital and knowledge have largely moved overseas to produce farmed fish in other countries.*

There is a global imperative to increase sustainable protein production with wild-caught and farm-raised seafood being a major component (Béné 2015; Costello et al. 2020). The United States has the ability to accomplish this goal while leading the world in environmental protection (NOAA n.d.-b). Froehlich et al. (2021, 7) compiled and analyzed past trends in farmed and wild seafood production and consumption in International Council for the ICES nations,[2] as well as the potential and need to increase aquaculture production by 2050. They found that the majority of ICES nations lack long-term strategies for aquaculture growth, with an increasing gap between future domestic production and consumption—resulting in a potential 7.7 million ton domestic seafood deficit by 2050, which would be supplemented by imports from other countries (e.g., China).

And concluded (emphasis added and internal citations removed):

> There is historical precedent for ICES nations to be at the forefront of sustainable seafood production, whether through domestic and/or better trade dimensions. Over the decades, the exploration and implementation of new tools and strategies to better manage wild fisheries have been recognized and adopted to various extents among these nations. *While great strides were made to support best fisheries practices—including governance, funding, and research support—to recover many wild stocks, much less effort has been given in most of the ICES nations to usher in aquaculture practices in a similar, but more anticipatory manner.* Interestingly, we found that even with the apparent recognition by all current ICES countries that aquaculture will play an increasingly important role in future seafood production, most planning appears very short term and conservative. *Development of long-term aquaculture strategies is not just about absolute production and must also include measures to advance improved husbandry, technology, and participation in the changing seafood market, ideally with sustainability leading these components.* While the goals moving forward to 2050 by the ICES nations may be feasible as the growing challenges are addressed, growth predominantly depends on one country, Norway. *Even if the goals are met, it does not reconcile the deficits in seafood production, requiring increases in imports of seafood, often from places with considerably fewer rules and regulations for sustainable harvest or production. In addition, lack of aquaculture consideration creates a major gap in adaptively planning for the impact of climate change on the seafood sectors domestically and from exporting countries.*
>
> Governance is key to adaptive planning, and targeted policies that support, not just regulate, domestic aquaculture are needed if ICES countries wish to address the skewed production landscape. *In a global setting, the restrictive and complex regulatory structures have been identified as important factors stagnating the growth of aquaculture in Europe and North America and may have resulted in declining their share of world aquaculture production.*

Current seafood and aquaculture production were reported by Food and Agriculture of the United Nations in their *2020 State of World Fisheries and Aquaculture: Sustainability in Action* (FAO 2020, 2, 25, 173):

> Global fish production is estimated to have reached about 179 million tonnes in 2018, with a total first sale value estimated at USD 401 billion, of which 82 million tonnes, valued at USD 250 billion, came from aquaculture production. Of the overall total, 156 million tonnes were used for human consumption, equivalent to an estimated annual supply of 20.5 kg per capita.
>
> Aquaculture accounted for 46 percent of the total production and 52 percent of fish for human consumption. China has remained a major fish producer, accounting for 35 percent of global fish production in 2018. Excluding China, a significant share of production in 2018 came from Asia (34 percent), followed

[2]ICES is an acronym for the International Council for the Exploration of the Sea. The ICES member nations analyzed were Belgium, Canada, Denmark, Estonia, Finland, France, Germany, Iceland, Ireland, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Russia, Spain, Sweden, United Kingdom and United States.

> by the Americas (14 percent), Europe (10 percent), Africa (7 percent) and Oceania (1 percent).

The United States is a minor player in seafood production overall.

> Among the top ten countries with the largest total farmed and wild production in 2018, four exceed the 50 percent mark of aquaculture production as a percentage of total fish production (i.e., China 76.5 percent, India 57 percent, Viet Nam 55.3 percent and Bangladesh 56.2 percent); the other six are mostly well below the 50 percent mark (i.e., Peru 1.4 percent, the Russian Federation 3.8 percent, the United States of America 9 percent, Japan 17 percent and Norway 35.2 percent).

Going into the future, the UN-FAO predicts the United States will be dependent on the rest of the world for its seafood needs with production down by 8.5% and imports up by 3%.

> The bulk of the growth in fish exports is projected to originate from Asia, which will account for about 73 percent of the additional exported volumes by 2030. Asia's share in total trade of fish for human consumption will increase from 48 percent in 2018 to 50 percent in 2030. Advanced economies are expected to remain highly dependent on imports to meet their domestic demand. The European Union, Japan and the United States of America will account for 38 percent of total imports for food fish consumption in 2030, a slightly lower share than in 2018 (40 percent).

The lack of a national appreciation that the United States should be a major contributor to farmed seafood production appears to derive from a lack of domestic concern for food security and jobs and income for rural inland and coastal communities fortunate enough to host active fishing ports or farms (Rickard et al. 2020).

Myth: Federal regulations, permitting and environmental review processes are inadequate to manage offshore fish farms

In the United States, since the 1970s, the U.S. Environmental Protection Agency (EPA) has held authority to regulate discharges from fish farms (e.g., nutrients, chemicals and solid waste) under several iterations of the Federal Water Pollution Control Act (i.e., Clean Water Act).[3] More recently, environmental groups sought EPA reevaluation of the Clean Water Act standards applied to aquaculture.

During a four-year period, between 2000 and 2004, the agency completed a detailed technical review of its then-current standards and modern aquaculture methods, including those used for marine aquaculture. Formal rulemaking was conducted to ensure that Clean Water Act regulations for aquaculture met all standards of environmental protection mandated by Congress. In that process, the EPA determined, contrary to the position of some environmental groups prior to the effort, that the proposed and adopted revised regulations assured environmental protection.

The proposed rule was not challenged in court.

Current regulatory authority exists to appropriately protect marine water quality and benthic environmental systems (NOAA 2020c), manage fish escapes, protect wild fish stocks, marine mammals and migratory birds, protect essential habitat, require responsible drug and chemical use, ensure safe navigation, and assure consumers that they will have access to safe foods.

During January 2021, the U.S. Army Corps of Engineers (Corps) revised a nationwide permit for marine shellfish farming and created two new nationwide permits for seaweed and marine finfish farming. The Corps issues nationwide permits (NWPs) to authorize activities under Section 404 of the Clean Water Act, discharges of dredged or fill material into waters of the United States, and Section 10 of the Rivers and Harbors Act of 1899, structures and work in navigable waters, where those activities will result in no more than minimal individual and cumulative adverse environmental effects. The Nationwide Permits and final decision documents can be viewed here: https://www.usace.army.mil/Missions/Civil-Works/Regulatory-Program-and-Permits/Nationwide-Permits/.

In brief:

- NWP 48, Commercial Shellfish Mariculture Activities, authorizes the installation of buoys, floats, racks, trays, nets, lines, tubes, containers, and other structures into navigable marine waters of the United States. This NWP also authorizes discharges of dredged or fill material into waters of the United States necessary for shellfish seeding, rearing, cultivating, transplanting, and harvesting activities. Rafts and other floating structures must be securely anchored and

[3]The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. The basis of the CWA was enacted in 1948 and was called the Federal Water Pollution Control Act. The Act was significantly reorganized and expanded in 1972. "Clean Water Act" became the Act's common name with amendments in 1972 (33 U.S. Code § 1251-1387).

clearly marked. For the purposes of this NWP, the project area is the area in which the operator is authorized to conduct commercial shellfish aquaculture activities, as identified through a lease or permit issued by an appropriate state or local government agency, a treaty, or any easement, lease, deed, contract, or other legally binding agreement that establishes an enforceable property interest for the operator.

- NWP 55, Seaweed Mariculture Activities, authorizes the installation of buoys, long-lines, floats, anchors, rafts, racks, and other similar structures into navigable marine waters of the United States. Rafts, racks and other floating structures must be securely anchored and clearly marked. This NWP also authorizes structures for bivalve shellfish and/or seaweed farming if the structures for bivalve shellfish and/or seaweed production are a component of an integrated multitrophic structure (e.g., the production of bivalve shellfish or seaweed on the structure used for finfish farming, or a nearby structure that is part of the single and complete project).
- NWP 56, Finfish Mariculture Activities, authorizes structures in marine and estuarine waters, including structures anchor to the seabed in waters overlying the outer continental shelf, for finfish aquaculture activities including the installation of cages, net pens, anchors, floats, buoys, and other similar structures into marine navigable waters of the United States. Net pens, cages, and other floating structures must be securely anchored and clearly marked. This NWP also authorizes structures for bivalve shellfish and/or seaweed farming if the structures for bivalve shellfish and/or seaweed production are a component of an integrated multitrophic structure.

Other current federal regulatory authorities, unilaterally or in partnership with the states, provide enforceable standards to protect navigation and navigational aids, water and benthic quality, food safety, drug and chemical use, aquatic animal health, endangered species, wild fishery stocks (with respect to potential aquaculture impacts to those populations), marine mammals, migratory birds and essential fish habitat. The existing and newly proposed aquaculture permitting procedures also provide an opportunity for coastal states to comment on proposed federal operational permits associated with offshore marine aquaculture. Existing laws applicable to aquaculture operations include, but are not limited to, the Animal Health Protection Act; Animal Medicinal Use Drug Clarification Act; Coastal Zone Management Act; Endangered Species Act; Federal Food Drug and Cosmetic Act; Federal Insecticide, Fungicide, and Rodenticide Act; Fish and Wildlife Coordination Act; Federal Water Pollution Control Act (Clean Water Act); Food Safety Modernization Act; Lacey Act; Magnuson-Stevens Fishery Conservation and Management Act; Marine Mammal Protection Act; Migratory Bird Protection Act; National Environmental Policy Act; National Historic Preservation Act; National Marine Sanctuary Resources Act; National Invasive Species Act; Non-indigenous Aquatic Nuisance Prevention and Control Act; Outer Continental Shelf Lands Act; and Rivers and Harbors Act (Price et al. 2017).

Through Executive Order, rulemaking, judicial rulings and an opportunity to comment on significant federal permitting by other federal agencies, the U.S. Environmental Protection Agency, National Oceanic and Atmospheric Administration (National Marine Fisheries Service), U.S. Department of Agriculture (Animal and Plant Health Inspection Service), U.S. Army Corps of Engineers, U.S. Coast Guard, U. S. Department of Defense, Federal Aviation Administration, U.S. Fish and Wildlife Service, Bureau of Safety and Environmental Enforcement, Bureau of Ocean and Energy Management, and state agencies (agriculture, natural resources, and environmental protection) have an important regulatory role relative to offshore aquaculture and, in particular, the coastal states are provided an opportunity to comment on proposed federal permits and leases associated with offshore marine aquaculture (NOAA 2019; 2020c).

