Science in Action: Exploring the Future of U.S. Aquaculture

A COMPASS Roundtable on Ocean Aquaculture

As the population continues to expand—both domestically and globally—identifying secure, safe sources of protein is a critical need. With two-thirds of the planet covered in water, it is logical to turn to the ocean as an arena for producing food. Globally, aquaculture is the fastest growing food sector,[i] underscoring the importance of understanding the scientific, policy, and social implications of ocean aquaculture.

As with all types of cultivated food production, there are complex and interwoven challenges and opportunities in ocean aquaculture.[ii] Indigenous knowledge and current research can answer questions around environmental safeguards, ecological impacts, long-term sustainable use of marine resources, and the social dimensions of ocean aquaculture. While we've developed a deeper scientific understanding of aquaculture, there remains a gap between the state of the science, federal policy, and public perceptions of ocean aquaculture in the U.S.[iii]

In order to help provide research insights on the science related to aquaculture, COMPASS convened a roundtable discussion with scientists and policymakers in July 2019. The Roundtable examined ways that science can inform safe, sustainable, and socially acceptable ocean aquaculture in the United States. In preparation, COMPASS staff examined the U.S. aquaculture landscape by speaking with more than 50 scientists, managers, policymakers, and tribal representatives.

These stage-setting conversations reflected the key concerns surrounding ocean aquaculture such as best management practices, economics, pollution, interactions with wild populations, and climate change. They also highlighted some of the scientific, technological, and cultural advancements in contemporary aquaculture that could address and reduce some of the perceived risks. Ultimately, 16 scientists, representing this wide range of knowledge and experience, participated in the Roundtable discussion along with congressional staff and federal agency representatives.

Roundtable Goals

The overarching goal of the Roundtable was to envision and identify science-based components for future sustainable aquaculture efforts that contribute to a healthy ocean environment, thriving coastal communities, and improved food security. Specific goals included:

- Enhancing connection among key people and ideas related to ocean aquaculture in the U.S.
- Examining the current state of science, research, and practice for sustainable aquaculture.
- Capturing and reporting key ideas articulated by participants in a proceedings document to be shared broadly.

Scientists provided five-minute overview ‘flash talks’ on various aspects of aquaculture, which in combination with federal agency and congressional legislative policymaker insights, served as the basis for rich and engaging discussions. Highlights of these flash talks are noted below in the Scientific Insights and Considerations for the Future sections. Additional information on the federal agency and legislative aspects of the Roundtable are available in the Appendix, as are summaries of the flash talks.

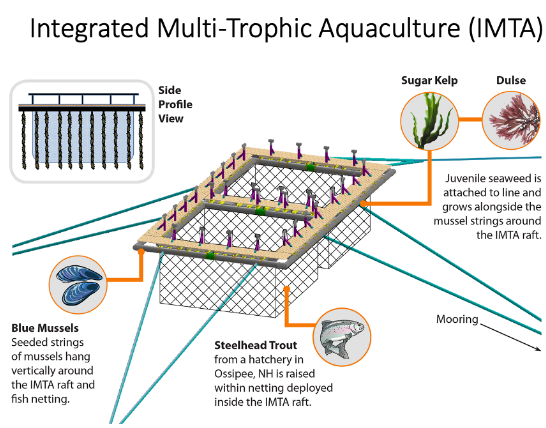
Scientific Insights

Highlights from the scientific presentations. For more details, please see Appendix III, or the archive of presentations, available here.

Aquaculture takes relatively little space for food production, and its ecological impacts such as its carbon footprint, and energy and freshwater usage, are also much smaller per unit of food than many other terrestrial animal production systems. This makes for an efficient food production system, complimentary to the existing animal production industry.[v]

Since relatively little space is required for aquaculture operations, siting can be highly selective and should consider a variety of factors including environmental and socio-economic drivers and impacts.[iii, iv] Due to its scalable nature, there is no ‘one-size fits all approach’ to aquaculture and site-specific factors should be identified before permitting, implementation and regular monitoring can occur. Ongoing monitoring of aquaculture operations is vital.

