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Securing a sustainable future for US seafood in the wake of a global crisis

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Abstract

The United States seafood industry is undergoing rapid change, as a result of the current trade war with China, ongoing global COVID-19 pandemic, and new governance mandates. The Executive Order *on Promoting American Seafood Competitiveness and Economic Growth*, signed in May 2020, proposes wild-capture fisheries deregulation and prioritization of aquaculture, with an emphasis on offshore development. Recent disruption of wild-caught seafood supply and demand could create space for sustainable aquaculture growth, but expansion could also undermine wild fisheries livelihoods and economics if integrated management between industries is ignored. Here, we review the current state of US seafood and outline *five guiding principles* around the implementation, and possible modifications, of the Executive Order to facilitate sustainable US fisheries and aquaculture: **(1)** make precise and strategic fisheries reforms that continue to support sustainable wild fisheries, **(2)** integrate aquaculture and fisheries using an ecosystem-based approach, **(3)** improve aquaculture data collection, **(4)** address social resistance to aquaculture, and **(5)** reconcile nationalism in a global market. Regardless of the Head of State, implementation of these science-informed principles is critical for balancing social-ecological tradeoffs between wild captured and farmed seafood systems, and for ensuring a more resilient US seafood sector under an anticipated future of increased volatility.

Keywords: aquatic farming, North America, policy, consumption, trade, livelihoods

A system in flux

The effects of the COVID-19 pandemic are rippling across the world, including the virus hotspot of the United States [1]. As society and individuals grapple with the physical, psychological, behavioral, and financial toll of this disease, our food systems are experiencing significant changes in the way food is produced, distributed, and consumed. US seafood has also experienced major disruptions from the trade war started in 2019 with China—the world's largest seafood consumer [2,3]. These shocks add considerable uncertainty when projecting the impact of recent policy changes, including a sweeping executive order, pandemic relief funding, and a changing administration in the White House [4]. Together, these impacts and changes present both the opportunity to chart a new trajectory for sustainable US seafood, but also risk destabilizing current trends of sustainability in commercial fisheries. Here, we provide guidance on how to increase production and ensure a sustainable future for US seafood when the world emerges from the current crisis.

The effects of the pandemic started early for the US seafood sector [5]. A large proportion of value usually stems from restaurant orders (75%), which declined dramatically starting in mid-March 2020, co-occurring with reduced or delayed commercial and recreational fishing across most states [5,6]. Similarly, shellfish farmers downsized, and in some cases delayed seeding their crops in hopes of waiting out the decline in demand [7]. Many community-supported fisheries (e.g., [8]) expanded their supplies of diverse seafood direct to local consumers, while larger businesses, such as those producing farmed salmon and trout, rapidly shifted from restaurant to retail sales

[5,7]. Combined, commercial aquaculture and fisheries contribute an estimated $7.1 billion in annual landings, while the industry as a whole (including recreational activities) accounts for over $200 billion in sales and approximately 2 million jobs [9,10]. Seafood specific aid made available by the Federal government amounted to $300 million or 0.014% of the CARES Act and <1% of total landings buybacks [5,7]. Federal support has been identified by people in the seafood sector as perhaps the most critical to successfully weather large, negative disruptions, in this case from COVID-19 [11].

Uncertainty is at an all-time high as the US seafood sector grapples with the myriad of shocks from COVID-19, the ramifications of the Executive Order [4] signed in May 2020 – during some of the lowest points for the industry [5] – and the potential actions by the incoming Biden administration. Here, we briefly describe the current state of US seafood and provide five guiding principles for the implementation and revision of the Order's mandates to facilitate a pathway towards sustainable and economically prosperous fisheries and aquaculture in the US:

1. *Make precise and strategic fisheries reforms*
2. *Integrate fisheries & aquaculture through an ecosystem-based approach*
3. *Collect more comprehensive aquaculture data*
4. *Explicitly address social resistance to aquaculture*
5. *Reconcile nationalism in a global market*

Current state of US fisheries and aquaculture

Before the pandemic, annual domestic seafood production in the United States was approximately 5.5 million tonnes. The US is the largest net seafood importer in the world, with a growing "trade deficit" (imports > exports) and an import seafood dependence of 62-65% [3], which was one of the key motivations listed for the Executive Order, although there are disagreements around the economic interpretations (e.g., [12]). The vast majority (>90%) of domestic production comes from wild capture fisheries (Fig 1), most of which are sustainably managed and therefore have limited scope for additional wild harvest [13]. The national aquaculture sector plays a much smaller role, contributing just 8% of all domestic production in recent years (Fig 1). Marine aquaculture, particularly offshore (3-200 nm from the coast), is increasingly identified as an area where the US could support substantial seafood growth [14–16]. Americans consume ca. 1 million tonnes more than is domestically produced (Fig 1) and certainly have an appetite for farmed seafood: three of the top four consumed taxa are mostly farmed, but all three are primarily raised in other countries: salmon (global farmed:wild ratio = 2.7:1), shrimp (3:1), and tilapia (8.3:1) [17]. These consumption patterns create important social and environmental tradeoffs that have led to calls for more domestic aquaculture production and improvements in trade policies to support sustainable practices. The complex suite of agencies and regulations governing aquaculture are often blamed for the slow growth of aquaculture in the US [15,18–20], and the need for aquaculture policy reform has been garnering increasing attention from the Federal (e.g., [21]), state, and local governments (e.g., [22]).

