Good Food Institute

New blue foods for biodiversity

The promise of alternative seafood

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About GFI

The Good Food Institute is a nonprofit think tank working to make the global food system better for the planet, people, and animals. Alongside scientists, businesses, and policymakers, GFI's teams focus on making plant-based and cultivated meat delicious, affordable, and accessible. Powered by philanthropy, GFI is an international network of organizations advancing alternative proteins as an essential solution needed to meet the world's climate, global health, food security, and biodiversity goals. To learn more, please visit www.gfi.org.

Executive summary

The global demand for seafood is rising, and to meet that demand sustainably, we need to scale alternative methods of seafood production.

As the human population grows, incomes rise, and the average lifespan increases, so too does the demand for seafood. For the past 60 years, the global growth rate of seafood consumption has outpaced population growth, and global seafood production is now projected to increase by 14 percent (from 2020 levels) by 2030.[1] However, our marine, coastal, and freshwater ecosystems have a limited capacity to feed a growing population. While stronger governance, innovations in science and technology, and market incentives have improved the sustainability of fisheries and aquaculture in some areas, growing pressure on natural and human resources is still rapidly degrading the productivity and resilience of ocean and coastal ecosystems—and the diversity of life that depends on them.

As pressure on ocean ecosystems intensifies, biodiversity is declining across the globe. More than one million species are in danger of extinction,[2] and some scientists estimate that one-third of all plant and animal life alive today may be extinct by 2070.[3] Research suggests that protecting and restoring biodiversity will require a massive overhaul of our global food system to decrease waste and increase sustainability and efficiency.[4] And just as a diverse and sustainable food system is critical for biodiversity, biodiversity is foundational to a productive and resilient food system. Indeed, biodiversity loss can lead to food scarcity, nutritional deficits, economic insecurity, and international conflict.[5] It can even increase the risk of human exposure to zoonotic pathogens.[6]

The world is at an inflection point. A growing appetite for healthy, sustainable, and socially responsible seafood coupled with advances in bioengineering, agriculture, and food science have sparked innovations in alternative seafood (specifically plant-based and cultivated seafood).

Plant-based seafood—derived from terrestrial plants, algae, or fungi—mimics the flavor and texture of conventional seafood. By contrast, cultivated seafood is identical to conventional seafood at a cellular level but is produced by cultivating muscle and fat cells from fish (or other aquatic species).

Alternative seafood can help meet growing demand while complementing existing efforts to improve the sustainability of wild-caught fisheries and aquaculture around the world.

Support from governments, nonprofits, academia, and industry will be necessary to realize the potential of cultivated and plant-based seafood as accessible, affordable, and sustainable alternatives.

In both the public and private sectors, momentum is building to advance global solutions to curb biodiversity loss while addressing the socio-economic, environmental, and human health challenges associated with conventional seafood production. Stakeholders focused on interdependent (but often siloed) issues such as biodiversity conservation, seafood sustainability, climate resilience, food security, and sustainable livelihoods can accelerate progress across all of these areas by working together to advance alternative seafood.

By prioritizing collaboration, information sharing, financing, capacity building, consumer outreach, and governance reform, the conservation community can be influential in advancing the development, uptake, and impact of alternative seafood.

Greater support for government funding for open-access research and development of alternative proteins is a critical need. Likewise, those working to realign seafood industry subsidies with sustainable practices can call upon decision makers to give alternative seafood producers equal access to subsidies, which can contribute not only to domestic economic development and job creation but also to the protection of marine ecosystems. Broader support for more domestic production of alternative seafood can also help combat seafood fraud and mislabeling by enabling more regulatory oversight of the seafood supply chain. Meanwhile, grassroots organizations can increase consumer awareness of and demand for alternative seafood. Only with the full force of the broader conservation community and partners in the public and private sectors can alternative seafood scale fast enough to help protect and restore biodiversity.

Introduction

A growing global population is fueling an ever-increasing demand for seafood. This demand is stretching the production capacity of our ocean and coasts, threatening the biological diversity upon which a functional and stable food system depends. While there have been improvements to the sustainability of wild-capture fisheries and aquaculture, we need additional and categorically new forms of seafood production to sustainably meet current and future demand.