Florida Sea Grant funds an offshore demonstration project

To inform the public concerning current net pen production practices and regulatory oversight, in 2018 the Florida Sea Grant Program funded a one sea cage demonstration farm approximately 72 kilometers out from Florida's Gulf Coast. The Sea Grant program hosted a public workshop in 2019, Pioneering Offshore Aquaculture, consisting of production, site selection, regulatory and economic implication presentations. A commercial partner, Ocean Era, Inc., applied for a National Pollutant Discharge Elimination System (NPDES) permit from the Environmental Protection Agency (EPA), and a Rivers and Harbor Act Section 10 permit from the U.S. Army Corps of Engineers.

The estimated production by one net pen, 39,287 kg live weight pounds for one production cycle of the native almaco jack (*Seriola rivoliana*), is below the EPA's Concentrated Aquatic Animal Production NPDES threshold of 45,454 kgs; however, the EPA permitted the farm as if production exceeded the CAAP threshold. Multiple consultations were conducted with the appropriate federal or state agencies including Endangered Species Act Section 7, Essential Fish Habitat provisions under the Magnuson-Stevens Fishery Conservation and Management Act, Fish and Wildlife Coordination Act, National Historic Preservation Act, and the Coastal Zone Management Act. Additionally, EPA invoked the voluntary provisions of the National Environmental Policy Act and performed Ocean Discharge Criteria evaluation pursuant to Clean Water Act Section 403. EPA sought comments from the other federal and state agencies, and posted for public comment a draft permit and environmental analyses, as well as held a public hearing. Approximately, 44,500 public comments were submitted on the draft NPDES permit and supporting documents

The EPA issued a NPDES during September 2020. The project is currently being appealed and the NPDES permit remains ineffective until the appeal process is over. We invite and encourage your independent analysis of the federal permits and interagency environmental evaluations. The full NPDES permit package is posted here: https://www.epa.gov/npdes-permits/ocean-era-inc-velella-epsilon-aquatic-animal-production-facility-national-pollutant.

Ocean Era, Inc. also applied in November 2018 for a Department of the Army permit pursuant to Section 10 of Rivers and Harbors Act (Section 10) from the U.S. Army Corps of Engineers (Corps). For finfish aquaculture activities in coastal waters and in federal waters on the outer continental shelf, the Corps regulates structures and work in navigable waters of the United States. A Department of the Army Section 10 permit is required for structures and work in, over, under, and affecting navigable waters and may authorize structures in navigable waters of the United States, including federal waters over the outer continental shelf, in support of the proposed finfish aquaculture activity. The authority of the Secretary of the Army, acting through the Corps of Engineers, to prevent obstructions to navigation in navigable waters of the United States was extended to artificial islands, installations, and other devices located on the seabed, to the seaward limit of the outer continental shelf by Section 4(f) of the Outer Continental Shelf Lands Act of 1953 as amended[4]. The Corps is currently reviewing this pilot-scale (single net-pen) finfish aquaculture project to determine whether a permit can be issued for an obstruction or alteration of any navigable water of the United States, the construction of any structure in or over any navigable water of the United States, or the accomplishment of any other work affecting the course, location, condition, or capacity of such waters. The public notice was posted for public comment on October 5, 2020 and comments were due to the Corps by November 19, 2020.

An offshore farm federal permit applicant is responsible for contacting coastal states for a Coastal Zone Management Act (CZMA)[5] consistency review and National Historic Preservation Act (NHPA)[6] concurrence. Within the Florida Department of Environmental Protection (DEP), the Florida State Clearinghouse (SCH) administers the intergovernmental coordination and review process of certain state and federal activities within the state of Florida which involve federal financial assistance and/or direct federal activity. As such, SCH is the responsible authority for coordinating CZMA compliance as well as NHPA consultations and subsequent concurrence from the Florida State Historic Preservation Office. Ocean Era, Inc. prepared a Coastal Consistency Determination demonstrating compliance with 24 enforceable policies (Florida Statute Chapters) incorporated into an existing, federally-approved Florida Coastal Management Plan. They also contracted for an archaeological review and analysis report as a component of their Baseline Environmental Survey report for the benthic surveys (side scan sonar, magnetometer, and sub-bottom profile). These reports are publicly available as components of the federal permitting application.

Candidate offshore farms can benefit from NOAA marine spatial planning

An Executive Order, Promoting American Seafood Competitiveness and Economic Growth, signed on May 7, 2020 included a provision requiring the

[4]The Outer Continental Shelf Lands Act is codified in 43 U.S. Code 1333(e).
[5]The Coastal Zone Management Act is codified in 16 U.S. Code § 1456 Section 307 (c) (1) [or (2)] and the requirements for a consistency determination that are set forth in regulations at 15 Code of Federal Regulations § 930 (c).
[6]The National Historic Preservation Act requires federal agencies to evaluate the impact of all federally funded or permitted projects on historic properties (buildings, archaeological sites, etc.) through a process known as Section 106 Review (54 U.S. Code § 300101 through § 320303).

Department of Commerce, in an inclusive, transparent consultation with the departments of Defense, Interior, Agriculture, Homeland Security, Environmental Protection Agency, and regional federal fishery management councils and state and tribal governments. to identify geographic areas in the Exclusive Economic Zone[7] suitable for commercial aquaculture (finfish, shellfish and seaweed). Commerce, through the National Oceanic and Atmospheric Administration (NOAA), was to solicit and consider public comment to minimize conflicts with ocean users and prepare programmatic environmental impact statements for selected areas. NOAA has begun this effort and identified for public comment Aquaculture Opportunity Areas in the Gulf of Mexico and off of Southern California. An Aquaculture Opportunity Area is to be a small defined geographic area evaluated to determine its potential suitability for commercial aquaculture.

The agency has developed and implemented a measured, thoughtful approach that incorporates expertise in ocean and benthic biology, ecology, species and chemistry across the entire agency that are operationalized through a Coastal Aquaculture Siting and Sustainability Analysis completed by the National Centers for Coastal and Ocean Science. Notably, delineating an Aquaculture Opportunity Area does not replace or reduce regulatory requirements for individual farms by the federal agencies or additional environmental analysis through an Environmental Assessment or Environmental Impact Statement as required by the National Environmental Policy Act. Establishing Aquaculture Opportunity Areas does assist farmers to identify oceanic locations least likely to impact the environment or interfere with other users.

The development by NOAA of on-line farm siting tools reflects the incorporation of extensive and generally distinct and unconnected environmental and economic data sets to realize the potential for marine spatial planning. While desktop analysis is no substitute for in situ survey, stakeholder and public input and environmental monitoring the rapid development of the technological tools to avoid environmental and societal conflict is an invaluable addition to the state and federal regulatory processes to appropriately site and operate offshore farms (Gentry et al. 2016; 2017; Lester et al. 2018).

Environmental regulatory costs are significant within the United States

Engle and Stone (2013, 274) argued, and we agree:

a. "The regulatory environment in the United States has become increasingly stringent in recent years in terms of both the number and complexity of regulations that affect U.S. aquaculture.
b. Especially difficult is the lack of a lead agency at both federal and state levels to effectively coordinate and streamline regulatory and permitting processes that result in timely decisions and more certainty for investment in new enterprises and expansion of existing operations. The overall cumulative effect has been continued increases in the regulatory costs and risk faced by aquaculture growers in the United States."

State and Federal regulatory agencies incur costs and there is little appreciation by the agencies, public or the farming community of their aggregated impact. Publicly funded research is quantifying the effort and aggregated costs farms must expend to acquire and maintain permits. Peer-reviewed papers describing the scope and magnitude of regulations for sportfish, baitfish, Pacific Coast shellfish and salmonid farming are available (van Senten and Engle 2017; van Senten, Dey, Engle 2018; Engle, van Senten, Fornshell 2019; van Senten et al. 2020) and on-going research is analyzing regulatory costs for East Coast shellfish, catfish, tilapia, hybrid striped bass, redfish and ornamental fish (aquarium and water gardening) farming.

As an example, 161 salmonid farms (trout and salmon) representing 94% of U.S. production across 17 states (Colorado, California, Idaho, Maine, Michigan, Missouri, Nebraska, New York, North Carolina, Ohio, Oregon, Pennsylvania, Utah, Virginia, Washington, West Virginia, Wisconsin) provided economic data that Engle et al. (2019, 531, 546) reported:

[7]The exclusive economic zone is that portion of the ocean where the United States and other coastal nations have jurisdiction over natural resources. The U.S. Exclusive Economic Zone (EEZ) extends no more than 200 nautical miles from the territorial sea baseline and is adjacent to the 12 nautical mile territorial sea of the U.S., including the Commonwealth of Puerto Rico, Guam, American Samoa, the U.S. Virgin Islands, the Commonwealth of the Northern Mariana Islands, and any other territory or possession over which the United States exercises sovereignty. Under certain U.S. fisheries laws, such as the Magnuson-Stevens Fishery Conservation and Management Act, the term "exclusive economic zone" is defined as having an inner boundary that is coterminous with the seaward (or outer) boundary of each of the coastal states. While its outer limit is the same as the EEZ on NOAA charts, its inner limit is coterminous with the coastal states' boundary at two nautical miles except for Texas, western Florida, and Puerto Rico, which claim a nine nautical mile belt.

- “The number of unique permits does not adequately portray the effort required by survey respondents. An individual permit may require a series of substantive (and sometimes expensive) actions on the part of the farmer that must be filed with the agency as one step in the permit application process. These can include engineering studies, surveys of wetlands, or endangered species impact studies that must be filed sequentially. Respondents reported 1,244 filings of this nature, with a mean of 12/farm (median = 6) that ranged from 1 to 135/farm. Each of these filings required time and personnel in addition to other expenses, with each filing contributing to the total complexity of what individual salmonid farms must comply with.”
- “Study results showed that the regulatory system in the United States increased on-farm costs annually by an average of $150,506, or $2.71/kg, for a national regulatory cost of $16.1 million/year. In addition, regulatory actions on U.S. salmonid farms resulted in lost markets with an annual value of $66,274/farm, lost production of $49,064/farm, and an estimated value of thwarted expansion attempts of $375,459/farm. Nationally, the value of markets lost because of regulatory actions was $7.1 million/year, $5.3 million/year of lost production, and $40.1 million/year in thwarted expansion attempts. Smaller-scale farms were affected to a disproportionately greater negative extent than larger-scale farms.”