[FIG 1 HERE]

Executive Order: a changing tide for the US seafood industry

The May 7, 2020 Executive Order on *Promoting American Seafood Competitiveness and Economic Growth* asserts a broad initiative to increase US seafood production, with a particular focus on offshore aquaculture [4]. Of note, the Order designates NOAA as the lead governing agency for marine production, in addition to its current mandate over fisheries. With timelines ranging from months to several years, Federal and State agencies are being asked to reassess how commercial fisheries are managed, create standardized and predictable permitting process for aquaculture, revise trade policy through a Seafood Trade Task Force, and update aquatic animal health regulation. To promote offshore aquaculture expansion, NOAA is tasked with identifying 10 offshore areas over the next five years for finfish, seaweed, or integrated aquaculture production; two areas have already been identified [23]. Within the context of a new administration that could overturn or modify this executive order, we suggest these guiding science-based principles.

1. Make precise and strategic fisheries reforms

The Executive Order includes a directive to "*reduce burdens on domestic fishing and to increase production*," while maintaining sustainability as defined by Magnuson–Stevens Fishery Conservation and Management Act (MSFCMA) and Marine Mammal Protection Act (MMPA). Increasing overall production of wild-caught fish would be difficult, since a high fraction (85%) of US assessed stocks are already fished at or near maximum sustainable levels [3]. Many fisheries have layers of regulations that directly limit total allowable catch and control where, when, and how fish are caught [24]. It may be possible to reduce some of the latter regulations, while retaining catch limits, and still ensure fisheries remain ecologically and economically sustainable. Changes might include modified gear restrictions for better control over which species are caught, increased flexibility for switching fisheries or gears [25], changes to how quota is allocated, among multispecies fisheries (e.g., west coast groundfish [26,27]), and reallocating quota to account for climate change-driven distribution shifts [28] (e.g., black sea bass [29]). Additionally, in some fisheries, the government could shoulder some observer costs and/or increase use of electronic (video) monitoring [30], which could adjust both mechanism and source for incurring regulatory costs. In many cases, cost-effective burden reductions could be achieved through more accurate scientific estimates of fish trends and status by increasing and supporting scientific surveys for stock assessments [28,31–34]. The departing US Administration has also implemented a separate Modified Proclamation [35] to open the Northeast Canyons and Seamounts Marine National Monument to fishing, even though the gains from this action are likely to be small [3], counterproductive and perhaps more performative than useful (or legal) for fishers [36]. Ultimately, any changes in fisheries regulations need to be scientifically tested, e.g. Management Strategy Evaluations (MSE)], to ensure they do not threaten fisheries sustainability [37,38]. Some changes may improve profitability, but few changes are likely to substantially increase wild landings.

2. Integrating aquaculture & fisheries through an ecosystem-based approach

There is considerable potential for better integrated management for US wild capture fisheries and aquaculture to improve system resilience in the face of disruption (Fig 2).

The two sectors are mostly managed separately, even though they interact directly and indirectly in space and through feed, seed, and markets [39]. Separate management approaches may be a function of the previous lead agency for all aquaculture being the Department of Agriculture, whereas fisheries are managed by NOAA under the Department of Commerce. However, with NOAA designated as the coordinating body for marine aquaculture, there is stronger potential to align principles from Ecosystem-based Fisheries Management (EBFM) [40–42] and the Ecosystem Approach to Aquaculture (EAA) [43–46] (Fig 2). EBFM and EAA are already in use in their respective sectors to varying degrees, providing an opportunity to build a sustainable management framework that more explicitly integrates fisheries and aquaculture, alongside community well-being and equity, environmental health and the economy. For instance, well-managed, strategically-sited and planned marine aquaculture can reduce environmental impacts and even improve local conditions with extractive farmed species (e.g., bivalves, seaweeds) [47–49], but poorly managed operations can degrade the health of stocks—wild and farmed—and ecosystems [39]. Further, some marine aquaculture systems rely on healthy fisheries (e.g., capture-based aquaculture, fed species) and even contribute to increasing harvest of wild fisheries (e.g., supplemental hatcheries). Thus, management actions in either sector can have important sustainability consequences for both systems [39]. This interdependence is likely to become even more important as aquaculture grows and diversifies rapidly, as prefaced in the Executive Order. An ecosystem approach begets better monitoring and evaluations of the system, beyond a single species or sector, through formal assessments and MSE [46,50–52]. Moreover, coordination and better data streams through an ecosystem approach are central to adaptive management, especially across systems, which can help buffer impacts of shocks, be they COVID-19 or climate change [53,54] (Fig 2).

[FIG 2 HERE]

3. Collect and release more comprehensive aquaculture data

"*Suitable reporting*" by US aquaculture owners and operators—in line with fisheries management requirements— is another important mention in the Executive Order and a key feature of ecosystem-based management**.** Currently, aquaculture value and volume reporting is not standardized and largely determined state-by-state, while Federal reporting of value data happens at 5-year census increments [55]. Notably, annual state-level aquaculture data are often not publicly available, like they are for wild fisheries, and USDA only reports one year (c. 2005) of sparse marine volume information [55]. It is difficult to set sustainable seafood development goals and build resilience in the sector without basic time-series data on what is produced, where, and how [47,56,57]. In fact, the COVID-19 pandemic has highlighted the real-world impact of uncertainty in aquaculture location and scale data, which creates confusion and inequities in relief funding allocation [11]. Going forward, annual production and on-farm metrics (e.g., feed conversion ratios, feed source/amount, survival, environmental measures, sales, etc.) should be standardized so state and federal agencies can accurately set targets and reference points to compare production (value and volume) over time and space (Fig 2). Improved data are essential for assessing environmental and economic farming impacts, modeling environmental versus husbandry effects, and monitoring volatility of long-term production, all of which would likely improve confidence for insurance agencies, investors, and the public.