Much of current ocean aquaculture uses single-species monoculture that, like much land-based mono-cropping, focuses narrowly on maximizing the production of a single species, rather than mimicking natural, healthy, integrated systems. Using principles of polyculture, an Integrated Multi-Trophic Aquaculture approach can be an option to help address monoculture problems and risks as different trophic level species help mitigate the impacts of others such as uptake of nutrients.[vi]



Over the past several decades, research has informed changes to what finfish are fed. Knowledge of nutrient (e.g., proteins, lipids, vitamins, and minerals) requirements has advanced. In parallel, the number of ingredients available for feed production has greatly expanded. Notably, proteins in contemporary feeds can come from non-fish sources including plants and microorganisms. While the Fish-in: Fish-out (FIFO) ratio in the 1980s and 1990s was about 5:1, now it’s as low as 1:2, demonstrating how research-based advancements in feeds have improved the productivity of aquaculture.[vii, viii]

Determining the commercial viability of farming a fish species can take up to 20 years and requires understanding consumer preferences, if sufficient production and processing infrastructure exists, and what biological life cycle challenges are involved in raising the species. A marine finfish aquaculture scoping workshop and survey conducted in 2017 identified 17 species that could potentially be farmed in the United States.[ix]

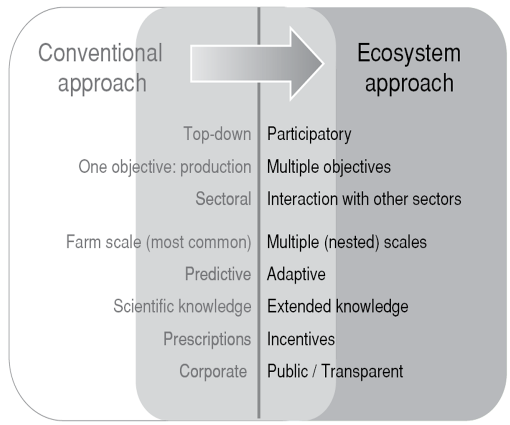
Scientific Considerations for the Future of U.S. Aquaculture

Highlights from the group discussion and breakout groups during the Roundtable.

A Framework for Aquaculture

To be considered sustainable, aquaculture should be evaluated through the triple bottom line of people (social), planet (ecological), and profit (economic). Participants noted that while "sustainability" often assumes an endpoint, it actually requires continued improvement and is an ongoing, iterative, and dynamic process. To that end, several example frameworks were discussed during the Roundtable.

There was strong consensus that the native and Indigenous Peoples' 'Seven Generations' approach to benefits and impacts is an important and valuable lens through which to calibrate sustainable aquaculture endeavors. Following Indigenous People's approaches to aquaculture, contemporary efforts can mimic natural ecosystems, use native species, and endeavor to build a community-based economy. [x] Discussion suggested that U.S. aquaculture practices could benefit from learning more about restorative and regenerative agriculture as well as permaculture approaches and increase the utilization of extension agent expertise.



Relatedly, an ecosystem approach to aquaculture, such as the Food and Agriculture Organization's framework, considers how aquaculture integrates into the wider ecosystem in such a way that it fosters sustainable development, equity and resilience within broader social-ecological systems.[xi]

Ecological Considerations

A key concern is how to curtail diseases and biosecurity risks with which aquaculture has historically been associated. Opportunities exist to manage risk, including monitoring, understanding the source of any disease, potential downstream impacts to wild populations, and proactive measures to reduce risk through ideal animal husbandry practices.

Situation	Hazard/Risk	Mitigation Approaches
Farmed fish is exotic to the area	Invasion impacts and probability	• Model risk • Use sterile fish • Domestication • Choose low risk fish • Healthy wild ecosystems
Local wild species is the same as escaped fish	Likelihood of genetic change in the wild stock leading to fitness loss	• Model risk • Maintain healthy wild populations • Use local parents • Use wild parents • Use sterile fish • Have multiple species for culture • Domestication

With respect to escapements, sterilization or other limits on the ability of aquaculture species to interbreed with native species are key factors. With respect to disease, oceanographic and epidemiological models could be coupled to project how disease vectors travel in the ocean to minimize the risk of disease spread.

Determining appropriate aquaculture siting will require modeling current conditions and should take into consideration the future of that environment, particularly with respect to climate change. Siting decisions may also be made based on the operations' proximity to endangered species to help avoid issues such as entanglements.