Similarly, a recent analysis examined the regulatory costs imposed on Pacific Coast shellfish farmers. van Senten et al. (2020, 14–16) reported (internal citations omitted):

- “The United States was ranked as the 8th largest producer of mollusks in 2016, with an estimated production volume of 173,700 metric tons. While the Pacific coast states of Washington, Oregon, and California represent only 22% of the total number of U.S. farms in the 2012 Census of Aquaculture; these three states accounted for 54% of the value of U.S shellfish. The major production species include a variety of clams, mussels, and oysters; with oysters accounting for the largest production value. Shellfish aquaculture on the Pacific coast of the U.S. includes the production of Pacific oysters (Crassostrea gigas), Kumamoto oysters (Crassostrea sikamea), eastern oysters (Crassostrea virginica), Olympia oysters (Ostrea lurida), Geoduck clams (Panopea generosa), Manila clams (Venerupis philippinarum), Blue mussels (Mytilus edulis), Mediterranean mussels (Mytilus galloprovincialis), abalone (Haliotis spp.), and several other minor species.”
- “The Pacific coast shellfish industry has contended with extensive delays in permitting resulting in high regulatory costs and substantial lost sales and opportunities. Mean annual regulatory costs for Pacific coast shellfish producers were estimated to be $240,621 per farm and $68,936 per hectare. The total annual regulatory burden for the Pacific coast region was estimated at $15.6 million per year, with an additional $110 million in annual lost sales revenue in addition to $169.9 million per year in lost business opportunities. The majority of regulatory costs captured by the study were indirect costs of compliance such as manpower for compliance, legal expenses, and changes in equipment or management for compliance; the total accounting for 85% of regulatory costs on average across the Pacific coast region.”
- “Regulatory costs associated with obtaining licenses and permits across the region were 1.4 times the costs associated with ongoing monitoring, reporting, and compliance. California had the greatest total state regulatory cost ($6,158,446) and the greatest mean per-farm regulatory cost ($473,727 per farm). Study results point to regulatory constraints to growth of the shellfish industry with more than one-third reporting that regulations prevented them from expanding to meet market demand.”
- Smaller-scale producers were affected negatively by regulatory costs to a disproportionately greater degree than were larger farms. Study results suggest that there is a strong need for streamlining the permitting process to achieve substantial reductions in the time required to obtain permits. The results from this study confirm that the Pacific coast shellfish industry, like the salmonid and baitfish/sportfish sectors in the U.S., is constrained by the U.S. regulatory environment; affecting the industry’s ability to meet the growing demand for U.S. shellfish aquaculture products.”

Myth: Marine net pens or sea cages are factory farms that in US waters would contribute marine pollution caused by excess feed, untreated fish waste, antibiotics, and antifoulants.

Feed management and fish growth

Feed is a significant cost to all fish farms and can range from 50% to 60% of variable costs. As a consequence, farmers invest in employee training and infrastructure to store, handle, deliver and monitor feed to fish as efficiently and with as little loss as possible (Belle and Nash 2008). The practical aspects of feed monitoring technology is rarely presented in science literature; although, sophisticated approaches have been adopted to include cameras, Doppler radar, infrared detection, sonar sensors and water quality sensor arrays (Ang and Petrell 1997; Michel et al. 2002; Beveridge 2004; Belle and Nash 2008; Garcia et al. 2010; Zion 2012; Føre et al. 2018). Current feed monitoring in the United States utilizes farm employees observing feed consumption via video for each cage in an array of cages to stop feed delivery when fish near satiation. To further improve feed monitoring, machine learning and artificial intelligence systems are producing quantitative and accurate data to standardize decision making and visual assessment by feed operators to better manage expensive feeds (Sclodnick et al. 2021).

Feed conversion ratio (FCR) (weight of feed offered/weight of fish produced) have trended downward as feed management and feed quality have improved from 3:1 (3 pounds of feed to 1 pound of harvested fish) to around 1:1 (Belle and Nash 2008). Welch et al. (2010, 241) explored every aspect of the complex topic of feeding carnivorous (fish and crustacean) marine species, reporting a FCR for Atlantic salmon of 1.3:1 and FCRs for gilthead sea bream (*Sparus aurata*), yellowtail flounder (*Limanda ferruginea*), cobia (*Rachycentron canadum*) and cod (*Gadus morhua*) of less than 1.5:1. These FCRs are well-below the most efficient feed converting agricultural animal, the chicken at 1.9:1, and the trend in fish meal, fish oil replacement within compounded marine finfish feeds has resulted in a fish-in, fish-out ratio for fed marine finfish is approaching 1:1. They also reported (internal citations removed):

> …alternative feed ingredients and formulations have been investigated for nearly every species of commercially important fish including, for example, Atlantic salmon (*Salmo salar*), red drum (*Sciaenops ocellatus*), cobia (*Rachycentron canadum*), turbot (*Psetta maxima*), European sea bass (*Dicentrarchus labrax*), gilthead sea bream (*Sparus aurata*), Japanese flounder (*Paralichthys olivaceus*), yellowtail (*Seriola quinqueradiata*) and rainbow trout (*Oncorhynchus mykiss*).

Farm productivity

Offshore aquaculture critics do not appreciate the potential for offshore farm productivity and how little of the federally managed waters beyond coastal state boundaries might be utilized to greatly increase farmed seafood. The U.S. has jurisdiction over 11.3 million square kilometers of the ocean which is referred to as the Exclusive Economic Zone (EEZ). Nash (2004) estimated that 500 sq. km of ocean, managed under existing regulations, could produce 600,000 metric tons or more of high-quality seafood. Theoretically, the farming of 2,500 sq. km, an area representing .0002% of the EEZ, or less than half the size of Delaware, would double U.S. edible seafood production. To provide a sense of the magnitude of US EEZ aquaculture potential, Gentry et al. (2017), conservatively estimated the U.S. could grow all the seafood caught and imported for domestic consumption in 0.01% of federally managed marine waters. For their estimate, they used a low density of farms per square kilometer, low fish density within a farm and average growth rates rather than choosing the fastest growing species (Gentry, personal communication). These estimates should not be interpreted to mean farms will be co-located on the same site or all of this ocean capacity can or should be utilized. Current U.S. regulation of ocean use, that includes the opportunity for coastal states to comment on proposed projects, as well as consideration of ocean science and empirical knowledge from farming in nearshore waters, will inform farm siting and operations to protect the environment as this framework has successfully accomplished in state marine waters.

Fish density

The success of every farm growing animals, terrestrial or aquatic, depends upon the health and growth of the livestock. Fish grown at-sea in net pens benefit from standard practice of a low volume, 2% to 3%, of fish ready for harvest relative to the volume of the sea cage or net pen. As a different and complimentary measure, Belle and Nash (2008) presented fish density at harvest (23 kilograms per square meter) as a loading rate of 0.024 kilograms per liter per minute at the average current velocity during a full tidal cycle for Cobscook Bay Maine (2.5×10^6 liters per minute). They compared this loading rate to that typical for trout flow-through raceways (1.5 to 2.0 Kg/L per minute) and noted net pens should be classified as low-intensity production systems.

The fish to cage volumes is extremely low when juvenile fish are introduced to containment. All of the numbers cited in this section are for market-ready fish or the highest volume of fish to volume of water within the enclosure. Turnbull et al. (2005, 124, 131) examined Atlantic salmon at three stocking densities within multiple cages managed under typical commercial production practices to eliminate variation in water quality, current flow and cage deformation that can occur under different sea conditions. Over the study period the authors reported, "The calculated cage density ranged from 9.7 to 34 kilogram per cubic meter, a wider range than was normal within the industry at the time" meaning the fish represented from .97% to 3.4% of the cage volume.[8] To assess fish physical condition, i.e., welfare, they measured growth (length and weight), stress (plasma glucose and cortisol) and damage (12 assessments of fins and body). Their results were mixed as can be expected from a dynamic ocean environment. They concluded:

> The non-linearity of the relationship between welfare and stocking density suggests that, below a critical point around 22 kg m^3 [2.2% of the cage volume] increasing density did not reduce welfare under the conditions studied on a commercial farm…It is clear from this study that good welfare can be maintained at high densities and that conversely low densities are no guarantee of good welfare.

Hernández et al. (2016, 58) evaluated the effect of density at harvest (15, 20 and 22 kg m^3) on the performance (weight gain, three growth rate measures, total biomass, survival, and feed conversion) and profitability (selling price, cost of juveniles and feed costs) of spotted rose snapper cultured in commercially managed floating sea cages off of Mexico. They reported "…spotted rose snapper reared at harvest density of 20 kg/m^3 [2% of cage volume] exhibit improved biological and economical indices under a given set of environmental conditions."

Fish density in a production system is a complex question dependent upon species behavior, physiology, and water quality. To test density effects, Roque d'Orbcastel et al. (2010, 115) created a flow through system for sea bass, *Dicentrarchus labrax*, a fish commonly grown in European net pens. They found:

> "Biological performances (DFI [daily feed intake], SGR [specific growth rate]) were decreased at 100 kg m^{-3}, but no significant differences were noticed on stress response (cortisol) and disease resistance in sea bass reared in a flow through system at densities between 10 – 100 kg m^{-3}. These results confirmed that a high density is not a chronic stress factor for sea bass when feed access is non limiting and water renewal rate per kg of fish biomass enables maintenance of the water quality parameters (mainly O_2, CO_2, TAN) within the range of recommended levels for such species. Decrease in growth performances at 100 kg m^{-3} in both RAS [recirculating aquaculture systems] and FTS [flow through system] suggest that maximal density for sea bass should be comprised between 70 [7%] and 100 kg m^{-3} [10%], whatever the rearing system."

Current at-harvest stocking density for Atlantic salmon in the United States is 25 to 30 kg m^3 or 2.5% to 3% of the enclosure volume (Sebastian Belle, personal communication, Maine Aquaculture Association; Jim Parsons, personal communication, Cooke Aquaculture Pacific).

Farmed fish mortality rates

Lorenzen (1996, 636–637, 639, 640–641) examined the mortality–weight relationships in fish in different natural ecosystems (lakes, rivers and the ocean), and in aquaculture systems (ponds, cages and tanks) to find mortality rates at unit weight in aquaculture were significantly lower than in natural ecosystems. The analysis included broad groups of fish in particular ecosystems, as well as individual populations, species and families. The author reported that the life of a fish under natural conditions is hardly an easy one. "The principal sources of natural mortality in fish populations are predation, parasitism and infectious diseases, noninfectious diseases, starvation, and hostile environmental conditions." He also noted, "In aquaculture, mortality is dominated by non-predation sources such as diseases, water quality problems, or winter starvation" He further commented, "Predation is much reduced in aquaculture as compared to natural ecosystems, but is not entirely absent." In summarizing his analysis, the author reported,

> The greatest differences in survival between unexploited natural ecosystems and pond/cage and tank aquaculture systems occur in small fish. At a body weight of 1 g[ram] for example, the average annual survival is 5% in natural ecosystems, 10% in ponds or cages, and 40% in tanks. At a weight of 1000 g[ram], the average annual survival in unexploited natural ecosystems is 66%, compared to 87% in ponds or cages, and 95% in tanks." He recommended that farms

[8] A cubic meter of water weighs 1,000 kilograms. The calculation is kilograms of fish/1,000 kilograms x 100 = percentage of fish to water volume.

that outplant juveniles to ponds and cages should culture juvenile fish to a larger size before doing and noted "…transfer from tanks into ponds or cages as fish grow is borne out in many established aquaculture systems, and the analysis of mortality–size relationships thus corroborates the conventional wisdom of aquaculturists.

The Norwegian Veterinary Institute reported survival for sea cage farmed salmon during 2015–19 of 83.8% to 85.8% for 966 to 1,015 active farming sites that harvested 1.2 million to 1.4 million tons each year (Sommerset et al. 2020).