To improve data quality and reliability, mechanisms are needed for independent evaluations of aquaculture reporting, including advisory councils, better data access for independent scientific institutions, and auditing (e.g., NOAA Seafood Inspection Program). Such data management standards are commonplace for US commercial fisheries management [58] and should be extended to aquaculture. Interagency data coordination, led by an entity such as NOAA, and buy-in from marine farmers to adopt better data practices and technology (e.g., [59,60]) are necessary for this to be achieved and would likely be adopted more quickly and ubiquitously with governmental subsidies, at least initially, and improved knowledge sharing [61]. Ultimately, just like wild fisheries, reliable and consistent data are a fundamental ingredient for robust modeling and strategic planning for sustainable aquaculture growth.

4. Explicitly address social resistance to aquaculture

Even with stronger political and regulatory support, and high US consumption of farmed seafood, aquaculture expansion within the US may be hampered by a lack of social acceptance and communities reluctant to support its development locally [62]. North Americans eat seafood primarily based on product recognition, taste, and price [63], and there is no guarantee communities will support local aquaculture development. Indeed, domestic efforts around marine aquaculture development have experienced strong opposition, including in the Gulf of Mexico and Washington state [62]. This underscores the point that if local stakeholders are not involved in the process of new aquaculture development, the Executive Order and other efforts might do little to advance domestic production. Lack of stakeholder involvement may also affect the equity of such aquaculture growth [46,64]. As in fisheries and ecosystem-based management approaches, accounting for social "carrying capacity" is critical [46]. For instance, good site selection through spatial planning and public engagement is an essential first step in an ecosystem-based approach and can minimize social concerns (e.g., impacts on wildlife), conflicts with other ocean uses (e.g., fishing), and overall risk (e.g., proximity to critical habitat) [62,65,66]. Offshore farming may be an important step in this process by minimizing intersectoral conflict and impact in an increasingly busy coastal area [15,16,67,68]. Of note, NOAA may be well positioned to support these goals given their lead role in fisheries and now marine aquaculture, as well as their continued work in national spatial data resources and planning (e.g., [69]). That said, scientific integrity and trust that decisions from NOAA are based on science and informed by data are absolutely critical. Undermining the science that underpins an ecosystem approach could erode the potential to effectively build long-term social license for aquaculture in US waters.

5. Reconcile nationalism in a global market

The COVID-19 pandemic's disruption of food supply chains has highlighted the risks of reliance on foreign imports for food, which may advance proposed nationalistic food strategies focused on reducing the US seafood trade deficit. As previously noted, the focus on the seafood deficit itself is perhaps misguided given that the US is a wealthy nation with an economy centered on technology and services, rather than resource extraction [12]; though displaced social and environmental impacts still apply. The Executive Order emphasized the role of the Seafood Trade Task Force, set to focus on fair market access via trade policy and negotiations [70]. The outgoing administration's focus on the seafood deficit must also reconcile with the Order's objective of identifying "*opportunities to improve access to foreign markets*" and the reality of a highly globalized seafood market. Seafood is among the most traded food commodities in the world [3], and the US is both the top importer and among the top five exporters of seafood [2,17]. Yet, past efforts to make US farmed seafood competitive with foreign farmed products through labelling and trade barriers have been largely unsuccessful. For example, the US imposed tariffs of 63% on Vietnamese catfish imports, implemented more rigorous import inspections, and passed a law to prevent labelling Asian catfish as catfish [71]. Despite the extreme measures, Vietnamese catfish imports have grown, while US catfish sales have remained relatively flat [55]. Further, imposing import restrictions comes at a cost to consumers and can result in challenges under the auspices of the World Trade Organization and retaliatory tariffs by exporting nations [72], which hamper efforts to develop foreign markets for US seafood and beyond.

Meanwhile, trade negotiations and import restrictions targeted at addressing illegal, unreported and unregulated (IUU) fishing and preventing slavery and child labor along the supply chain could produce broad sustainability and human rights benefits. Slave labor on fishing vessels, as well as child and migrant labor in processing plants has been documented in global supply chains, including in Thailand, a top seafood exporter to the US [73]. These interrelated, illegal practices lower production costs, giving exporters an advantage [74]. Addressing them would help level the playing field for US producers and would be aligned with existing law [75]. In the long term, the combined effects of pandemic-related trade disruptions and questions about whether the US is a reliable trade partner may hamper the goal of improving access to foreign seafood markets. Therefore, the government needs to consider technical challenges (e.g., [76]) alongside paths ensuring trade partner confidence in US export reliability. In doing so, the US can maintain and support the expansion of sustainable domestic seafood producers in high value foreign markets.

Conclusions

During this period of turmoil, uncertainty, and rapid policy change, it will be a challenge to develop institutions and governance that can guide American seafood towards a sustainable future that supports economic development, healthy oceans, and food security. Another change is coming less than a year after the Seafood Executive Order and CARES Act, with the new Biden administration taking control January 20th, 2021. Although a new administration often overturns many actions of their predecessor, it is unclear which parts of this executive order might stay, especially with "regenerative aquaculture" appearing in *The Ocean-Based Climate Solutions Act* [77] introduced to the Democratic majority House and the amended bipartisan *Advancing the Quality and Understanding of American Aquaculture Act* re-introduced to the Senate in

October 2020 [21]. The science-informed principles outlined here are pertinent to the future of US seafood, no matter the Head of State.

We can maintain the sustainability of wild capture fisheries while expanding domestic marine aquaculture, if the two seafood sectors are managed integratively using an ecosystem-based approach. This will depend on recognition of the importance of seafood in our coastal communities and for the well-being of our country as a whole. Continued integrity and reliance on the best-available science and improved monitoring are crucial to help assess how specific policies can be achieved in concert with system-wide management to benefit society and the environment. Early and continued consultation with coastal communities and stakeholders must be recognized as a key component in striking this balance, especially to foster and maintain trust in science-informed decisions. Scientific independence must be upheld as we look to a likely future of increased climatic and political instability. Flexibility and adaptive capacity within our institutions and participation in global trade can add resiliency to our seafood systems so that we can collectively survive, and ideally thrive, into the future.