Determining the right feed recipe and feeding protocols are vital, in order to maximize feeding efficiency for target species and minimize effects on other species and habitat. As with the poultry industry, feed guidelines may need to be revisited on a periodic basis.

Climate change and plastic pollution may affect aquaculture from a physiological lens. Elevated temperatures and acidification can decrease the shell strength of scallops. Microplastics (synthetic particles < 5mm), which come in the form of beads, flakes, and fibers, are often consumed by organisms because they are mistaken for food. Additional research is needed on microplastics in shellfish to enhance our understanding of the effects on aquacultured species and human health. [xii]

Economic Considerations

There are several economic and technological opportunities and trends in U.S. seafood production relevant to aquaculture. Technological advancements in aquaculture could increase the amount of automation in practice, while offering opportunities to co-locate farms with other offshore endeavors such as wind farms. Ultimately, these novel changes could foster the growing interest in certain fishing communities to supplement seasonal incomes by supporting other on-water enterprises and increase domestic seafood production.

Species	Status
Spotted Wolffish	Experimental
Southern Flounder	Experimental
Summer Flounder	Experimental
Tripletail	Experimental
Greater Amberjack	Experimental
Spotted Seatrout	Technologically Feasible
California Halibut	Technologically Feasible
Almaco Jack	Commercially Ready
California Yellowtail	Commercially Ready
Black Sea Bass	Commercially Ready
Cobia	Commercially Ready
Atlantic Cod	Commercially Ready
Striped Bass	Commercially Ready
White Seabass	Commercially Ready
Red Drum	Commercially Ready
Florida Pompano	Commercially Ready
Sablefish	Commercially Ready

One approach to determining species viability is to measure a fish's "Technological Readiness Level" (a term borrowed from NASA). [MOU2] As noted above, a marine finfish aquaculture scoping workshop and survey conducted in 2017 identified 17 species that could potentially be farmed. [xiii]

It would be valuable to build on previous research and continue to compare trade-offs among different forms of protein production to understand how food can meet demand while simultaneously mitigating as many environmental consequences as possible. [xiv]

Social Considerations

Engaging coastal community needs, values, and wellbeing in planning, siting, and other decision-making for aquaculture expansion can help foster inclusion of aquaculture in mixed coastal livelihoods particularly among fishing groups, supplement seasonal incomes, support other on-water enterprises, and increase domestic seafood production.

Research is needed to learn more about coastal community perceptions around aquaculture. People's experiences with aquaculture as a benefit or harm are highly variable. As aquaculture and related policies evolve, active engagement with and opportunities for participation by marine and coastal stakeholders where aquaculture operates are important.

Aquaculture is an Indigenous practice in many parts of the world, including Hawaii where ancestral fish ponds are being revived as part of a larger ecosystem approach to land and ocean management. As a result, social license is high, efforts focus on native species/natural processes, and ecosystem benefits abound.

Given the number of hatcheries managed by states and First Nations, discussions revealed a need for greater public understanding of the role this type of aquaculture already plays in finfish production, especially along the West Coast. Additionally, social license, community-focused economic benefit, and Indigenous traditions around a seven-generation approach to managing fisheries can provide a useful framework for aquaculture operations.

Climate Change Impacts

It is clear aquaculture is not immune to climate change, but the scale of impact is less certain. The impacts and management strategies cross-cut the three themes of sustainability, and plans for adaptation should be included in any aquaculture development.

Overall, without adaptive measures, aquaculture production of bivalves and finfish are likely to decline due to extreme temperatures and acidification --which can decrease shell strength --along with a suite of other co-occurring climate-linked threats, such as sea level rise and floods, severe storms, harmful algal blooms, and stress-induced disease outbreaks. Climate change may also affect some farmed seaweeds, which have potential to sequester carbon and mitigate some local effects of acidification and low oxygen in marine environments. There are ways to adapt to changing conditions through better management and governance, support for integrated systems (e.g., seaweeds next to finfish), selective breeding, flexible siting, and selecting diverse species that are more tolerant to different conditions. Importantly, better forecasting and monitoring of these systems are also sorely needed if any adaptive strategies are going to be effective.