Plant-based and cultivated seafood (collectively "alternative seafood") can help fill the growing gap between supply and demand with a smaller environmental footprint. Plant-based seafood provides the flavor and texture of conventional seafood but is made from plants, algae, or fungi. Meanwhile, cultivated seafood (also referred to as cellular aquaculture, cell-based seafood, etc.) is the components of fish or invertebrates that people consume cultivated in a bioreactor (also called a cultivator). Cultivated seafood does not create animal waste (e.g., bones, scales, eyes, or bycatch) or contain contaminants (e.g., plastics, mercury, or polychlorinated biphenyls (PCBs). While alternative seafood production complements existing efforts to improve the sustainability of wild fisheries and aquaculture, diversifying seafood consumption patterns to include plant-based and cultivated seafood offers environmental benefits and can help stem and reverse biodiversity loss.

But how do these alternatives compare with conventional seafood?

How and to what extent can alternative seafood address the biodiversity crisis?

How can policymakers and the ocean conservation community contribute to our understanding and the advancement of alternative seafood?

This paper explores these questions and the role alternative seafood may play in protecting and restoring biodiversity. That said, the alternative seafood sector is still in its infancy. Understanding whether and how plant-based and cultivated seafood can begin to address key environmental challenges—including biodiversity loss—will require a commitment of resources and expertise from a range of stakeholders such as scientists, economists, social scientists, funders, policy makers, food system experts, and conservation advocates.

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Seafood supply and demand

The global consumption of seafood (both marine and freshwater) has increased at an average annual rate of three percent since 1961. Worldwide, the annual per capita consumption of seafood products has more than doubled over the last 60 years from 9.9 kg in the 1960s to 20.2 kg in 2020.[7] In response to this growing demand, total fisheries and aquaculture production reached an all time high of 214 million metric tons in 2020, of which 73 percent (157 million metric tons) was for direct human consumption. While aquaculture production grew to a record high of 122.6 million metric tons in 2020,[8] global capture fisheries production decreased by four percent compared with the average of the previous three years to 90.3 million metric tons.[9] In addition to the impacts associated with the COVID-19 pandemic, this decline is indicative of the fact that marine-capture fisheries have little room for further growth: an estimated 93 percent of global fish stocks are either fished at maximum sustainable levels (57.3%) or overfished (35.4%).[10] Increasingly, people are looking to aquaculture to fill the growing gap between supply and demand. Indeed, total aquaculture production rose by 527 percent between 1980 and 2018,[11] but while aquaculture remains one of the fastest-growing food production sectors, annual growth has declined since its peak in the 1980s and 1990s.[12]

Driven by strong global demand, the value of the global seafood industry continues to grow (estimated value in 2020 was $151 billion), however the global seafood market is characterized more by value growth than volume growth.[13,14] Despite the increasing value and demand for seafood, seafood production is precarious and risk-laden. Globally, seafood consumption is growing at an annual rate of 3.1 percent,[15] but supply is only expected to grow at an annual rate of 1.3 percent over the next decade.[16] Geopolitical uncertainty, trade tariffs, climate change, and the limited production capacity of wild populations and ecosystems threaten the productivity and resilience of both aquaculture and wild-capture fisheries.[17]

Echoing the global trend, U.S. consumer demand for seafood has steadily risen over the past decade. In 2020, Americans consumed 19 pounds of seafood per capita, an increase of three pounds from 2017.[18] Yet this is still just over half of the U.S. Dietary Guidelines' recommendation. Both the U.S. committee responsible for the Dietary Guidelines and the United Nations Food and Agriculture Organization (UN FAO) agree that to meet this weekly recommendation, aquaculture production would have to increase rapidly and substantially. Alternative seafood—and particularly cultivated seafood, which has the same nutritional profile as and fewer contaminants than conventional seafood—could help fill that gap.

Biodiversity and seafood production

Ocean and coastal environments offer a range of ecosystem services upon which life depends—from the oxygen we breathe to the food we consume, to the water we drink. However, anthropogenic pressures are driving an unprecedented decline in global marine biodiversity, and the loss of genetic, species, and ecosystem biodiversity threatens the productivity and resiliency of ocean ecosystems.[19] The primary drivers of marine biodiversity loss include habitat destruction and modification as well as direct exploitation from unsustainable fishing practices. Meanwhile, the cumulative effects of other stressors (including climate change and ocean acidification) are compounding and accelerating biodiversity loss in ocean and coastal habitats around the world.[20]

While there have been efforts to stem the tide of biodiversity loss via protected areas, habitat restoration, species conservation, enhanced research and monitoring, and other interventions, evidence indicates that marine biodiversity continues to decline. A 2019 report from the Intergovernmental Platform on Biodiversity and Ecosystem Services noted that humans have significantly altered

two-thirds of the ocean, which is up from 40 percent in 2008.[21] To reverse this trend in biodiversity loss, new and novel strategies are needed. Alternative seafood offers an opportunity to diversify seafood production, reduce our environmental footprint, and restore marine biodiversity and ecosystem functionality.