References

[1] M. Roser, H. Ritchie, E. Ortiz-Ospina, J. Hasell, Coronavirus Pandemic (COVID-19), Our World in Data. (2020). https://ourworldindata.org/coronavirus/country/united-states (accessed May 28, 2020).

[2] J.A. Gephart, M.L. Pace, Structure and evolution of the global seafood trade network, Environ. Res. Lett. 10 (2015) 125014. https://doi.org/10.1088/1748-9326/10/12/125014.

[3] J.A. Gephart, H.E. Froehlich, T.A. Branch, Opinion: To create sustainable seafood industries, the United States needs a better accounting of imports and exports, PNAS. 116 (2019) 9142–9146. https://doi.org/10.1073/pnas.1905650116.

[4] EO, Promoting American Seafood Competitiveness and Economic Growth, 2020. https://www.federalregister.gov/documents/2020/05/12/2020-10315/promoting-american-seafood-competitiveness-and-economic-growth (accessed November 10, 2020).

[5] E.R. White, H.E. Froehlich, J.A. Gephart, R.S. Cottrell, T.A. Branch, J.K. Baum, Effects of COVID-19 on US fisheries and seafood consumption, Fish and Fisheries. (2020). https://doi.org/10.31219/osf.io/9bxnh.

[6] D.C. Love, F. Asche, Z. Conrad, R. Young, J. Harding, E.M. Nussbaumer, A.L. Thorne-Lyman, R. Neff, Food Sources and Expenditures for Seafood in the United States, Nutrients. 12 (2020) 1810. https://doi.org/10.3390/nu12061810.

[7] J.A. Gephart, Richard S. Cottrell, Halley Froehlich, Elizabeth Nussbaumer, Joshua S. Stoll, Easton White, Covid-19 Seafood Impacts, (2020). https://doi.org/10.5281/zenodo.3866189.

[8] J.S. Stoll, H.L. Harrison, E. De Sousa, D. Callaway, M. Collier, K. Harrell, B. Jones, J. Kastlunger, E. Kramer, S. Kurian, Alternative seafood networks during COVID-19: Implications for resilience and sustainability, (2020).

[9] NOAA, Economic impact of U.S. commercial, recreational fishing remains strong | National Oceanic and Atmospheric Administration, (2018). https://www.noaa.gov/media-release/economic-impact-of-us-commercial-recreational-fishing-remains-strong (accessed October 26, 2020).

[10] NOAA Fisheries, Fisheries of the United States, 2018 | NOAA Fisheries, NOAA. (2020). https://www.fisheries.noaa.gov/feature-story/fisheries-united-states-2018 (accessed November 10, 2020).

[11] J. van Senten, M.A. Smith, C.R. Engle, Impacts of COVID-19 on U.S. aquaculture, aquaponics, and allied businesses, Journal of the World Aquaculture Society. 51 (2020) 574–577. https://doi.org/10.1111/jwas.12715.

[12] S. Malhi, The seafood trade deficit is a diversionary tactic, TheHill. (2018). https://thehill.com/opinion/energy-environment/407575-the-seafood-trade-deficit-is-a-diversionary-tactic (accessed November 10, 2020).

[13] R. Hilborn, R.O. Amoroso, C.M. Anderson, J.K. Baum, T.A. Branch, C. Costello, C.L. de Moor, A. Faraj, D. Hively, O.P. Jensen, H. Kurota, L.R. Little, P. Mace, T. McClanahan, M.C. Melnychuk, C. Minto, G.C. Osio, A.M. Parma, M. Pons, S. Segurado, C.S. Szuwalski, J.R. Wilson, Y. Ye, Effective fisheries management instrumental in improving fish stock status, PNAS. (2020). https://doi.org/10.1073/pnas.1909726116.

[14] R.R. Gentry, H.E. Froehlich, D. Grimm, P. Kareiva, M. Parke, M. Rust, S.D. Gaines, B.S. Halpern, Mapping the global potential for marine aquaculture, Nature Ecology & Evolution. (2017) 1. https://doi.org/10.1038/s41559-017-0257-9.

[15] S.E. Lester, R.R. Gentry, C.V. Kappel, C. White, S.D. Gaines, Opinion: Offshore aquaculture in the United States: Untapped potential in need of smart policy, PNAS. 115 (2018) 7162–7165. https://doi.org/10.1073/pnas.1808737115.