Pathogen-environment-fish dynamic

LaPatra and MacMillan (2008, 487, 488) note:

> "The relationship among pathogens, fish, and the environment is complex and the mere presence of a pathogen does not necessarily induce disease, even in a potentially susceptible species. Pathogen and fish may coexist with no economic, physiological, or ecological consequence."

> "The risk of disease transfer between captive and wild stocks depends on a complex set of factors that includes culture system type, degree of hydrological connectivity between the aquaculture facility and the environment, health of the captive stock and wild fish population, environmental quality inside and outside the aquaculture facility, and characteristics of the pathogenic microorganism-such as pathogenicity, ability to multiply and remain viable in the aquatic environment, survival time outside the host, and the number of infection units required to cause infection and pathogenicity."

After reviewing 22 cases of pathogens affecting marine fish in North America, LaPatra and MacMillan (2008, 490) summarized:

> "Pathogen exchange between farmed animals and wild populations was documented for most of the disease organisms studied. However, harmful effects were more commonly documented for pathogen transmission from wild to farmed populations than vice versa. Overall, pathogen transmission from farmed to wild animals was rarely documented and there was even less evidence that transmission resulted in disease."

Excess feed, untreated fish waste and nutrients

Current farm and feed management practices refute the claims that offshore marine aquaculture causes water quality or benthic ecology damage. A recent peer-reviewed paper analyzed nutrient contributions to the ocean by an offshore fish farm composed of 16 to 22 sea cages with a standing crop that ranged from 571,907 kgs to 1,360,000 kg of fish during two, two-year periods (2012–13 and 2017–18). Welch et al. (2019, 12, 15) reported:

> While continued monitoring will be necessary to evaluate the long-term effects on the benthic and water column ecosystems, the data reported here indicate that the net effect of the nutrients emitted by the aquaculture facility in coastal Panama has been minimal over the duration of the time that monitoring has occurred.

Considering offshore marine fish production in the context of oceanic ecology, the authors commented (internal citations omitted):

> …nutrients of the sort discharged by aquaculture facilities are not, ipso facto, pollution. N [nitrogen] and P [phosphorus] lie at the base of the ocean's food web and drive the primary production that, in turn, drives global fisheries production. A growing body of literature supports the notion that large-scale nutrient inputs from aquaculture facilities can have positive effects on fisheries over large (regional) spatial scales. These studies correlate the installation of large-scale aquaculture facilities with increases in fish stock biomass, as well as the mean trophic level and aggregate amount of wild fishery landings in a region. These studies suggest that nutrients flow quickly through phytoplankton at the base of the trophic pyramid and up to higher-order consumers.

A peer-reviewed analysis by Froehlich et al. (2017, 4, 7) reported that a global literature search found "A total of 70 publications, spanning 1999 to 2016 used the term "offshore aquaculture" and were biologically focused." Notably, these studies concerned farms located in the USA, Spain or Germany and for those studies they summarized:

> …studies that focused on potential ecological impacts of offshore farms, although few (n = 17), tended to report no significant effect. Modeling the probability of a measurable impact based on these studies revealed a 'farm ecotone' of ~90 m[eters]; beyond this distance, evidence of an environmental impact being extremely unlikely.

Marine net pen farms attract wild fish in considerable abundance and diversity. Fish are attracted to the pens or cages for the shelter they provide and to consume feed and particulate matter that may escape. Dempster et al. (2002) censused aggregations of wild fish around nine floating sea-cage fish farms along a 300 kilometer stretch of the Spanish coastline in the south-western Mediterranean Sea noting twenty-seven fish species were recorded at the farms, with two families, Sparidae (12 species) and Carangidae (4 species), being particularly abundant.

Dempster et al. (2002) censused wild fish surrounding five Spanish net pen farms noting almost 200,000 wild fish belonging to 53 species representing Sparidae (8 species), Carangidae (6 species), Mugilidae (5 species) and Chondrichthyid rays (7 species) commonly observed. Özgül and Angel (2013) compared the composition and abundances of wild fish populations around two fish farms in the Red Sea and at nearby reference locations. Fish assemblages were evaluated over three months. A total of 87,238 fishes, representing 39 species and 25 families and a number of trophic levels, were observed. Overall, the abundance, biomass, and diversity of wild fish were much greater at the sea cages than at the open-water reference sites, at both fish farms. It was noteworthy that 35 out of the 39 species observed at the farms were juveniles and adults of coral-reef fish species. Dempster et al. (2002) and Özgül and Angel (2013) suggested fishing should be restricted around farms to create small, pelagic marine protected areas and to allow wild fish to serve as sinks to assimilate lost feed and particulate matter.

Consumption of lost feed by wild fish can be significant to the benefit of the waters and benthos and to the fish. Felsing et al. (2005) investigated the potential for wild fish aggregations to assimilate lost feed and particulate matter in Western Australian waters through three treatments arranged in duplicate, cages without exclusion nets (normal situation); cages surrounded by a 35-mm mesh exclusion net (preventing wild fish access to the sea bed and water column near the cage); and empty cages surrounded by exclusion nets (to control for effects from the exclusion net). In addition, four reference sites without cages were sampled. The experiment was terminated after 62 days, at a final stock density of 5.6 kilogram/cubic meter within the sea cages. Sampling found significantly greater accumulation of nutrients and fine sediments under the cages enclosed in the exclusion net than in other treatments and sites. The accumulation of nutrients at these sites was correlated to distinct changes in macrofaunal community composition, with a sharp increase in overall macrofaunal abundance and a growing dominance of capitellid polychaetes. Based on a comparison between sedimentation rates within and outside excluded areas, the proportions of the total sedimenting nutrients consumed by wild fish were calculated to be 40% to 60%. The authors concluded that in the natural coastal system of Western Australia, or comparable environments, wild fish are potential important consumers of cage aquaculture waste materials. The fact that sediment carbon, nitrogen and phosphorus did not increase below cages with fish and no exclusion nets suggests that the benthic fauna, including surface grazing fish, at these sites were able to assimilate much of the remaining total sedimentary nutrients.

Halide et al. (2009) investigated wild fish diversity adjacent to floating fish cages used to culture groupers, *Epinephelus fuscoguttatus* and *Cromileptes altivelis*, and rabbitfish, *Siganus* spp., in South Sulawesi, Indonesia. The authors reported wild fishes were significantly more abundant in near-surface depths around the margins of the cages in the morning than at other times of day, and corresponding to the time when the fish within the cages were fed with formulated diets. There were 29 species of wild fishes, belonging to 25 genera, associated with the cages. Of these, 5 species were observed feeding on pellets passing through the cage: *Abudefduf vaigiensis*, *Pterocaesio tile*, *Monodactylus argenteus*, *Neopomacentrus violascens* and *Sphaeramia orbicularis*. The total biomass of wild fishes outside the cages exceeded the biomass of the fish in the cages. Aggregations of wild fishes outside the cages consumed a total amount of organic material equivalent to that of the uneaten food leaving the cages, and directly consumed 27% of the lost pellets, significantly reducing organic waste from the cages.

Fernandez-Jover et al. (2007) sampled wild Mediterranean horse mackerel (*Trachurus mediterraneus*), from populations aggregated around two Mediterranean fish farms and from two natural control populations and reported differences in body condition, stomach content and fatty acid composition. They concluded the improved physiological condition of wild fish associated with farms could increase the spawning ability of coastal fish populations, if wild fish are protected from fishing while they are present at farms.

These studies may reflect outcomes for farms located in the exclusive economic zone of the United States managed by US farmers. Farms must conform to established production practices and federal regulations that require the efficient feeding of optimal feed formulations, feed management to reduce feed loss, feeding equipment maintenance, employee training in efficient feeding practices, and recordkeeping and reporting of feed efficiency (conversion of feed to the amount of fish produced) (Belle and Nash 2008). In the United States farms must comply with strict discharge standards and are closely monitored against a set of environmental impact metrics. If they exceed those discharge standards or impact metrics their National Pollution Discharge Elimination System (NPDES) permits granted by the U.S. Environmental Protection Agency can be rescinded. Without a valid NPDES permit they must cease operations.

Antibiotics

The United States severely restricts the availability and use of aquatic animal medicines via the Food, Drug and Cosmetic Act. Other chemicals (e.g., disinfectants, detergents or other cleaning agents) that may be used by aquaculture facilities are regulated by the U.S. Environmental Protection Agency (EPA 2006) and must be declared on a facility discharge permit. In most cases those permits require monitoring of effluents to ensure discharges of any of those chemicals do not exceed strict thresholds established in the permits. The U.S. Food and Drug Administration reviews and approves aquatic animal medicines utilizing the same regulatory paradigm as that for human medicine (e.g., effectiveness to mitigate disease, effects to the animal, effects to the environment directly or indirectly, risk to human health). It is illegal to use antibiotics as a growth promoter or prophylactically to prevent the outbreak of clinical disease. There are no antibiotics approved for use on marine fish such as cobia, snapper, flounder, halibut, cod or any of the other candidate fish for offshore marine aquaculture (FWS 2020). Antibiotics must be used in conformance to label instructions or as prescribed by a veterinarian (NOAA n.d.-a). Federal regulations require that farms report medication use prior to administering a medication and following treatment. A farm must describe potential chemical use in their EPA permit application and conform to permit conditions if use is allowed. In most cases those permit conditions require environmental monitoring to detect any possible antibiotic residues. If residues are detected farms are required to change their operations to reduce any risk of environmental impacts (EPA 2006).

Reverter et al. (2020, 3) conducted a double meta-analysis (460 articles) to explore antimicrobial resistance and global aquaculture. They calculated a Multi-Antibiotic Resistance Index (MAR) of aquaculture-related bacteria (11,273 isolates) for 40 countries. These countries account for 93% of global aquaculture production. They found:

> Twenty-eight countries out of the 40 studied displayed MAR indices higher than 0.2, a threshold considered to be an indication of high-risk antibiotic contamination. The mean global MAR index of aquaculture-related bacteria was 0.25 (SE = 0.01). Zambia (0.56) followed by Mexico (0.55) and Tunisia (0.53) were the countries with the highest MAR indices, whilst Canada (0.02), France (0.03) and USA (0.08) displayed the lowest.

Antifoulants

Biofouling in marine environments occurs when animals and plants attach to the hard and soft surfaces associated with fish, shellfish and seaweed production gear (e.g., cages, nets, baskets, floats, ropes and anchors). The growing animals and plants will add weight and drag, restrict water flow impacting filter feeding or oxygenation, reduce marketable value or shelter pathogens and parasites. Direct economic costs to the farm have been conservatively estimated at 5 to 15% of production costs (Adams et al. 2011; Bannister et al. 2019; Fitridge et al. 2012).