Conclusion

The Roundtable was convened to envision and identify science-based components for future sustainable aquaculture efforts that contribute to a healthy ocean environment, thriving coastal communities, and food security. Discussions centered around scientific and technological advancements, holistic and integrative approaches, and community buy-in, or social license, that is needed to ensure a healthy ocean, thriving coastal communities, and food security.

A major goal of this Roundtable was to bring together policymakers, federal agency representatives, and scientists to exchange ideas, engage in dialogue, and build new working relationships. As the federal dialogue continues around the role of U.S. aquaculture, we hope that scientific expertise and the wisdom of Indigenous People have a seat at the table. We appreciated the insights from our legislative and executive branch colleagues, as well as the time and effort from our scientific experts who attended. A special thanks to the Meridian Institute for their partnership on facilitation, and to the COMPASS team including Lori Arguelles, Kacey Hirshfeld, Heather Mannix, Stephen Posner, and Priya Shukla (Policy Engagement Fellow).

Participants

Participants included scientists and practitioners who study the ecological, economic, and social aspects of nearshore and offshore aquaculture as well as staff members from key agencies involved in the implementation of aquaculture policies and regulations. In addition to those listed below, COMPASS Capitol Hill staff members shared their insights.

Michael Chambers	*University of New Hampshire*
Barry Costa Pierce	*University of New England*
Linda D'Anna	*University of North Carolina, Chapel Hill*
Megan Davis	*Florida Atlantic University*
Halley Froehlich	*University of California, Santa Barbara*
Steve Gaines	*University of California, Santa Barbara*
Karen Gray	*GreenWave*
Kurt Grinnell	*Jamestown S'Klallam Tribal Council*
Hauke Kite-Powell	*Woods Hole Oceanographic Institution*
Sarah Lester	*Florida State University*
Kelly Lucas	*University of Southern Mississippi*
Jacqueline Padilla-Gamiño	*University of Washington*
Mike Rust	*National Oceanic and Atmospheric Administration*
Guillaume Salze	*KnipBio, Inc.*
Michael Tlusty	*University of Massachusetts, Boston*
Kawika Winter	*University of Hawai`i at Mānoa*

Paul Doremus	*National Oceanic and Atmospheric Administration*
Jennifer Molloy	*Environmental Protection Agency*
Brett Koonse	*U.S. Food and Drug Administration*
Caird Rexroad	*Agriculture Research Service/U.S. Department of Agriculture*

Appendix I

Federal Agency Roles and Responsibilities

Several federal agencies have various roles and responsibilities related to aquaculture, and efforts are also coordinated through the National Science and Technology Council (NSTC) Interagency Working Group on Aquaculture (WGA). Co-chairs of the working group include the White House Office of Science and Technology Policy, the Department of Commerce's National Oceanic and Atmospheric Administration, and U.S. Department of Agriculture's Agricultural Research Service. Additional members of the NSTC's WGA include the Army Corps of Engineers, Department of Interior, Food and Drug Administration, Environmental Protection Agency, and Office of Management and Budget. Two of the three co-chairs participated in the Roundtable as did half of the agencies.

Highlights of participating agencies roles include:

- The **National Oceanic and Atmospheric Administration (NOAA)** is an agency rooted in the science-based management of marine resources and oftentimes helps translate that science for policy purposes by developing decision-making tools. NOAA oversees aquaculture operations through its Fisheries program, where it supports research (e.g., through grant-making programs like Sea Grant) and policymaking at the federal level to monitor sustainable seafood production efforts.

- The **Environmental Protection Agency (EPA)** has several key roles related to aquaculture, including regulating point source discharges under the Clean Water Act National Pollutant Discharge Elimination System (NPDES) program, and working with state programs authorized to also implement the program. EPA also collaborates on fish contamination studies, and develops guidance on fish and shellfish consumption for state, local, regional and tribal environmental health officials to help inform their fish advisories. EPA also plays review and comment, repository, and public notice roles for other federal agencies under the National Environmental Policy Act

- The **United States Department of Agriculture (USDA)** conducts research and develops technology to help problem-solve any issues that stakeholders are facing. The USDA houses the Aquaculture Research Service, which specifically examines the biology and genetics of farmed animals and experiments with methods to increase yield, efficiency, quality, and food safety. The USDA also attempts to generate data that may be useful to the policymaking process and offers funding opportunities for novel and pertinent aquaculture research.