[16] S.E. Lester, J.M. Stevens, R.R. Gentry, C.V. Kappel, T.W. Bell, C.J. Costello, S.D. Gaines, D.A. Kiefer, C.C. Maue, J.E. Rensel, R.D. Simons, L. Washburn, C. White, Marine spatial planning makes room for offshore aquaculture in crowded coastal waters, Nature Communications. 9 (2018) 945. https://doi.org/10.1038/s41467-018-03249-1.
[17] FAO, The State of World Fisheries and Aquaculture 2020: Sustainability in action, FAO, Rome, Italy, 2020. https://doi.org/10.4060/ca9229en.
[18] M.R. DeVoe, Marine aquaculture in the United States: Current and future policy and management challenges, Trends and Future Challenges for US National Ocean and Coastal Policy. National Oceanic and Atmospheric Administration, Silver Spring, MD. (1999) 85–93.
[19] B. Cicin-Sain, S.M. Bunsick, R. DeVoe, T. Eichenberg, J. Ewart, H. Halvorson, R.W. Knecht, R. Rheault, Development of a policy framework for offshore marine aquaculture in the 3-200 mile US ocean zone, University of Delaware, Center for the Study of Marine Policy, 2001. http://www.gulfcouncil.org/Beta/GMFMCWeb/Aquaculture/offshore%20marine%20aquaculture.pdf (accessed July 21, 2015).
[20] Sea Grant, Overcoming Impediments to Shellfish Aquaculture through Legal Research and Outreach: Case Studies, Sea Grant Law, 2019.
[21] C.C. Peterson, H.R.6191 - 116th Congress (2019-2020): AQUAA Act, (2020). https://www.congress.gov/bill/116th-congress/house-bill/6191 (accessed November 10, 2020).
[22] P. Berube, Consideration of Authorization to Disburse Funds to Develop a Statewide Aquaculture Action Plan, (2020) 6.
[23] N. Fisheries, NOAA Announces Regions for First Two Aquaculture Opportunity Areas under Executive Order on Seafood | NOAA Fisheries, NOAA. (2020). https://www.fisheries.noaa.gov/feature-story/noaa-announces-regions-first-two-aquaculture-opportunity-areas-under-executive-order (accessed November 10, 2020).
[24] R. Hilborn, Measuring fisheries management performance, ICES J Mar Sci. (2020). https://doi.org/10.1093/icesjms/fsaa119.
[25] K. Kroetz, M.N. Reimer, J.N. Sanchirico, D.K. Lew, J. Huetteman, Defining the economic scope for ecosystem-based fishery management, PNAS. 116 (2019) 4188–4193. https://doi.org/10.1073/pnas.1816545116.
[26] D.S. Holland, Markets, pooling and insurance for managing bycatch in fisheries, Ecological Economics. 70 (2010) 121–133. https://doi.org/10.1016/j.ecolecon.2010.08.015.
[27] K. Kauer, L. Bellquist, M. Gleason, A. Rubinstein, J. Sullivan, D. Oberhoff, L. Damrosch, M. Norvell, M. Bell, Reducing bycatch through a risk pool: A case study of the US West Coast groundfish fishery, Marine Policy. 96 (2018) 90–99.
[28] B.A. Dubik, E.C. Clark, T. Young, S.B.J. Zigler, M.M. Provost, M.L. Pinsky, K. St. Martin, Governing fisheries in the face of change: Social responses to long-term geographic shifts in a U.S. fishery, Marine Policy. 99 (2019) 243–251. https://doi.org/10.1016/j.marpol.2018.10.032.
[29] ASMFC, DRAFT ADDENDUM XXXIII TO THE SUMMER FLOUNDER, SCUP, AND BLACK SEA BASS FISHERY MANAGEMENT PLAN FOR PUBLIC COMMENT, Atlantic States Marine Fisheries Commission, 2020. https://www.mafmc.org/actions/bsb-commercial-allocation (accessed November 10, 2020).
[30] C. Ewell, J. Hocevar, E. Mitchell, S. Snowden, J. Jacquet, An evaluation of Regional Fisheries Management Organization at-sea compliance monitoring and observer programs, Marine Policy. 115 (2020) 103842. https://doi.org/10.1016/j.marpol.2020.103842.
[31] J. Holzer, Harvest Reporting, Timely Information, and Incentives for Technology Adoption, Am J Agric Econ. 99 (2017) 103–122. https://doi.org/10.1093/ajae/aaw045.

[32] B. Hutniczak, D. Lipton, J. Wiedenmann, M. Wilberg, Valuing changes in frequency of fish stock assessments, Can. J. Fish. Aquat. Sci. 76 (2018) 1640–1652. https://doi.org/10.1139/cjfas-2018-0130.
[33] R. Hilborn, C. Costello, The potential for blue growth in marine fish yield, profit and abundance of fish in the ocean, Marine Policy. 87 (2018) 350–355. https://doi.org/10.1016/j.marpol.2017.02.003.
[34] K.M. Kuykendall, Management strategy evaluation for the Atlantic surfclam, Spisula solidissima, using a fisheries economics model, (2015).
[35] Proclamation 9496, Proclamation on Modifying The Northeast Canyons And Seamounts Marine National Monument, 2020. https://www.federalregister.gov/documents/2016/09/21/2016-22921/northeast-canyons-and-seamounts-marine-national-monument (accessed November 10, 2020).
[36] BDN Editorial Board, Trump didn't save Maine's fishing industry, Bangor Daily News. (2020). https://bangordailynews.com/2020/06/08/opinion/trump-didnt-save-maines-fishing-industry/ (accessed October 28, 2020).
[37] A.E. Punt, D.S. Butterworth, C.L. de Moor, J.A.A. De Oliveira, M. Haddon, Management strategy evaluation: best practices, Fish Fish. 17 (2016) 303–334. https://doi.org/10.1111/faf.12104.
[38] N. Bunnefeld, E. Hoshino, E.J. Milner-Gulland, Management strategy evaluation: a powerful tool for conservation?, Trends in Ecology & Evolution. 26 (2011) 441–447.
[39] T. Clavelle, S.E. Lester, R. Gentry, H.E. Froehlich, Interactions and management for the future of marine aquaculture and capture fisheries, Fish and Fisheries. 0 (2019). https://doi.org/10.1111/faf.12351.
[40] T.E. Dolan, W.S. Patrick, J.S. Link, Delineating the continuum of marine ecosystem-based management: a US fisheries reference point perspective, ICES J Mar Sci. 73 (2016) 1042–1050. https://doi.org/10.1093/icesjms/fsv242.
[41] K.N. Marshall, L.E. Koehn, P.S. Levin, T.E. Essington, O.P. Jensen, Inclusion of ecosystem information in US fish stock assessments suggests progress toward ecosystem-based fisheries management, ICES Journal of Marine Science. (2018).
[42] K.N. Marshall, P.S. Levin, T.E. Essington, L.E. Koehn, L.G. Anderson, A. Bundy, C. Carothers, F. Coleman, L.R. Gerber, J.H. Grabowski, E. Houde, O.P. Jensen, C. Möllmann, K. Rose, J.N. Sanchirico, A.D.M. Smith, Ecosystem-Based Fisheries Management for Social–Ecological Systems: Renewing the Focus in the United States with Next Generation Fishery Ecosystem Plans, Conservation Letters. 11 (2018) e12367. https://doi.org/10.1111/conl.12367.
[43] D. Soto, J. Aguilar-Manjarrez, N. Hishamunda, others, Building an ecosystem approach to aquaculture. FAO/Universitat de les Illes Balears Expert Workshop. 7û11 May 2007, Palma de Mallorca, Spain, (2008). http://agris.fao.org/agris-search/search.do?recordID=XF2015032435 (accessed February 8, 2017).
[44] C. Brugère, J. Aguilar-Manjarrez, M.C.M. Beveridge, D. Soto, The ecosystem approach to aquaculture 10 years on – a critical review and consideration of its future role in blue growth, Reviews in Aquaculture. 11 (2019) 493–514. https://doi.org/10.1111/raq.12242.
[45] J. Weitzman, Applying the ecosystem services concept to aquaculture: A review of approaches, definitions, and uses, Ecosystem Services. 35 (2019) 194–206. https://doi.org/10.1016/j.ecoser.2018.12.009.
[46] J. Weitzman, R. Filgueira, The evolution and application of carrying capacity in aquaculture: towards a research agenda, Reviews in Aquaculture. 12 (2020) 1297–1322. https://doi.org/10.1111/raq.12383.