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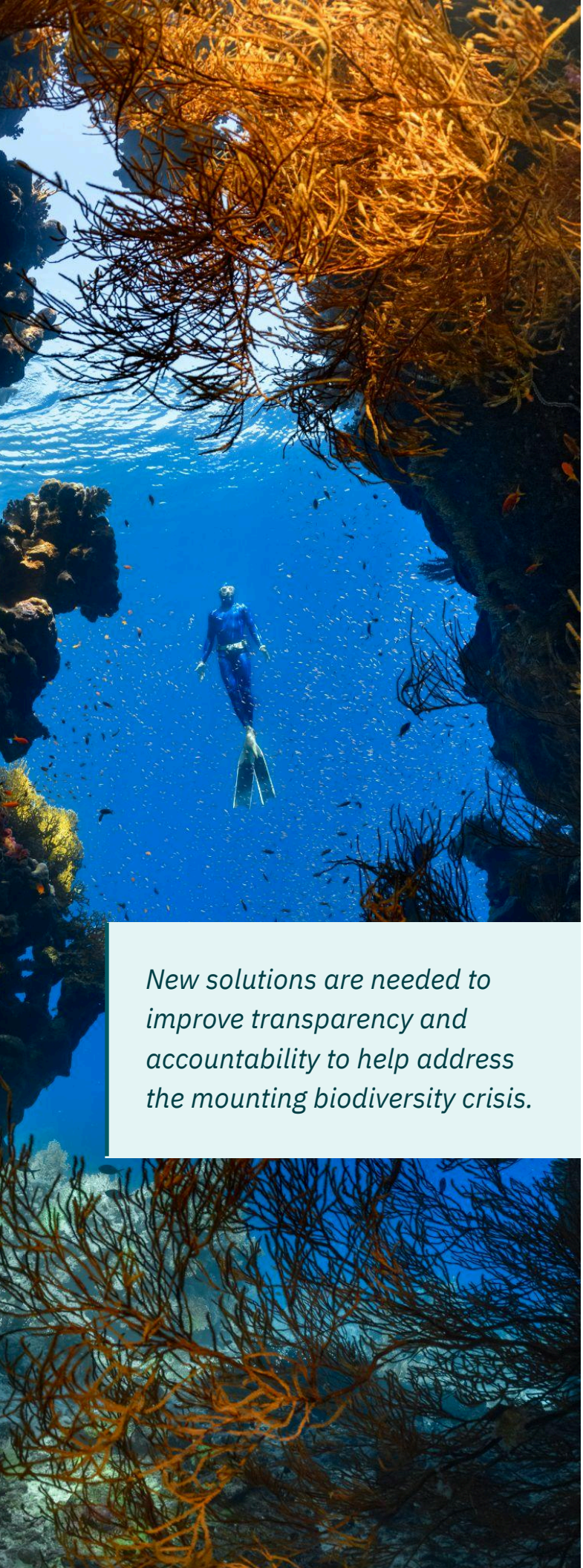
The challenges of conventional seafood

Globally, the seafood industry has contributed to the economic and food security of millions of people while shaping the history and culture of many regions. Increasingly, however, growth in the commercial seafood sector is coming at the expense of ocean health, human rights, and food security. As marine resources become scarcer, some are capitalizing on the opacity of the sector and turning to unfair and exploitative labor practices to lower costs and increase profits. In recent years, there has been heightened scrutiny around the issues of slavery, unfair labor, and worker abuse in the seafood industry.[22] Human rights and labor abuses, while often driven by greed, corruption, socio-economic and cultural inequities, and deteriorating economic conditions, are closely linked to environmental degradation and biodiversity loss.

The UN FAO recognizes that both capture fisheries and aquaculture face major challenges, ranging from weak governance and poor management to unsustainable fishing practices and illegal, unreported, and unregulated (IUU) fishing.[23] The UN classifies government subsidies that exacerbate these challenges as "harmful subsidies." The sector has made progress in improving management, transparency, and accountability. Nevertheless, the global patchwork of laws and treaties governing fisheries and aquaculture—combined with the lack of enforcement in many places—makes it difficult for



New solutions are needed to improve transparency and accountability to help address the mounting biodiversity crisis.

consumers, brands, and policymakers to verify the sustainability of different products and make informed decisions. New solutions are needed to improve transparency and accountability to help address the mounting biodiversity crisis.