- The **Food and Drug Administration (FDA)** works with government agencies and aquaculture enterprises to regulate food safety. Specifically, the FDA approves which therapeutics/antibiotics can be used in aquaculture and then provides training and protocols to minimize biosecurity risks at aquaculture facilities.

Appendix II

Legislative Roles and Responsibilities

A panel of staff members from Capitol Hill discussed their perspectives on how science and scientists can effectively contribute to federal policy dialogues around aquaculture. Main topics of discussion included:

- Overview of the state of aquaculture legislation on Capitol Hill and office and committee interest and jurisdictions.
- Opportunities and best practices for scientists to engage with legislative staff, including the ways in which Capitol Hill staff typically use and access scientific information.
- Outstanding science questions that staffers hear and are wrestling with when it comes to developing marine aquaculture in the United States.

Staff members discussed the current state of the aquaculture discussion on Capitol Hill. Interest in aquaculture was revived in 2017 by Senator Wicker, who subsequently introduced the 2018 AQUAA bill. The group discussed various perspectives on aquaculture including the possibility of closing the national seafood deficit through increased domestic aquaculture. There was significant discussion of an “environmental bonus”, the idea that operating in the United States with stricter environmental regulations would be an advantage over countries operating with fewer regulations. The group discussed how to engage non-coastal states in the discussion. In particular, alternate feeds have been a potential option for collaboration as non-coastal states could benefit from producing soy beans or other ingredients as a feed source.

Staff members shared that some key scientific questions continue to be raised in these discussions. In particular, questions about feeds, escapes, disease and how communities will be affected by offshore aquaculture were common. Questions also arose about which species are technologically ready to be utilized in aquaculture operations in federal waters and the scalability of aquaculture offshore.

All participating congressional staff members emphasized the importance of engaging scientists and using science in aquaculture discussions and policy frameworks.

Appendix III

<u>Scientific Insights</u>

Steve Gaines: *Role of aquaculture for food security on a national and global scale*
By 2050, nearly 10 billion people are expected to share this planet, which combined with growth in wealth will double the demand for animal-derived protein. Achieving this would require converting 5 billion acres of land which would release several gigatons of greenhouse gases. However, the ocean offers opportunities to grow protein with a smaller footprint. For example, to fulfill worldwide protein needs with just goats and sheep, you would need a tract of land the size of South America. In contrast, you could produce the same volume of protein with mussels using a stretch of coastline equivalent to New Zealand's.

Hauke Kite-Powell: *Economic perspective on the trends and opportunities in aquaculture*
There are several opportunities and trends in U.S. Seafood production. While there is growing interest among aquaculturists to cultivate seaweeds and shellfish at larger scales, certain municipalities (e.g., in New England, Southern California) are also providing permits to perform aquaculture at smaller scales that circumvent some of the more financially and logistically complex regulatory components. Additionally, technological advancements in aquaculture could increase the amount of automation in practices, while offering opportunities to co-locate farms with other offshore endeavors (e.g., wind farms). Ultimately, these novel changes could foster the growing interest in certain fishing communities to supplement seasonal incomes by supporting other on-water enterprises and increase domestic seafood production.

Barry Costa-Pierce: *Framing for an ecosystems approach to aquaculture*
The FAO's ecosystem approach to aquaculture considers how aquaculture integrates into the wider ecosystem in such a way that it fosters sustainable development, equity and resilience within the broader wider social-ecological systems. Achieving this requires not only technological advancements but also social-ecological research that actively involves stakeholders and First Nations in the outcomes of this approach and the process. For example, these groups have identified aquaculture's presence on surface waters conflicts strongly with the existing marine transportation economy and tourism of many places by impairing the transit and viewsheds of communities. Aquaculture engineering advances in subsurface systems gain an accelerated social contract by not only reducing obstructions, they are better able to weather storm surges due to their separation from high energy surface waves.