[47] H.E. Froehlich, R.R. Gentry, B.S. Halpern, Conservation aquaculture: Shifting the narrative and paradigm of aquaculture's role in resource management, Biological Conservation. 215 (2017) 162–168. https://doi.org/10.1016/j.biocon.2017.09.012.
[48] R.R. Gentry, H.K. Alleway, M.J. Bishop, C.L. Gillies, T. Waters, R. Jones, Exploring the potential for marine aquaculture to contribute to ecosystem services, Reviews in Aquaculture. (2019).
[49] H.K. Alleway, C.L. Gillies, M.J. Bishop, R.R. Gentry, S.J. Theuerkauf, R. Jones, The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature, BioScience. 69 (2019) 59–68. https://doi.org/10.1093/biosci/biy137.
[50] E.A. Fulton, A.D.M. Smith, D.C. Smith, P. Johnson, An Integrated Approach Is Needed for Ecosystem Based Fisheries Management: Insights from Ecosystem-Level Management Strategy Evaluation, PLOS ONE. 9 (2014) e84242. https://doi.org/10.1371/journal.pone.0084242.
[51] P.J. Cranford, P. Kamermans, G. Krause, J. Mazurié, B.H. Buck, P. Dolmer, D. Fraser, K. Van Nieuwenhove, X.O. Francis, A. Sanchez-Mata, An ecosystem-based approach and management framework for the integrated evaluation of bivalve aquaculture impacts, Aquaculture Environment Interactions. 2 (2012) 193–213.
[52] E.A. Fulton, A.E. Punt, C.M. Dichmont, C.J. Harvey, R. Gorton, Ecosystems say good management pays off, Fish and Fisheries. 20 (2019) 66–96.
[53] R.S. Cottrell, K.L. Nash, B.S. Halpern, T.A. Remenyi, S.P. Corney, A. Fleming, E.A. Fulton, S. Hornborg, A. Johne, R.A. Watson, J.L. Blanchard, Food production shocks across land and sea, Nature Sustainability. (2019) 1. https://doi.org/10.1038/s41893-018-0210-1.
[54] K.K. Holsman, A.C. Haynie, A.B. Hollowed, J.C.P. Reum, K. Aydin, A.J. Hermann, W. Cheng, A. Faig, J.N. Ianelli, K.A. Kearney, A.E. Punt, Ecosystem-based fisheries management forestalls climate-driven collapse, Nature Communications. 11 (2020) 1–10. https://doi.org/10.1038/s41467-020-18300-3.
[55] USDA, USDA/NASS QuickStats Ad-hoc Query Tool, (2020). https://quickstats.nass.usda.gov/results/CA62A751-1DF1-3148-8738-AEEE6A0F54C2 (accessed May 30, 2020).
[56] P.B. Bridson, J.M.S. Stoner, M. Fransen, J. Ireland, The aquaculture sustainability continuum – defining an environmental performance framework, Environmental and Sustainability Indicators. (2020) 100050. https://doi.org/10.1016/j.indic.2020.100050.
[57] G.D. Stentiford, I.J. Bateman, S.J. Hinchliffe, D. Bass, R. Hartnell, E.M. Santos, M.J. Devlin, S.W. Feist, N.G.H. Taylor, D.W. Verner-Jeffreys, R. van Aerle, E.J. Peeler, W.A. Higman, L. Smith, R. Baines, D.C. Behringer, I. Katsiadaki, H.E. Froehlich, C.R. Tyler, Sustainable aquaculture through the One Health lens, Nature Food. 1 (2020) 468–474. https://doi.org/10.1038/s43016-020-0127-5.
[58] J.S. Link, F.E. Werner, K. Werner, J. Walter, M. Strom, M.P. Seki, F. Schwing, J. Rusin, C.E. Porch, K. Osgood, K. Moline, R.D. Methot, P.D. Lynch, D. Lipton, K. Koch, E.A. Howell, J.A. Hare, R.J. Foy, D. Detlor, L. Desfosse, J. Crofts, N. Cabana, A NOAA Fisheries science perspective on the conditions during and post COVID-19: Challenges, observations, and some possible solutions, or why the future is upon us, Can. J. Fish. Aquat. Sci. (2020) cjfas-2020-0346. https://doi.org/10.1139/cjfas-2020-0346.
[59] N. Davé, Introducing Tidal - X, the moonshot factory, Tidal. (2020). https://blog.x.company/introducing-tidal-1914257962c3 (accessed June 25, 2020).
[60] R. Gortan, The oyster farmer who created a game-changing digital solution, The Fish Site. (2020). https://thefishsite.com/articles/the-oyster-farmer-who-created-a-game-changing-digital-solution (accessed November 10, 2020).
[61] G. Kumar, C. Engle, C. Tucker, Factors Driving Aquaculture Technology Adoption, Journal of the World Aquaculture Society. 0 (2018). https://doi.org/10.1111/jwas.12514.