Wild-capture fisheries

Wild-capture fisheries represent one of the last vestiges of humans' hunting and gathering past. Unsustainable fishing practices, however, are a key driver of marine biodiversity loss globally.[24] Overfishing, illegal fishing, habitat loss, and degradation, as well as the incidental catch of non-target species (bycatch) and discards can alter ecosystem dynamics and decrease genetic, species, and ecosystem biodiversity. These stressors are compounded by the impacts of climate change, ocean acidification, coastal development, plastic pollution, eutrophication, and noise pollution in an increasingly industrialized ocean space.

The biodiversity impacts of wild-capture fisheries are highly variable and depend on the type of gear being used, the biological community where fishing is occurring, and the magnitude and frequency of fishing activities. One-by-one fisheries (e.g., harpooning, polling, and handlining) tend to be among the most selective and lowest impact forms of fishing but are limited by the target species which tend to be larger pelagic species such as tuna and swordfish. Bottom-tending mobile gear like scallop dredges and bottom trawlers can adversely impact benthic biodiversity by disturbing the seabed and damaging or destroying benthic structures and the species associated with those structures. Static fishing gear such as pots, traps, nets, and longlines can also have significant impacts on marine biodiversity. As with mobile gear, static gear can increase sediment suspension and cause changes to the benthic community and to the physical structures within those communities.[25]

It can also lead to bycatch and entanglement of non-target fish and marine wildlife (e.g., marine mammals, sea turtles, and seabirds). Meanwhile, gear like longlines and purse seines that target highly migratory pelagic species often have high levels of bycatch of juveniles and vulnerable marine wildlife.

While efforts to innovate and adapt fishing gear to mitigate these impacts are ongoing, the collective impact of wild-capture fisheries is negatively affecting marine biodiversity and interfering with ecosystem functionality at local and global levels.

Aquaculture

As the volume of wild-caught seafood has plateaued, aquaculture production is increasing to meet the growing demand for seafood in the United States and abroad.[26] Aquaculture now accounts for half of the global seafood supply[27] and nearly half of the seafood imported to the United States.[28] Marine, freshwater, and brackish (coastal) aquaculture systems are not monolithic and vary by species and geography. They range from fish ponds, pens, and cages to rafts, ropes, and stakes for molluscs and seaweed. Depending on the stocking density of organisms, the level of inputs, and the degree of management, aquaculture systems can range from extensive to intensive.

The rapid expansion and diversification of aquaculture globally have outpaced many governments' capacity to develop strong management frameworks and mitigate environmental impacts. Where governance is lacking, market-based incentives, such as certification and rating programs, are creating standards and providing guidance to support more sustainable aquaculture and inform good governance. Even so, as aquaculture intensifies it becomes clear that aquaculture alone cannot reliably and sustainably fill the supply gap.[29]

As aquaculture operations struggle to maximize growth efficiency and minimize costs, they encounter a variety of sustainability and biodiversity challenges. When poorly managed, aquaculture can have global biodiversity impacts through demand for fish feed as well as localized impacts from production operations. Poor siting decisions and operational management can damage coastal wetlands and nearshore habitats by adding feed residues, waste, antibiotics, hormones, diseases, and alien species to the local environment.

New modes of seafood production

Diversifying our food system to include new modes of sustainable, healthy, and socially responsible seafood production is critical to close this gap between supply and demand and to minimize the above stressors on marine biodiversity. Both plant-based and cultivated seafood offer an opportunity to do just that.

Plant-based seafood

While plant-based products have been on the market for decades, the category is evolving rapidly, and the consumer trend towards more conscious consumption is accelerating the diversification of plant-based proteins, including seafood. Eyeing the popularity of plant-based meat (e.g., the Impossible Whopper and Beyond Burger), brands are developing plant-based products that provide the taste and texture of seafood but eliminate or mitigate the environmental and health risks associated with conventional seafood: heavy metal and micro-plastic contamination, antibiotic use, food-borne illnesses like ciguatera, and allergenicity. U.S. food producers, including giants like Tyson Foods, Cargill, and General Mills are taking note and producing or investing in plant-based proteins. However, this is not limited to terrestrial meat alternatives. For instance, Bumble Bee Foods is partnering with emerging plant-based seafood companies to diversify their own portfolios, meet their sustainability commitments, and stay ahead of the competition.