Offshore marine fish farms must comply with federal regulations applicable for all marine use of antifoulants as does every commercial or recreational watercraft owner, navigation buoy manufacturer or public or private entities that maintain buoys and markers, and similarly for antifoulants applied to marine structures. In the case of commercial net pen farms most farms have eliminated net exchange and the use of antifoulants on nets and are using mechanical robotic net cleaners or copper-alloy metal mesh.

The use and application of antifoulants in the marine environment is regulated by EPA under authority granted the Clean Water Act and Federal Insecticide, Fungicide, and Rodenticide Act. Antifouling coatings registrants must obtain approval from the U.S. EPA's Office of Pesticide Programs, which oversees periodic pesticide registrations and reviews, and regulates pesticide use to prevent significant adverse effects on non-target organisms. Containers of antifoulants include EPA approved label instructions regulating storage, handling, application, and disposal. The EPA's Office of Water is responsible for implementing the Clean Water Act, and similar statutes designed to maintain aquatic ecosystems to protect human health; support economic and recreational activities; and provide healthy habitat for fish, plants, and wildlife.

Sclodnick et al. (2020) summarized production benefits associated with copper-alloy metal mesh netting associated with sea cages noting improved fish growth rates, feed conversion ratios and lower mortality rates created by improved water exchange and reduced parasitism. A recent study conducted by the Naval Information Warfare Center Pacific by Earley et al. (2020, 289) examined metal leaching rates for four copper alloy materials and one traditional coated-nylon net material during a 365 day field test in San Diego Bay, California and modeled the theoretical deployments of 50 copper-alloy mesh aquaculture pens in San Diego Bay CA (an arid, Mediterranean bay with a low flushing regime) and Sinclair Inlet, WA (a cold water, high flushing regime environment) to assess overall environmental loading in these representative scenarios. The authors concluded (internal citation omitted):

> The results from the current study indicate that environmental loading of metals from copper alloy materials is higher than from antifoulant-treated nets. However, using the weight of evidence approach presented here, the overall effect of this metal input is not interpreted to be environmentally detrimental. This difference (in metal release rates) is important for farming pen maintenance purposes, including factors such as control of water flow obstruction, steady oxygen availability, decrease in the probability for establishment of pathogen vectors and control on the total weight of the pen structure.

Sclodnick et al. (2020) reported copper and zinc concentrations for two farms located in Panama and Mexico using copper alloy mesh net pens for 468- and 435-days water and sediment monitoring, respectively. Measurements were taken at a reference site 1000 m away from the pens perpendicular to the dominant current direction, as well as 50 m upstream, 50 m downstream and adjacent to the pens. Muscle, skin and liver samples were taken from cobia (*Rachycentron canadum*) produced at the Panama site and analyzed for copper content. The authors reported dissolved copper levels at both farms stayed below 1 µg/L at all times.[9] There was no significant difference in the dissolved copper levels between the reference site and other measurement sites at either location. There was also no observable increase in dissolved copper levels over time at the Mexico location although there was a significant difference in dissolved copper levels between the sampling days at the Panama location. Zinc concentrations also remained within safe levels, never exceeding 0.82 µg/L at any point.[10] Copper and zinc levels in the sediments did not show a significant increase over time and were biologically unavailable through binding with acid volatile sulfides to form insoluble sulfide complexes. The average copper concentration in the muscle tissue, an 8 oz. portion of cobia, was 0.046 mg of copper or 5.1% of the Institute of Medicine's recommended daily allowance. There was no significant difference in copper levels of the skin or liver tissue samples. The absence of any increase in liver copper levels suggests that the fish's physiology and welfare are not impacted by brass mesh. The authors concluded, "…brass mesh is environmentally compatible with high energy marine environments and a commercially viable product for open ocean aquaculture farms."

Myth: Offshore farms entangle marine animals

The federal permitting process for offshore farms requires interagency consultations, required by the National Environmental Policy Act, to enforce the provisions of the Endangered Species Act, Marine Mammal Protection Act, Migratory Bird Treaty Act and Magnuson-Stevens Fishery Conservation and Management Act to prevent injury or death to listed species, marine mammals and birds and to prohibit unpermitted fishery harvest, possession or sale. Price and Morris (2013, iv) evaluated entanglements across the globe and summarized:

> At modern fish farms, impacts to predatory sharks and marine mammals are being minimized with improved net technologies and removal of dead fish from cages to prevent predation on cultured fish. Siting away from known aggregation sites and installing rigid predator exclusion nets are effective at preventing negative impacts to cultured fish, farm structures and marine predators. Acoustic deterrent devices are not consistently useful against sea lions and seals and may have deleterious impacts to non-target marine mammals. In the U.S., nonlethal interventions to prevent marine mammal predation are preferred.[11] At marine fish farms, entanglement in the farm structures may pose a slight threat to sea turtles, dolphins, whales and seabirds. Keeping lines taut and the water free of debris are effective at minimizing or eliminating conflict with marine mammals and turtles.

Unlike fishing gear that is designed to intentionally "catch" animals, aquaculture gear is designed to contain animals being cultured without hurting them or any wild animals that may occur around farms. A second in-depth analysis summarized interactions by at-risk sea turtles, sea birds, sharks and marine mammals with aquaculture production gear to inform the federal permitting process. The goal of the assessment was to strengthen the ability of the National Oceanic and Atmospheric Administration and other regulatory agencies to make science-based decisions and recommendations as part of the review and consultation

[9]The Environmental Protection Agency chronic water quality criteria for dissolved copper is 3.1 µg/L.

[10]The Environmental Protection Agency chronic water quality criteria for dissolved zinc is 81 µg/L.

[11]The authors should have clarified non-lethal methods are required in the United States as authorized for all marine mammals and birds by the Marine Mammal Protection Act and the Migratory Bird Protection Act, respectively, and specific marine mammals and birds when listed under the authority of the Endangered Species Act.

process required by the National Environmental Policy Act to permit nearshore and offshore aquaculture operations (Price et al. 2017).

Myth: Farms displace wild animals from important habitats and farmers harm marine mammals

US farms do not displace wild animals or submerged aquatic vegetation. The site where a farmer proposes to locate a farm is regulated by the Endangered Species Act, Marine Mammal Protection Act, Migratory Bird Protection Act, Magnuson-Stevens Fishery Conservation and Management Act, Section 404 of the Clean Water Act, Coastal Zone Management Act and state laws that mirror federal law or be more restrictive. In addition, the National Environmental Policy Act requires a lead federal agency to coordinate a review and comment by the other federal agencies charged with responsibilities under the named Acts to ensure their authorities and regulatory reach are reflected in an operational permit.

Price et al. (2017) published a technical memorandum for the National Oceanic and Atmospheric Administration to inform the agency and the public in carrying out their authorities under the Endangered Species Act, Marine Mammal Protection Act, Magnuson-Stevens Fishery Conservation and Management Act and Coastal Zone Management Act. The author found few at-risk species and aquaculture production gear interactions. As a surrogate they examined analogous fishery gear and then suggested preventative measures to include when siting a farm to avoid migration routes and resting, feeding and breeding habitats; farm worker training to avoid feeding or harassing visiting animals; properly tensioned lines; installation and maintenance of predation prevention nets; and similar commonsense practices.

All marine mammals (whales, dolphins, porpoises, seals, sea lions, walruses, polar bears, sea otters, manatees, and dugongs) are protected under the Marine Mammal Protection Act (MMPA). Some are also protected under the Endangered Species Act and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).[12]

[12]The Endangered Species Act authorizes the US Fish and Wildlife Service to implement Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) provisions and represent the US during meetings of the 183 signatories. CITES members focus on ensuring international trade in specimens of wild animals and plants does not threaten the survival of the species. Over 38,700 species – including roughly 5,950 species of animals and 32,800 species of plants – are protected by CITES against over-exploitation through international trade.

With some exceptions, the MMPA prohibits the harassment, hunting, capturing, collecting, or killing of marine mammals in U.S. waters and by U.S. citizens on the high seas. The Act also makes it illegal to import marine mammals and marine mammal products into the United States without a permit.

The National Oceanic and Atmospheric Administration is revising *Guidelines for Safely Deterring Marine Mammals*. The Marine Mammal Protection Act (MMPA) allows for specified persons to employ measures to deter marine mammals from damaging fishing gear and catch, damaging personal or public property, or endangering personal safety, as long as these measures do not result in death or serious injury of marine mammals. While the guidelines and specific measures are not mandatory, the MMPA provides protection from liability under the MMPA for marine mammal injury of death resulting from such deterrence measures by specifying that any actions taken to deter marine mammals that are consistent with the guidelines or specific measures are not a violation of the Act.

Myth: Escaped farm-raised fish adversely impact wild fish stocks

Belle and Nash (2008, 297–298) noted that escaping fish may pose a variety of environmental risks including pathogen transmission, interbreeding with wild conspecific to introduce new genetics, competition for resources, predation, colonization or disruption or damage to existing commercial or recreational fishing. The authors concluded:

> For most of the aquatic species commercially cultured in the United States, these outcomes have neither occurred nor are anticipated to occur because:

- Producers have a strong economic incentive to prevent escape of cultured animals and to recover animals that do escape;
- Most pathogens are naturally occurring and ubiquitous;
- Most species are cultured in their native range;
- Successful introduction and spread of a nonnative species often meet strong biological resistance; and
- Federal and state agencies have implemented a variety of invasive-species regulations to prevent, control, manage, or mitigate potential impacts.

This non-regulatory and regulatory framework has been effective for the United States. Farming fish in state waters, less than three miles from the coast and within coastal inlets and bays, is practiced to a limited extent in Hawaii, Maine and Washington. An analysis led by National Oceanic and Atmospheric Administration scientists, Rust et al. (2014, 520), reported for farms growing Atlantic salmon in nearshore waters:

> [U.S.] Marine fish farms are required to comply with regulations similar to those of other food-producing and marine industries. Existing U.S. regulations address the environmental effects of net-pen aquaculture effectively. Technological progress, better monitoring, and adaptive oversight of the U.S. net-pen aquaculture industry have resulted in sustainable, affordable, and domestically produced seafood.

Two studies examined whether farm escapes had any measurable genetic impacts on wild Atlantic Salmon populations in Maine. Both studies concluded that although there had been escapes from Maine salmon farms in the early days of their operation, no evidence of any genetic impacts could be detected in local wild Atlantic Salmon populations (King 1999; NRC 2003). An in-depth analysis concerning the risk of farming Atlantic salmon in Puget Sound, far from their natural range and in proximity to several Pacific salmon species, was completed by NOAA in 2002.

Waknitz et al. (2002, *x*) reported:

> …the risks associated with escaped Atlantic salmon are low, in particular:

- The expectation that Atlantic salmon will increase current disease incidence in wild and hatchery salmon is low.
- The risk that escaped Atlantic salmon will compete with wild salmon for food or habitat is low, considering their well-known inability to succeed away from their historic range.
- The risk that salmon farms will adversely impact Essential Fish Habitat is low, especially when compared to other commonly accepted activities that also occur in nearshore marine environments.