Kelly Lucas: *Exploring species most likely to be ecologically and economically successful*
Certain finfish species could feasibly be farmed in U.S. coastal waters based on economic and ecological parameters. A marine finfish aquaculture scoping workshop and survey conducted in 2017 identified 17 species that could potentially be farmed. While 5 are considered "experimental", 2 are "technologically feasible", and 11 are "commercially ready". However, to bring a "commercially ready" species to market requires considering a given fish's biology, the aquaculture environment, social dynamics, broodstock genetic requirements, production capacity at hatchery facilities, the land-based infrastructure available to support in-water operations, transportation needs, feeds, whether there even is market demand, and the general economic landscape.

Megan Davis: *Exploring the similarities between wild-caught fisheries and aquaculture*
Aquaculture and wild-caught fishing industries can share the seafood landscape. U.S. fisheries and aquaculture have a shared language that centers around management via sound science:

protecting ecosystem health and biological diversity, maintaining clean waters, and fostering technological advancements. This also applies to social dynamics: job creation and workforce development, economic and social welfare, resilience in working waterfronts, vibrant coastal communities, and the production/consumption of high-quality seafood. Thus, there are opportunities for mixed livelihoods -- fishers have extensive knowledge about the ocean and environment which make them an excellent asset to aquaculture, while aquaculture can provide seasonal jobs to fishers when they are not actively on the water.

Sarah Lester: *Science of siting and ways to facilitate decision-making and understand trade-offs*
Two categories of spatial planning analyses can be used when siting aquaculture operations to account for other ocean uses as well as environmental concerns and socio-economic values: (1) an absolute constraints analysis identifies locations as either available or closed to aquaculture based on spatial data layers and criteria related to regulatory, technological, environmental, and/or biological factors, and (2) a trade-off analysis (based on economic theory) identifies a suite of prospective spatial plans that balance multiple objectives, collectively maximizing aquaculture benefits while minimizing negative impacts on the environment and other ocean uses and management priorities.

Michael Tlusty: *Practical scientific aspects of aquaculture permitting and monitoring*
Sustainable aquaculture requires a practical approach to monitoring. Specifically, aquaculture has multiple impacts, but it is valuable to consider which is the most limiting (i.e., what factors will most greatly impact successful implementation). This is especially important when farming in offshore environments (e.g., factor could be storm surges or proximity to endangered species). Thus, an appropriate space and site-specific factors that need to be monitored must be identified before permitting, implementation, and regular monitoring can occur.

Linda D'Anna: *Exploring the social science components of aquaculture in communities*
Understanding the complexity and context surrounding perceptions about aquaculture (tied to experiences, economy, environment) is important for increasing social license. People's "experiences" with aquaculture as a benefit or harm are highly variable. And, there is much uncertainty about the environmental consequences of aquaculture. Even where there is broadly positive consensus, as around the "economic" aspects, questions remain for coastal communities, including whether aquaculture employment will adequately support local community members over the long term. Thus, in framing aquaculture policy, we must focus on measuring values and determine who decides which local concerns matter.

Kawika Winter: *Re-learning from our ancestors: the secrets to success of Hawaiian fishpond aquaculture*
Hawaiians have been practicing fish pond aquaculture for over 1000 years which has sustained more than one million people. Hawai'i supports six different kinds of aquaculture, including inland, coastal and reef ponds where they grow mostly mullet and milkfish. Thus, there is social license for aquaculture in Hawai'i, because Hawaiians see themselves as part of the ecosystem. The focus is on freshwater, which comes to the Island via rain and both collects and strains sediments through a combination of natural landscapes. Additionally, nutrients that are collected on the way to the fishponds are consumed there, releasing clean water devoid of sediment and nutrients into the local reef. Contemporary aquaculture efforts should mimic natural ecosystems, use native species, and endeavor to build a community-based economy.

Michael Chambers: *Advancing open ocean aquaculture technologies in New England*
Single-species "monocultures" make up 95% of all aquaculture. Polyculture and integrated multi-trophic aquaculture (IMTA) often use lower trophic level species and can be consolidated onto a floating structure where seaweed and steelhead trout can grow while simultaneously collecting mussel spat. The spat lines also trap added feeds; the fish take up nutrients, while the shellfish and seaweed absorb other in/organic materials. In small-scale structures with a 1:3 finfish:shellfish ratio, all excess nitrogen can be removed. This is something that can be adopted by fishers, and the next model of this could produce 40 tons of seafood, though challenges pertaining to specific ecosystems, predators, and oceanographic dynamics would need to be considered. While these rafts are not designed for the open ocean, the small-scale units could create opportunities for finfish culture.