Plant-based seafood is made with a broad range of processes and ingredients. The inputs vary widely and currently include soy, wheat, legumes (including pea protein), tomatoes, eggplant, seaweed, and konjac, among others. The biodiversity implications and the magnitude of environmental impacts differ across product categories and are influenced by the crops being farmed, geography, the production and harvest methods, and the scale of production, among other factors.[30] This variability applies even within specific product categories, which makes it difficult to generalize across a class of crop (e.g., soy or wheat). Further, there is limited research comparing

plant-based seafood's impacts to those of conventional seafood, with available data largely based on comparisons between plant-based proteins and farmed seafood.

While more research is needed to evaluate the relative impacts on biodiversity across and within different modes of seafood production, we can look at environmental indicators like land use and greenhouse gas (GHG) emissions that are associated with different crops in aggregate to draw some general conclusions about the relative biodiversity impacts of plant-based seafood production.

Cultivated seafood

Cultivated seafood (also referred to as cellular aquaculture, and cell-based and cell-cultivated seafood) is produced by directly cultivating the muscle and fat cells of fish, mollusks, or crustaceans. This production method replicates the internal biological processes externally, by cultivating a sample of muscle and fat cells with amino acids, salts, vitamins, fats, and other key nutrients needed to foster growth.[31] Essentially, it is seafood without the marine animal.

Proponents of cultivated seafood contend that this emerging sector could contribute to the conservation of endangered, threatened, overfished, and otherwise vulnerable marine and aquatic species. Creating cell lines from these species could reduce the economic and environmental pressures from fisheries and aquaculture. Diversifying the supply with cultivated sources of this seafood could limit the profitability of IUU seafood.

Whether cultivated seafood can help address the biodiversity crisis depends on its environmental footprint (locally and at scale) as well as if cultivated products can displace some of the demand for conventional seafood. Since the industry is still nascent, the biodiversity impacts of cultivated seafood production remain largely unknown. What research does exist treats cultivated seafood as analogous to cultivated meat since they use similar inputs and infrastructure. The biggest possible biodiversity risks from cultivated seafood production stem from impacts associated with land use and GHG emissions in the absence of clean energy infrastructure, while the biggest potential benefits stem from its ability to decrease pressure on marine species and habitats.

Opportunities to safeguard biodiversity through alternative seafood

While the biodiversity impacts of wild-capture fisheries and aquaculture are well documented, generalizing across these sectors is difficult because the specific impacts vary depending on the region, species, fishery, and mode of production. In the absence of more comprehensive comparative data on conventional seafood, we examine four specific opportunities to mitigate the broader environmental impacts of the sector as they relate to biodiversity conservation—with the caveat that not all impacts discussed below are relevant for all species or all production methods.

1. Protect and restore marine species.

Alternative seafood enables us to increase the global supply of seafood without increasing pressure on wild fish stocks. This creates myriad opportunities to better safeguard ocean biodiversity—from reducing overfishing and IUU fishing to minimizing the associated habitat impacts, bycatch, and ghost gear. Aquaculture also carries risk to wild populations and marine ecosystems through demand for fish feed as well as escapes, entanglement, and contamination. While many look toward aquaculture to fill the growing supply gap, leveraging alternative seafood could help us avoid increasing aquaculture's adverse impacts on marine biodiversity.

Conserve and rebuild overfished stocks

Reducing the systemic pressures that drive overfishing is critical to safeguard marine biodiversity, and adding new methods of production by making seafood from plants or directly from cells can reduce these pressures. A 2020 UN FAO report estimated that 34 percent of global fish stocks are overfished,[32] while another 60 percent are fished at maximum sustainable levels.[33] Conservationists agree that overfishing not only contributes to the loss of species diversity but can also disrupt trophic interactions (like predator–prey relationships), interfere with ecosystem functionality, and

decrease fish production. For example, more than one-third of all cartilaginous species (e.g., sharks, rays, and chimaera) are at risk of extinction due to overfishing.[34] Because many sharks and rays are keystone species and apex predators, their loss can destabilize food webs and trigger cascading impacts throughout marine ecosystems.

Ending overfishing and rebuilding overfished stocks are formidable challenges that will require multipronged interventions from both the public and private sectors. An important component is building up an alternative supply chain for seafood production that can reduce pressure on fisheries. According to the World Bank, global fishing effort will need to decline by five percent per year over a 10-year period to allow fish stocks to rebuild to sustainable levels. But, as the demand for seafood increases, so too do the economic and political pressures to increase fishing effort.[35] Plant-based and cultivated seafood can help minimize those pressures.