> …there appears to be little risk associated with escaped Atlantic salmon, in particular:

- There is little risk that escaped Atlantic salmon will hybridize with Pacific salmon.
- There is little risk that Atlantic salmon will colonize habitats in the Puget Sound chinook salmon and Hood Canal summer-run chum salmon ESUs [evolutionary significant unit].
- There is little risk that escaped Atlantic salmon will prey on Pacific salmon.
- There is little risk that existing stocks of Atlantic salmon will be a vector for the introduction of an exotic pathogen into Washington State.
- There is little risk that the development of antibiotic-resistant bacteria in net-pen salmon farms or Atlantic salmon freshwater hatcheries will impact native salmonids, as similar antibiotic resistance often observed in Pacific salmon hatcheries has not been shown to have a negative impact on wild salmon.

A highly publicized net pen collapse and escape of farm-raised Atlantic salmon in Puget Sound during 2017 resulted in state legislation phasing out nonnative fish culture when existing permits expire; however, "The new law, with bipartisan support, and the clear and explicit backing from many tribes and environmental NGOs, *unambiguously allows for the continued operation of commercial net-pen aquaculture in Puget Sound, including in areas where current operations currently exist* (WDFW 2020a, 2)."

An initial analysis of the collapse by the Washington Department of Natural Resources concluded (Clark et al. 2018, 113):

> What were the implications for the Puget Sound ecosystem from the Cypress Island Atlantic salmon net pen failure?

1. To date, there is no evidence that the escaped Atlantic salmon were eating native fauna nor is there evidence that they were sexually mature.
2. Over time, the [escaped] fish in the marine system contracted native pathogens and have shown decreasing health status.
3. Atlantic salmon have been found in a limited number of rivers in Puget Sound (Skykomish and Skagit rivers). Atlantic salmon have not been seen at any DFW [Department of Fish and Wildlife] hatchery despite monitoring. There is no indication that Atlantic salmon have been caught in Nooksack drainage or at Whatcom Creek Hatchery drainage. DFW was present at the chum spawns in late fall at Bellingham Technical College and did not see any Atlantic salmon in Whatcom Creek.
4. The limited numbers of Atlantic salmon found in the freshwater system appear healthy. There is no evidence that they were feeding in the freshwater system nor were they sexually

mature. The Atlantic salmon in freshwater may survive for some time.

> Monitoring through the winter and the subsequent fall will be critical to know if the Atlantics remain in the freshwater systems and if they are reproducing.

In the Washington case, public concern following the escape focused on the presence of piscine orthoreovirus in escaped Atlantic salmon that were tested for pathogens. Subsequent analysis revealed (PNFHPC 2017, 2):

> The ubiquitous nature of piscine orthoreovirus (PRV), its apparent historic presence in wild Pacific salmonid stocks in the Pacific Northwest and the lack of clear association with disease in Pacific salmonids suggest the virus poses a low risk to wild species of Pacific salmonids.

And state agency analysis of public comments further rebutted concerns that a unique pathogen or disease had been introduced (WDFW 2018).

A recent invited review of piscine orthoreovirus (PRV) summarized 10 years of study of this common and widely distributed salmonid virus (Polinski et al. 2020). The authors reported PRV may trigger heart and muscular muscle inflammation (HSMI); although, controlled experimental trials have failed to cause clinical mortality or morbidity. And, (Polinski et al. 2020, 1340) summarized (internal citations omitted):

> …neither the directionality nor the mechanism(s) responsible for exchanging PRV between farmed and wild populations are currently known. It has been postulated that interactions between wild and escaped farmed salmon, specifically when wild salmon migrate through aquaculture areas, may serve as potential mechanisms of virus perpetuation. Nevertheless, comparisons of PRV prevalence in wild adult salmon from regions of northern Norway with differing farming intensity and disease frequency showed no association between salmon farming and the prevalence of PRV infection in wild salmon. Similarly, in eastern Canada, no effect of aquaculture proximity on PRV infection was observed in returning wild Atlantic Salmon from two river systems. To date, HSMI has not been documented in any wild or escaped salmon in Europe or North America.

Relative to the Puget Sound fish farm that experienced a 2017 net pen system collapse. After a several year process that included public comment and litigation, the Washington Department of Fish and Wildlife analyzed more than 150 studies on marine aquaculture to conclude that farming of sterile, all-female steelhead posed no significant risk to the marine environment (WDFW 2020b) and the State of Washington Department of Ecology approved Clean Water Act authorized National Pollution Discharge Elimination System permit modifications to allow the farming of the steelheads at four sites previously used to raise Atlantic salmon (WDE 2020).

Maine net pen farms culture Atlantic salmon in proximity to Gulf of Maine Atlantic salmon population that is listed as endangered under the authority granted by the Endangered Species Act. Through a collaborative effort by the farming and environmental community a salmon containment policy was created in 2002 (Goode and Whoriskey 2003). Containment management is based upon a hazard analysis critical control point program and has resulted in no escapes since 2003.

The National Oceanic and Atmospheric Administration has developed a scientific decision-support tool entitled the Offshore Mariculture Escapes Genetics Assessment (OMEGA) model to better understand genetic effects should farmed fish escape and encounter wild stocks and aid in the design of management strategies to address the potential risks to marine resources (NOAA 2020b).

OMEGA is a mathematical model with inputs that include the size and growth characteristics of the cultured fish, the frequency and magnitude of escape events, survival rates of escapees in the wild, probability of escaped fish encountering wild counterparts and interbreeding, and the dynamics of the wild population. Outputs from OMEGA describe the influence these aquaculture escapees may have on the survival and fitness of the mixed population over time. NOAA Fisheries is using the OMEGA model to identify and evaluate the genetic risks associated with marine aquaculture operations, recommend management practices for responsible and sustainable aquaculture programs, explore the effects of regulatory and technical advances, and identify research priorities.

Aquaculture critics focus upon perceived escape risks while rarely acknowledging national efforts to maintain recreational fishing opportunities or rebuilding federal or state listed aquatic species through purposeful release of cultured animals to enhance. Nationally, 809 hatcheries (85 federal, 435 state, 29 nongovernmental organization, 96 tribal/First Nation, and 164 other facilities) stock approximately 2.6 billion fish annually to enhance recreational fishing or recover at-risk species. Trushenski et al. (2018, 291) concluded that hatchery efforts:

- Strengthen food security and directly or indirectly employ hundreds of thousands of Americans, helping to drive the U.S. economy.

- Provide fishing opportunities and help to bring imperiled species back from the brink of extinction, protecting the cultural and ecological legacies that will be passed on to future generations.
- Are the “storefronts” of aquatic resource management and conservation, helping the public to learn about and appreciate fish, whether for their instrumental or intrinsic value.

Marine aquaculture can and has contributed to improving climate change resilience in stocks, ecosystems, and communities by using different marine aquaculture tools and techniques. Corbin et al. (2016) reported aquaculture provides an alternative and augmentation to traditional wild-capture fishing, which can enhance the recovery of stocks under stress as well as provide economic benefit to fishing communities. Communities under stress can implement aquaculture as an adjunct, or even a replacement, for participation in wild-capture fisheries. In addition, aquaculture can propagate specific species under stress to augment the natural ecosystem. Aquaculture also has the potential to reduce the impacts of ocean acidification by culturing and augmentation of natural aquatic plants that reduce the levels of acidic components of seawater. Finally, culturing and propagation of specific species that are resistant to more acidic seawater can improve the ecological resilience of the ecosystems in which they are used as an augmentation.

Myth: Fish feed includes colorants

For certain wild fish, examples being Atlantic salmon and steelhead, the consumption of crustaceans, e.g., krill or forage fish that consumed crustaceans, influences the color of the fillet which can range from a light pink (low consumption) to the familiar reddish-orange (high consumption). The color is derived from carotenoids in the crustaceans metabolized by fish and stored in muscle to inadvertently influence flesh color. Not all crustacean eating fish metabolize carotenoids to influence flesh color, examples being cod, cobia, and red drum. The value of carotenoids in fish feeds was first discussed in 1981 when a fish nutritionist speculated including carotenoids in the diet could protect delicate tissues and reactive compounds within fish from oxidative damage (Tacon 1981). Later research confirmed the value and necessity of including carotenoids, astaxanthin and canthaxanthin, in compounded feeds to benefit overall animal health, fish-to-fish communication through skin color change, survival, growth, and reproduction (egg quality and larval survival) (Torrissen and Christiansen 1995). Today carotenoids are included in formulated diets for their farmed fish and crustacean health benefits, human health benefits and as a “quality criterion used by consumers to assess the nutritive value, health, freshness and taste of salmonids, crustaceans and other farmed fish” (De Carvalho and Caramujo 2017, 8).

Myth: Fish meal and fish oil in fish feeds is unsustainable

In 2018, about 88% (or over 172 million tons) of the 197 million tons of total global fish production was utilized for direct human consumption, while the remaining 12% (or about 24 million tons) was used for non-food purposes. Of the latter, 80% (about 20 million tons) was reduced to fishmeal and fish oil, while the rest (4 million tons) was largely utilized as ornamental fish, for culture (e.g., fry, fingerlings or small adults for on growing), as bait, in pharmaceutical uses, for pet food, or as raw material for direct feeding in aquaculture and for the raising of livestock and fur animals. Fish meal, fish oil and fishery by-products (skin, bone, and offal) are used in the production of terrestrial and aquatic animal feeds, biofuel and biogas, dietetic products (chitosan), pharmaceuticals (omega-3 oils), natural pigments, cosmetics, alternatives to plastic, and constituents in other industrial processes. A significant but declining proportion of world fisheries production is processed into fishmeal and fish oil because of increasing use of fishery by-products and the use of substitutes such as plant, insect, algae and microbial produced proteins and oils (FAO 2020).

Fishmeal and fish oil are still considered the most nutritious and most digestible ingredients for farmed fish, as well as the major source of omega-3 fatty acids (eicosapentaenoic acid [EPA] and docosahexaenoic acid [DHA]). However, their inclusion rates in compounded feeds for aquaculture have shown a clear downward trend, largely as a result of supply and price variation coupled with continuously increasing demand from the aquafeed industry. They are increasingly used selectively at specific stages of production, such as for hatchery, broodstock and finishing diets. The incorporation of fishmeal and fish oil in grower diets is decreasing. For example, their share in grower diets for farmed Atlantic salmon is now often less than 10% (FAO 2020).

Within the United States considerable public and private research investment has been made with the goal of reducing the amounts of fish meal or fish oil in diets that will yield excellent animal health, growth and final products with desirable human nutritional benefits (NOAA 2020d). The National Oceanic and Atmospheric Administration and U.S. Department of Agriculture (Rust et al. 2011, 1) support a research initiative to:

> …identify and prioritize research to develop feeds that will allow the aquaculture industry to increase production in a sustainable way that does not put additional pressure on limited wild fisheries, that maintains the human health benefits of seafood, and that minimizes negative environmental effects of the use of alternatives.