[62] H.E. Froehlich, R.R. Gentry, M.B. Rust, D. Grimm, B.S. Halpern, Public Perceptions of Aquaculture: Evaluating Spatiotemporal Patterns of Sentiment around the World, PLOS ONE. 12 (2017) e0169281. https://doi.org/10.1371/journal.pone.0169281.

[63] G. Murray, K. Wolff, M. Patterson, Why eat fish? Factors influencing seafood consumer choices in British Columbia, Canada, Ocean & Coastal Management. 144 (2017) 16–22. https://doi.org/10.1016/j.ocecoaman.2017.04.007.

[64] I. Galparsoro, A. Murillas, K. Pinarbasi, A.M.M. Sequeira, V. Stelzenmüller, Á. Borja, A.M. O´Hagan, A. Boyd, S. Bricker, J.M. Garmendia, A. Gimpel, A. Gangnery, S.-L. Billing, Ø. Bergh, Ø. Strand, L. Hiu, B. Fragoso, J. Icely, J. Ren, N. Papageorgiou, J. Grant, D. Brigolin, R. Pastres, P. Tett, Global stakeholder vision for ecosystem-based marine aquaculture expansion from coastal to offshore areas, Reviews in Aquaculture. n/a (2020). https://doi.org/10.1111/raq.12422.

[65] L.G. Ross, T.C. Telfer, L. Falconer, D. Soto, J. Aguilar-Manjarrez, R. Asmah, J. Bermúdez, M.C.M. Beveridge, C.J. Byron, A. Clément, Carrying capacities and site selection within the ecosystem approach to aquaculture, Site Selection and Carrying Capacities for Inland and Coastal Aquaculture. 19 (2013).

[66] Aguilar-Manjarrez, D. Soto, R. Agudo, Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture., 2017.

[67] H.E. Froehlich, A. Smith, R.R. Gentry, B.S. Halpern, Offshore Aquaculture: I Know It When I See It, Frontiers in Marine Science. 4 (2017) 154. https://doi.org/10.3389/fmars.2017.00154.

[68] R.R. Gentry, S.E. Lester, C.V. Kappel, C. White, T.W. Bell, J. Stevens, S.D. Gaines, Offshore aquaculture: Spatial planning principles for sustainable development, Ecology and Evolution. 7 (2017) 733–743. https://doi.org/10.1002/ece3.2637.

[69] NOAA, OceanReports, NOAA Office for Coastal Management. (2020). https://coast.noaa.gov/digitalcoast/tools/ort.html (accessed June 25, 2020).

[70] NOAA, Federal task force proposals set stage for new seafood trade strategy | National Oceanic and Atmospheric Administration, News & Features. (2020). https://www.noaa.gov/news/federal-task-force-proposals-set-stage-for-new-seafood-trade-strategy (accessed October 30, 2020).

[71] J. Margolis, The US and Vietnam continue their 17-year-old trade dispute over catfish, The World. (2018). https://www.pri.org/stories/2018-04-25/great-catfish-war-rages (accessed May 30, 2020).

[72] M. Kreiter, World Trade Organization Rules US China Tariffs Illegal, Recognized Chinese Intellectual Property Theft, International Business Times. (2020). https://www.ibtimes.com/world-trade-organization-rules-us-china-tariffs-illegal-recognized-chinese-3046159 (accessed October 30, 2020).