Reduce wasteful bycatch and discards

Investing in an alternative seafood supply chain also presents an opportunity to reduce collateral impacts on non-target fish and wildlife. Bycatch, or the incidental capture and/or mortality of non-target species, is one of the principal threats to marine biodiversity. While non-target species with subsistence or commercial value are sometimes retained, frequently non-target fish and wildlife that are of low value or prohibited by regulations, are discarded dead or dying. Together, bycatch and discards make up an estimated 16 to 32 percent of seafood waste.[36] Discards alone account for approximately 10 percent of the world's annual catch.[37, 38] In the United States, as much as two billion pounds (roughly 20 percent of the total catch) of fish are discarded by U.S. fisheries each year.[39] This volume of marine wildlife loss amounts to an annual economic loss of at least $1 billion for the United States.[40] Because alternative seafood production results in neither bycatch nor discards, its adoption could alleviate global seafood production waste and biodiversity loss.

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Minimize biodiversity loss from ghost gear

Reducing the amount of new and existing fishing and aquaculture gear in coastal and marine ecosystems could help protect biodiversity, with positive ecological effects for decades or even centuries. Each year, up to one million tons of fishing gear is abandoned, lost, or otherwise discarded, becoming "ghost gear."[41, 42] Drifting aimlessly, ghost gear kills approximately 136,000 seals, sea lions, and large whales every year.[43] Birds, turtles, fish, and other species are also injured and killed through entanglement or ingestion.[44] Scientists for the National Oceanic and Atmospheric Administration (NOAA) caution that ghost gear can also damage ecologically important and sensitive marine habitats like coral reefs, seagrass beds, and mangroves, exacerbating marine biodiversity loss.[45] Ghost gear also reduces fishery yields and income. One study of the Washington state Dungeness crab fishery estimated an annual loss of 178,874 legal crabs with an ex-vessel value of $744,296 from lost crab traps.[46] While improving fishing gear (e.g., on-demand technology for fixed gear fisheries) and incentivizing gear retention (e.g., creation of markets for recycled and upcycled fishing gear) can also help address these challenges, scaling alternative seafood production may lead to a reduction in the volume of ghost gear and associated mortalities and help keep fishery yields at sustainable levels.

Increase wild capture seafood supply transparency and accountability

The United States imports 62 to 65 percent of its seafood,[47] often from countries that lack rigorous governance systems and enforcement capacity to manage fisheries sustainably.[48] Increasing domestic seafood supply through alternatives and shortening the seafood supply chain could increase supply chain transparency and decrease U.S. economic support of IUU fishing. IUU fishing includes fishing activities that break the law (illegal), fail to disclose catches to authorities (unreported), and occur beyond the jurisdiction of fisheries management (unregulated). One study estimated annual global losses associated with IUU fishing from unsustainable fishing practices, destructive and indiscriminate gear, and catches that include vulnerable or protected species to be up to $23.5 billion, representing 26 million tons of fish—or one in five wild-caught fish.[49] Building a robust domestic supply of alternative seafood can support a transition away from IUU sources abroad and help level the competitive field for responsibly managed domestic fisheries. Specifically, reducing the demand for seafood from IUU fishing would help level the playing field for fishers who follow the law and support public efforts to conserve and sustainably manage marine resources. Moreover, since the catch associated with illegal fishing goes unreported, reducing it would also contribute to more accurate total catch estimates and population assessments, which are needed to manage fishery resources sustainably.

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Reduce aquaculture escapes, contamination, and wildlife mortality

Shifting production toward alternative seafood and away from less sustainable forms of aquaculture may mitigate the impact of seafood production on marine ecosystems and wildlife populations. For instance, open net pens (such as those used to farm salmon) can compromise the surrounding environment through the free exchange of chemicals, waste, parasites, and disease—all of which can harm biodiversity. Like certain types of fishing gear and ghost gear, aquaculture operations, including net pens and even vertical lines used to grow shellfish and seaweed, can attract, entrap, entangle, drown, and otherwise interfere with marine wildlife including seabirds, sea turtles, and marine mammals.[50]

When net pens or ponds are connected to adjacent natural bodies of water, fish can escape and mix with wild populations. Scientists warn that the presence of non-natives can interfere with the natural behavior of wild populations and even threaten their survival by increasing competition for food, habitat, and spawning partners. Reproduction between farmed and wild populations can also compromise the genetic integrity of wild populations and decrease their ecological fitness. Where these escapees establish and reproduce successfully, they become invasive species. Even without escaping, farmed fish can spread diseases and parasites such as sea lice to wild populations.[51] By contrast, neither cultivated nor plant-based seafood pose a risk of genetic contamination or disease spread as production occurs in a clean and contained facility.