Cottrell et al. (2021, 3) tackled the complex topic of feeding carnivorous or herbivorous fish compounded diets incorporating soybean, canola, maize, wheat and nut-derived proteins, oils and carbohydrates. They report a shift, through time, of the dietary profile of each fed aquatic species, increased overall species composition of farmed fish production, and the actual trophic position of wild forage fish used in feeds to yield "…a substantial reduction in the effective trophic level of aggregate production of fed aquaculture: from 2.63 in 1995 to 2.23 in 2015." In response to recommendations that fed aquaculture should focus on low tropic level species (e.g., carp and tilapia), they concluded, "…it is the reduced dependence on fishmeal and oil in feeds across farmed taxa that has overwhelmingly influenced the [lowering of] effective trophic level of fed aquaculture."

An example of the progress made in fish feed, through private investment, is an announcement by the Illinois Soybean Association describing the successful incorporation of a plant-based ingredients in a tuna feed. Please see https://www.ilsoy.org/article/pioneering-soy-based-tuna-feed. An important aspect of fish feeds produced in the United States, and fed by U.S. farmers, is that the corn and soybean in those feeds are U.S. grown and not imported from other nations.

Turchini et al. (2019, 13, 33) authored an in-depth review paper examining the progress to replace fish meal and fish oil in compounded feeds, aquatic animal nutrition, feed manufacture, nutrient complementarity and functionality, and related advances in research and application. The authors report (emphasis added):

> …fish nutritionists have endeavored to develop aquaculture feed (aquafeed) formulations that support or enhance growth of cultured fish while controlling costs. Much of this effort has been focused on reducing reliance on limited marine resources. Whereas cultivation of herbivorous and omnivorous species has readily transitioned to feeds containing little to no fish meal (FM) or fish oil (FO), such formulations have been more difficult to implement in the feeding of carnivorous fish and crustaceans. Despite the various challenges, these efforts have been successful in a broad sense. *Fish meal and FO inclusion rates have dropped steadily over the past 20 years, and feed prices—while increasing—are not as volatile or as high as they would be if the old formulations were sold today.*

The goal of their paper is to convincingly argue that a change in direction is needed. Feed research should refocus for a "…greater emphasis on nutrients, including those not considered strictly nutritionally essential … to encourage further evolution of the industry and to efficiently move aquaculture nutrition beyond the incremental advances achieved in recent years."

A paper by Kok et al. (2020, 8) reexamined fish meal and fish efficiency assessments in light of progress to incorporate plant derived protein and lipids into fish feeds, insect meals, algae oils and fish processing by-products. The authors focused on a commonly used metric, Fish In:Fish Out ratio, meaning the amount of fish required in compounded fish feeds to produce an amount of farm-raised fish, and concluded (emphasis added):

> Efforts to reduce the dependency of aquaculture on marine resources by alternate feed ingredients have significantly reduced the amount of fishmeal and fish oil in aquafeed formulations for most farmed fish species. Results show that most aquaculture species groups assessed in this study are net producers of fish, while farm raised salmon and trout are net neutral, producing as much fish biomass as is consumed. Of the species groups analysed in this research, only the production of eel is a net consumer of fish. However, it is important to note that FIFO could vary within species and between production systems. *Overall, global fed-aquaculture as a whole, currently produces three to four times as much fish as it consumes.*

The U.S. aquaculture community utilizes feed formulations that strive to achieve appropriate nutrition rather than focusing on fish meal or fish oil as an indicator for sustainability. Farmers take their animal stewardship responsibilities very seriously and good nutrition is key to animal health and care. Farms should be recognized for utilizing compounded feeds appropriate for their aquatic animal and production system and advances in the formulation of compounded feeds is improving at a rapid rate. The feed used today will not be the feed of tomorrow.

Myth: Farm-raised fish will displace U.S. fisheries and are cheap and of low-quality

Fundamentally for U.S. farmers it is very difficult to produce "cheap" fish in the United States because of the plethora of federal and state natural resource and environmental regulations focused on aquatic animal culture, possession, sale and health, water use and quality, land use and access to markets and local, state and national labor, safety, business regulations and permits and mandated minimum wage.

As examples of U.S. prices for farm-raised catfish and tilapia versus imported products. The 2018 average pond bank price for U.S. grown live catfish was \$0.949 per pound, the average price for fresh fillet was \$4.54, the average price for frozen fillet was \$4.04 per pound. In contrast, the average 2018 price for imported catfish frozen fillet from China was \$2.54 per pound and frozen fillet from Vietnam was \$1.64 per pound.

Most U.S. tilapia producers sell whole, live fish to regional markets where price can be quite variable. During 2018, the national farm gate price ranged from \$1.50 to \$3.50 per pound depending upon region. Using a 33% yield to fillet, the meat value (not including transportation and processing) would have been \$4.50 to \$10.50 per pound. In contrast, the average 2018 price for imported fresh fillet tilapia was \$3.05 per pound and frozen fillet tilapia \$1.68 per pound.[13]

Competition with US wild-caught fisheries

The National Oceanic and Atmospheric Administration (NOAA) produced a thoughtful and constructive economic analysis (Rubino 2008, 8). The editor wrote a summary within Chapter One commenting upon potential competition between farmed and wild-caught seafood (internal citations omitted):

> The effect of increased U.S. aquaculture on U.S. wild caught fisheries will depend in part on whether new markets are created for increased U.S. aquaculture production, how fast and at what volumes new production comes to the market, whether new U.S. aquaculture production is a substitute for existing wild catch or imports, and whether U.S. fishermen participate in aquaculture production.
>
> At the NOAA National Marine Aquaculture Summit in June 2007, and in other venues from the Gulf of Mexico to the Pacific Northwest, some commercial fishermen and others have expressed concern that aquaculture will hurt wild harvest in the United States. It is clear that aquaculture products, whether imported or domestic, may compete with wild caught fisheries in some markets. They also compete with chicken, beef, and pork. Studies have also shown that global aquaculture production, notably of salmon and shrimp, contributed to temporarily reduced market prices for U.S. wild caught and farmed U.S. shrimp and for U.S. salmon caught from both wild and hatchery raised and released stocks. The net effect of temporarily reduced prices and year-round product availability due to aquaculture production is that the total market for and consumption of shrimp and salmon, wild and farmed, has increased significantly. Ultimately, wild products have been able to position themselves as the premium, higher priced product in the marketplace (Knapp 2008).
>
> What is also clear – and often missing from the discussion of competition – is that competition will exist with or without domestic aquaculture. The marketplace is global and demand for seafood products is growing. The United States cannot meet consumer seafood demand through wild caught fishing activities alone. Seafood imports and other forms of protein, such as beef and chicken, already provide significant competition. Seafood business executives speaking at the National Marine Aquaculture Summit said that if seafood is not available from U.S. sources, their customers are demanding that they get it somewhere else. The challenge therefore is to integrate aquaculture into domestic seafood production so that U.S. boat owners, fishermen, processors, and marketing companies can benefit directly.

Competition with global farmed production

Knapp (2008, 182) utilized the history of Alaskan salmon to support a step-wise progression of events when farm-raised seafood enters a market. He hypothesized:

> In the short run, aquaculture tends to lower fish prices by increasing the supply of fish, harming fishermen but benefiting consumers." However, "over the longer run, aquaculture tends to increase the demand for fish as consumers become more familiar with fish; as fish become available in more locations, at more times, and in more product forms; and as fish farmers engage in systematic marketing to expand demand. Increasing demand tends to offset the effects of higher supply, resulting in less of a decline in fish prices.

Knapp then reported these "short run" events: a decline in wild-caught Alaskan salmon prices during the late 1980s followed farm-raised Atlantic salmon entry to the global market and other factors (i.e., large wild salmon harvests, a recession in Japan, and declining consumer demand for canned salmon). The dramatic growth in salmon supply during the 1990s corresponded with growth in U.S. salmon consumption by an enthusiastic public that found high-quality, fresh salmon everywhere in the marketplace (retail and

[13]U.S. producers provided the farm-gate values for US raised catfish and tilapia. Imported seafood prices are available from the Foreign Fishery Trade Data website provided by NOAA Fisheries: https://www.fisheries.noaa.gov/national/sustainable-fisheries/foreign-fishery-trade-data.

foodservice) at attractive prices. However, the "longer run" outcomes beginning in the early 2000s were: prices increased for wild-caught and farm-raised salmon as farm-raised production increased. And, under the pressure of this competition, certain wild-caught salmon captured prices typical of the 1980s through aggressive marketing and improved product handling.

These outcomes are counterintuitive given the backdrop of unrelenting innovation by the Atlantic salmon farming community and rapid expansion wherever sea conditions could support fish production. Kumar and Engle (2016, 145) reported (internal citations removed):

> The Atlantic salmon industry overcame several biological, ecological, and disease constraints throughout its history. Advanced automated feed monitoring systems provided greater resource and environmental management efficiency. Commercialization of genetic and vaccination programs improved growth and survival while nutritional developments reduced the use of fishmeal and oil while improving performance. Such continued technological advances resulted in continuous growth in Atlantic salmon production with significant reductions in cost of production. The Atlantic salmon industry is one of the leaders in terms of biological knowledge and production technology, raising a very resource-efficient species that is often termed "the super-chicken of the sea."

Cost competitiveness

Within the NOAA analysis, specific attention was focused on the basic economics of offshore aquaculture and a discussion of the major factors which might affect the costs, prices, profitability, and competitiveness (Knapp 2008, 47–48). In summarizing an in-depth analysis, the author noted:

> In competing with wild fisheries, in general, it will be difficult for U.S. offshore aquaculture to compete with those for which supply is year-round, reliable, and abundant. However, where wild fisheries are unable to meet market demand for a species at particular times, in particular locations, or for particular product characteristics, competitive opportunities will be created for aquaculture, including offshore aquaculture.
>
> At its current scale and given current technology, offshore aquaculture is a relatively high-cost way of growing fish. Currently, in the United States and elsewhere, offshore aquaculture is probably able to compete with inshore aquaculture only under limited circumstances, such as:

- When offshore farms are able to supply market niches which cannot be supplied by inshore farms, for reasons such as a lack of suitable sites, regulatory constraints, and transportation costs.
- When offshore weather and wave conditions are relatively mild, reducing the costs of building and operating offshore facilities relative to inshore aquaculture.
- When offshore farms enjoy significantly better water conditions than inshore farms, enabling faster growth or better survival.
- When offshore farms are able to take advantage of cost-lowering synergies with other facilities or activities, such as existing inshore farm facilities or offshore oil rigs.
- When offshore farms allow the installation and operation of farms larger than inshore farms and to take advantage of economies of scale.

Predicting the future is anything but an exact science and the author succinctly writes as much by noting:

> The true test of the economic potential of any industry is the market. No offshore aquaculture industry can develop in the United States without an enabling regulatory structure. Only by letting offshore aquaculture be tried can we learn what its economic potential might be.