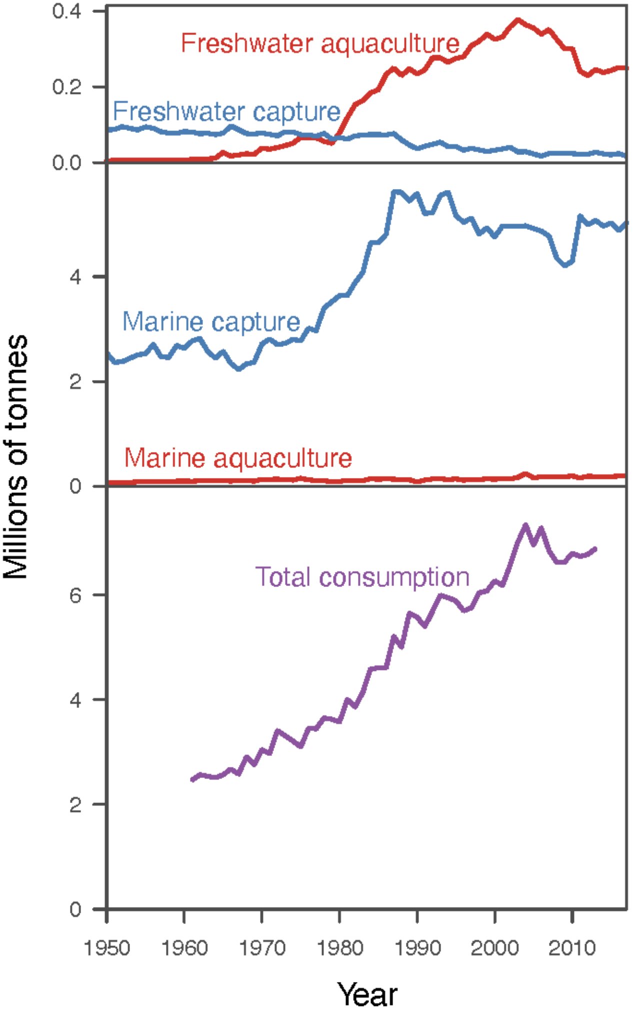
[73] B. Clark, S.B. Longo, R. Clausen, D. Auerbach, From Sea Slaves to Slime Lines: Commodification and Unequal Ecological Exchange in Global Marine Fisheries, in: R.S. Frey, P.K. Gellert, H.F. Dahms (Eds.), Ecologically Unequal Exchange: Environmental Injustice in Comparative and Historical Perspective, Springer International Publishing, Cham, 2019: pp. 195–219. https://doi.org/10.1007/978-3-319-89740-0_8.

[74] I. Chapsos, S. Hamilton, Illegal fishing and fisheries crime as a transnational organized crime in Indonesia, Trends Organ Crim. 22 (2019) 255–273. https://doi.org/10.1007/s12117-018-9329-8.

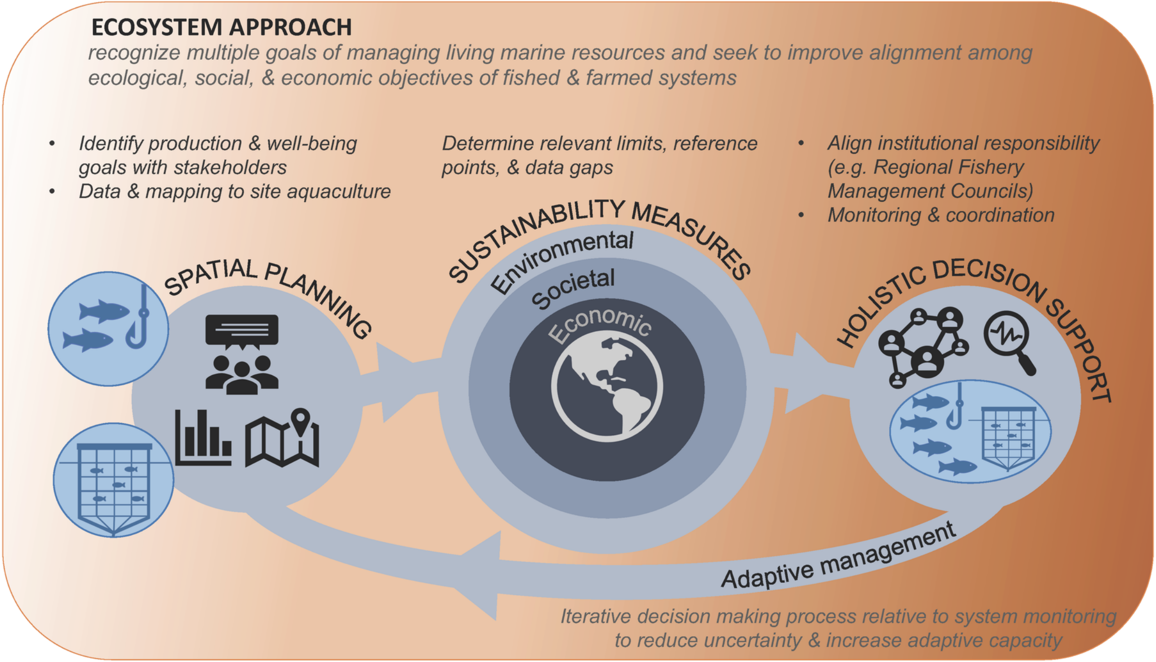
[75] H.R.644, Trade Facilitation and Trade Enforcement Act of 2015, 2016.

[76] NOAA, U.S. Seafood Import Monitoring Program, National Ocean Council Committee on IUU Fishing and Seafood Fraud. (2020). https://www.iuufishing.noaa.gov/RecommendationsandActions/RECOMMENDATION1415/FinalRuleTraceability.aspx (accessed June 25, 2020).

[77] R.M. Grijalva, The Ocean-Based Climate Solutions Act, 2020. https://www.congress.gov/bill/116th-congress/house-bill/8632 (accessed November 10, 2020).



Freshwater aquaculture
Freshwater capture
Marine capture
Marine aquaculture
Total consumption
Millions of tonnes
Year
0.4
0.2
0.0
4
2
0
6
4
2
0
1950
1960
1970
1980
1990
2000
2010


ECOSYSTEM APPROACH
recognize multiple goals of managing living marine resources and seek to improve alignment among ecological, social, & economic objectives of fished & farmed systems
• Identify production & well-being goals with stakeholders
• Data & mapping to site aquaculture
Determine relevant limits, reference points, & data gaps
• Align institutional responsibility (e.g. Regional Fishery Management Councils)
• Monitoring & coordination
SPATIAL PLANNING
SUSTAINABILITY MEASURES
Environmental
Societal
Economic
HOLISTIC DECISION SUPPORT
Adaptive management
Iterative decision making process relative to system monitoring to reduce uncertainty & increase adaptive capacity