Karen Gray: *A community-based approach to aquaculture and models for action and equity sharing*
Greenwave's model for restorative aquaculture and equitable solutions in coastal communities consists of vertical farming systems that are implemented along the open water in an effort to provide high production with a relatively small environmental footprint (20 acre farms, with a hatchery supporting 20-25 farms). They are low-tech, low-cost subtidal farms that do not impair viewsheds and are being operated by many women. Operation also includes a 2-year online training course to become farmers and environmental stewards. Right now, barriers to more broad implementation include state-specific permitting procedures and further research and development to improve the farms' performance.

Kurt Grinnell: *A tribal perspective on investing in community health and wealth*
The Jamestown S'Klallam's tribe, whose main village is in Port Townsend off of Puget Sound (known as "Qatay") has used local waters as "highways and grocery stores" since time immemorial. They only ever harvested what was needed for food and trade and then actively protected remaining resources to ensure that enough remained for the following seven generations. Today, tribal elders do harvest clams, but in order to reclaim their ancestral diets (an act of "food sovereignty"), the tribe now operates a shellfish farm and hatchery as well as a sablefish program because of a lack of seed and low recruitment of native species.

Mike Rust: *Risk assessment and management relative to genetics and escapes*
Where a hazard is any bad thing that could happen, a risk is the likelihood of a hazard occurring. We can mitigate these risks and also evaluate the benefits we gain by taking those risks. When we engage in aquaculture, there is the risk of fish escaping. Non-native Atlantic salmon had been farmed in the Pacific Ocean for 40 years before escapes occurred while endangered species recoveries were in progress. When thinking about this risk, the environment is part of the equation. For example, is the escaped animal even fit for the environment? Many things could eat these fish. But, of course there are economic and political risks in doing non-native finfish culture, but there are opportunities to mitigate the risk too.

Guillaume Salze: *New technology, science and trends in fish feeds*
Fishmeal is a frequent talking point when it comes to the nutritional quality of feeds. While feeds from 20-30 years ago consisted primarily of fishmeal, today's feeds contain much less thanks to two decades of research to find suitable alternatives. Proteins in contemporary feeds can come from non-fish sources including plants and microbes. While the Fish-in Fish-out (FIFO) ratio in the 80s and 90s was about 5:1, now it's as low as 1:2. Nevertheless, fishmeal is an ingredient, and as such is not required. Nutrients (proteins, lipids, vitamins, and minerals) are what's needed and

ingredients are but means to supply those nutrients. So, determining which combinations of ingredients are best for each cultured species is the true challenge.

Jacqueline Padilla-Gamiño: *Human impacts affecting aquaculture: case studies in acidification and pollution*
Climate change and plastic pollution may affect aquaculture from a physiological lens. Elevated temperatures and acidification can decrease the shell strength of scallops. And, with IMTA, different species will have unique responses to environmental stressors when grown in the same area. Microplastics (synthetic particles < 5mm), which come in the form of beads, flakes, and fibers, are often consumed by organisms because they are mistaken for food. A study from the University of Washington developed the first baseline for microplastics in oysters in the US west coast. It found that 50% of sites examined had wild oysters containing microplastics. Oysters had low abundance of microplastics, but the study was only able to identify 59% of the particles. The rest of the particles (41%) were not identified due to methodological constraints (fluorescence interference).

Halley Froehlich: *Emerging research and opportunities for climate change mitigation through aquaculture*
Climate change will affect aquaculture. Overall, without adaptive measures, aquaculture production of bivalves and finfish are likely to decline due to extreme temperatures and acidification, along with a suite of other co-occurring climate-linked threats, such as sea level rise and floods, severe storms, harmful algal blooms, and stress-induced disease outbreaks. Climate change may also affect farmed seaweeds, which have potential to sequester carbon and mitigate some local effects of acidification and low oxygen in marine environments. There are ways to adapt to changing conditions through better management and governance, support for integrated systems (e.g., seaweeds next to finfish), technological breakthroughs, selective breeding, flexible siting, and selecting diverse species that are more tolerant to different conditions. Importantly, better forecasting and monitoring of these systems are also sorely needed if any adaptive strategies are going to be effective.

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