Decrease marine resource needs for aquaculture feed production

Feed likely accounts for more than 90 percent of environmental impacts associated with aquaculture.[52] One of the main challenges of aquaculture, particularly in the case of carnivorous species like salmon, is that the feed requirements can exacerbate rather than relieve pressure on wild fish populations. Approximately 20 to 35 percent of wild-capture fishery landings become fishmeal and fish oil for feed in aquaculture and terrestrial animal

agriculture. In 2018, approximately 10 percent (18 million tons) of wild-capture fish was used for fishmeal and fish oil,[53] and the Marine Ingredients Organization (IFFO) estimates that 75 percent of that was destined for aquafeed. Moreover, two-thirds of current aquaculture production relies on fishmeal additives, an increase of 10 percent since 1980.[54] Meanwhile, neither plant-based nor cultivated seafood rely on marine-based aquafeed.

2. Decrease habitat transformation, land use, and associated emissions

For both aquaculture and alternative seafood production, the metric most closely linked to biodiversity loss is land use and habitat conversion. Similarly, wild-capture fisheries can affect the seafloor habitat. Where habitat transformation occurs, GHG emissions typically follow. Increasingly, climate change and ocean acidification—the result of increasing levels of carbon in the ocean and atmosphere—is also driving biodiversity loss and acting as a threat multiplier.[55, 56]

Land use in aquaculture and alternative seafood is a function of both the land used to support direct production of plant-based and farmed seafood as well as the land use associated with the production of plant-based feed (for aquaculture and cultivated seafood). Growing or processing food generally reduces an ecosystem's biodiversity, while driving GHG emissions (mainly carbon dioxide, nitrous oxide, and methane), which further threaten biodiversity. In general, animal products have larger land and carbon footprints per calorie than grain or vegetable products.[57] This difference is in part due to the inefficient conversion of feed calories to animal product calories.[58] For instance, it requires 100 grams of feed protein to produce 20 grams of chicken protein or 15 grams of protein from farmed shrimp.[59]

Reduce marine habitat impacts from wild-capture fisheries

From coral reefs to kelp forests and deep-sea canyons, coastal and marine habitats shelter and sustain a diversity of sealife. The extent of fishing impacts on marine habitats varies significantly and largely depends on the location, habitat type, and method of fishing. Developing cultivated and plant-based alternatives for species that are fished with the highest impact fishing methods could help create flexibility and stability in the seafood supply and a means by which governments can diversify seafood production and incentivize more sustainable practices. For instance, a shift towards plant-based or cultivated benthic species such as groundfish and scallops could reduce bottom-trawling and dredging,[60] two fishing techniques that have affected approximately 75 percent of the global continental shelf.[61]

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Limit aquaculture production site expansion and emissions impacts

Alternative seafood could also mitigate further conversion of land, the water column, or the seabed for aquaculture, which research shows can have negative effects on the local ecosystem and biodiversity. For example, removing ecologically important mangrove forests to make room for shrimp ponds has led to coastal erosion, poor water quality, and loss of biodiversity in many parts of the world.[62] Improperly sited, high-density aquaculture can also damage the surrounding water column and seafloor

habitat through nutrient and effluent build-up which can deplete the water of oxygen and facilitate algal blooms.

Complementing the existing seafood supply with alternative seafood can enable more judicious choices for aquaculture siting and keep aquaculture density to sustainable levels.

Minimize agricultural land needs for plant inputs

Alternative proteins[63] can enable more efficient calorie conversion from feed crop to final product and maximize food supply while minimizing habitat transformation and land use. Some believe that plant-based aquaculture feed is more sustainable than fishmeal because it does not require finite marine resources. However, feeding plants to fish is still less efficient than using plants to produce plant-based seafood.

While direct comparisons of land use between aquaculture and alternative seafood are complex and difficult, researchers at Johns Hopkins found that, per 100 grams of protein, the median land use footprint of plant-based seafood was 41 percent smaller than that of farmed fish.[64] They suggested that eating plant-based seafood instead of farmed fish could free up cropland to produce more food for direct human consumption and allow for the restoration of converted habitats. It stands to reason that scaling plant-based seafood rather than farmed seafood to meet the growing supply gap may mitigate additional pressure on both marine and terrestrial ecosystems.