Product quality

The U.S. domestic aquaculture industry is committed to supplying consumers with consistent, high quality, safe products that are produced in an environmentally sound manner. The marketplace success of U.S. farmed fish is consumer confirmation that we are meeting that commitment. Numerous federal and state agencies are involved with maintaining the wholesome attributes of farm-raised seafood.

The U.S. Food and Drug Administration works with state departments of agriculture, the Association of Food and Drug Officials, and the American Association of Feed Control Officials to regulate aquaculture food handling and processing and the manufacture of feeds to ensure that they are safe and do not contain contaminants or illegal substances as authorized by the Federal Food, Drug and Cosmetic Act and Public Health Service Act.

Furthermore, the Interstate Shellfish Sanitation Conference, in cooperation with the U.S. Food and Drug Administration and state agencies, administers a certification program requiring all shellfish dealers to handle, process, and ship shellfish (clams, oysters, mussels) under sanitary conditions and maintain records that the shellfish were harvested from approved waters. State agencies establish standards for shellfish growing areas and regularly monitor water quality to make sure that growing waters meet those standards.

Fish and shellfish packers, warehouses, and processors must comply with the mandatory requirements of the seafood Hazard Analysis Critical Control Point Program administered by the U.S. Food and Drug Administration. The program identifies potential food safety hazards and develops strategies to help ensure that they do not occur. In addition, all domestic food groups, including seafood, are subject to sampling under the FDA "Total Diet Study." This program is designed to randomly sample the domestic food supply to detect any potential contaminants and chemical residues.

New rules by the U.S. Food and Drug Administration authorized by the Food Safety Modernization Act have added additional regulations for the processing, handling and transportation of animal feeds and human food. Such controls help to make farm-raised seafood products safe and wholesome foods.

As U.S. farmers, we are at a very real price disadvantage and recognize import product prices as being one of our greatest challenges. In response, rather than a protectionist approach, the National Aquaculture Association has been working to develop markets that appreciate locally grown and high-quality fish, shellfish and seaweed products. And we are working to educate the culinary professionals of U.S. sustainable production practices, environmental stewardship and the nutritional benefits and value of buying U.S. grown foods.

Myth: American commercial fishing and marine finfish aquaculture cannot coexist

The claim that commercial fishing and marine aquaculture cannot coexist has been made for the last 39 years and has been proven false for 23 coastal states where the production of Atlantic salmon, oysters, clams and mussels has grown, prospered and in many instances was led by commercial fishermen. Globally, commercial fishing has continued in concert with the growth in marine aquaculture production, and in the few instances where marine sea cages have been constructed and operated in the United States (e.g., Hawaii, Maine and Puerto Rico) those farms were often welcomed by commercial and recreational fishermen.

Domestic wild capture fisheries cannot expand to meet the ever-increasing demand for seafood, given harvest restrictions that are designed to ensure sustainable wild fish populations. Without an increase in domestic aquaculture, this country will continue to rely heavily on foreign supplies, resulting in serious food security, food safety and environmental concerns, as well as the perpetuation of significant trade imbalances. The paucity of domestic aquaculture production means domestic demand satisfied by seafood imports will continue to expand foreign unsustainable production practices, unjust labor conditions and environmental degradation in countries that lack our legal, regulatory and enforcement capacities. By opposing the development of a domestic aquaculture sector, anti-aquaculture special interest groups bear some responsibility for these negative environmental and social impacts in countries with lower regulatory oversight.

Helvey et al. (2017, 66–67) addressed these issues noting, "The full impact of U.S. seafood consumption patterns needs to be considered at the global level in light of continuing efforts to further marine biodiversity protections. Failing to do so only serves to counteract the effectiveness of domestic actions by externalizing negative environmental costs to others (page 66)." The authors offered six solutions, presented here in-brief that should form the basic tenets of domestic farmed and wild seafood production:

1. "Increase awareness of U.S. fisheries. Most Americans remain unaware of the high environmental standards by which U.S. federal marine fisheries – and many state fisheries - are managed, in compliance with multiple state and federal laws.
2. Develop U.S. domestic aquaculture to complement capture fisheries. The global status of marine capture fisheries is considered stable; however, increased catches are considered unlikely, suggesting that aquaculture will need to play a greater role in seafood security
3. Support sustainable fishing practices in other nations. Such capacity-building efforts include transferring best fishing practices, technologies and monitoring practices to nations whose fisheries continue to supply U.S. markets.
4. Multilateral cooperation. Overarching World Trade Organization consistent trade laws and regulations can help address production and trade leakages and their negative impacts across the entire ranges of affected stocks.
5. Recognize the externalities of management decisions. Leakage occurs when the spatial scale

of intervention does not match the scale of the targeted problem. Ignoring environmental impacts associated with goods produced elsewhere creates … the "illusion of natural resource preservation."

6. Treat wild capture and aquaculture fisheries as part of the food system. Seafood represents a part of the nation's food system. Nonetheless, within the context of managing marine resources and ecosystem impacts, seafood rarely is acknowledged as a component of the human diet, despite its recognized importance as a source of nutrition and sustenance."

As farmers that produce a perishable product competing with the rest of the world for a small sliver of the U.S. seafood market, we believe our focus and the focus of U.S. fishermen should be on becoming the best and most efficient farmers and fishermen that we can be. Complaining that we cannot co-exist does not serve a shared goal of providing domestically produced product for the growing U.S. and global markets. By focusing on our collective ability to compete in world markets we will help preserve working waterfronts and ensure that coastal communities will remain resilient. Our competition is not each other, but low-cost foreign producers who do not have to comply with strict environmental and socio-economic regulations.

Where do we go from here?

From our perspective as commercial aquaculturists:

- The US aquaculture community (farmers, research and aquaculture extension specialists) is educated at the same universities or schools as are critics and regulators. We have taken the same courses in marine or freshwater biology, ecology to understand animal, plant and ecosystem function and the invaluable benefits of intact natural systems to society. Our farming methods and farm management are influenced by this education, research and the information and demonstration projects completed by aquaculture extension (Land Grant and Sea Grant programs).
- Public investment in environmental regulations at the federal and state levels provide sufficient protection or conservation of natural resources, but regulations appear to be a "growth industry" that can and does stifle innovation. We believe the thinking "the next regulation is the best regulation" creates an illusion of natural resource protection and triggers ever increasing importation of foods and goods from countries less protective of the environment, labor and food safety (Helvey et al. 2017).
- Public investment in marine aquaculture research has improved feeds, production systems, farm siting and management practices, species suitability, therapeutants, environmental interaction and animal health management (Love et al. 2017; NOAA 2020a; Rexroad et al. 2021). The American public should realize the significant and measurable returns for their invaluable investment through the expansion of the domestic aquaculture sector.
- A global imperative exists to plan for and develop the foods and food systems for a growing world population. Other countries, and thoughtful U.S. scientists, have recognized the farming of aquatic animals and plants can sustainably contribute to feeding future generations (Gentry et al. 2020). We believe we are and will farm sustainably and the science we have presented supports our belief. However, there are costs to sustainable aquaculture that can't be met if the trend in seafood imports and values continues.
- Working on the farm is a tough, dirty, risky occupation that requires of farm owners, managers and employees a wide range of education, skills and experience. The regulatory cost hurdle to start a farm is becoming insurmountable which is contributing to fewer startup farms and opportunities for small farm to explore product marketability and production methods.

In an effort to reverse and mitigate these trends, the National Aquaculture Association and a number of state aquaculture associations have advocated for a national aquaculture economic development initiative. Canada, Chile, China, India, Indonesia, Ireland, Norway or Vietnam, all of which are significant exporters of farm-raised seafood to the United States, have used national economic development initiatives to:

- Encourage infrastructure development such as working waterfront, transportation, feed production, cold storage and processing.
- Expedite technology transfer and adoption to reduce costs, increase production, and reduce environmental effects.

- Train an aquaculture and commercial fishing savvy workforce.
- Encourage entrepreneurial development by:
- educating bankers and investors as to the opportunities for aquaculture and commercial fishing to create, sustain and strengthen rural economies, jobs and income,
- improving and expanding existing financing programs,
- creating investment incentives including tax credits and a property right in coastal and oceanic waters,
- developing risk management tools; and,
- creating incentives for states, provinces or regions that wish to step up and support commercial fishing and aquaculture.

The development of a national aquaculture economic development initiative for the United States should include private sector representatives, who understand what is required to build aquaculture farms and operate successful ancillary businesses. A jointly led task force by Agriculture and Commerce composed of state and federal economic development representatives and aquaculture stakeholders should guide the initiative and develop specific recommendations for actions that federal and state governments should take, a time table for those actions, and a series of metrics designed to measure program efficacy.

Concluding thoughts

There is little doubt that the detractors, and often well financed critics, of U.S. offshore marine aquaculture, particularly finfish farming, have significantly contributed to its lackluster growth compared to other countries (Tiersch and Hargreaves 2002; Knapp and Rubino 2016). Proponents acknowledge marine aquaculture is not risk free in terms of potential environmental, economic, social and cultural impacts and challenges remain to achieving sustainable production. The good news is these challenges are well known, as described in the preceding text, and they are the focus of not only the American science and technology enterprise, but by a global network of scientists from many coastal nations focused on expanding seafood production from the ocean. The realities of the current marine aquaculture seascape bode well for a more productive future:

1. There is a clear global imperative to sustainability produce more seafood from capture and culture fisheries to meet constantly growing demand. The U.S. has the marine resources to become a major exporter, if U.S. law can be amended to grant offshore farmers a property right or security of tenure for sites in federal waters.
2. U.S. farmers work within a very complex and effective legal, regulatory, and science-driven environment to anticipate and mitigate potential impacts.
3. Farm level management decisions and federal and state regulatory frameworks are working together to bring about environmentally beneficial siting, operational and production outcomes.
4. Commercial aquaculture advocates in government, universities and the farming community have recognized it is essential to reach out to decision-makers and the public, as well as the critics, with the latest research and empirical results to describe an accurate picture of the risks and rewards to farming the sea.
5. Greater communication and engagement efforts, targeted public research expenditures, and greater offshore, commercial-scale farming experience will enhance the U.S. marine aquaculture track record going forward.
6. Farming offshore is not risk-free. Fortunately, we can and are looking to nations like Canada, Chile, China, Japan, Norway, Panama, Mexico and nations bordering the Mediterranean Sea that are well ahead of the United States in producing farmed seafood to learn from their mistakes and successes.
7. The current federal permitting process is thorough, complex, time-consuming and expensive. We believe this is as it should be. As we collectively gain experience, knowledge and environmental data, the time and expense may lessen but the permitting process should always be rigorous. We, as citizens of the United States, are desirous of protecting and conserving the oceans for the next seven generations.[14]

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[14]This paper is dedicated to Kurt Grinnell of the Jamestown S'Klallam Tribe. Kurt spoke, planned and worked to develop and manage marine aquaculture (shellfish and finfish culture) for the tribe. He also spoke frequently and eloquently to encourage us to plan and act for the next seven generations.

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