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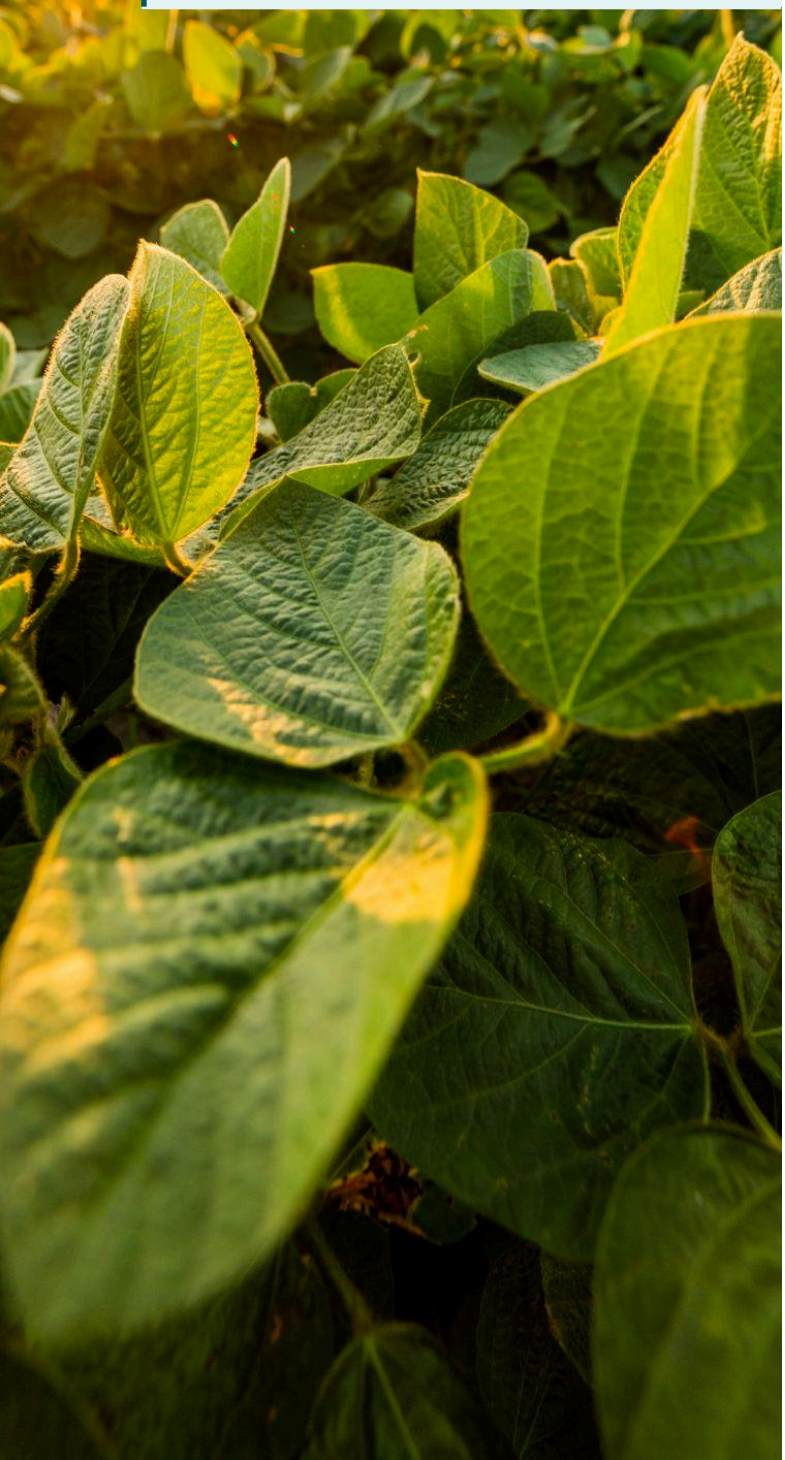

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The current data for cultivated meat also indicates significant potential land savings. Echoing a 2015 anticipatory life cycle analysis (LCA) of the cultivated meat industry, which suggested that cultivated meat production could use less land than livestock,[65] a 2023 anticipatory LCA for cultivated meat concluded that the land use footprint of cultivated meat may be around 2.5 m^2 crop-eq./kg product—substantially lower than chicken (6.8), pork (7.5), and beef (5.5 to 24.3).[66] Another recent study from Johns Hopkins reinforced this conclusion but noted that estimates of land-use intensity have a large range between 1–11 m^2/year/100g protein depending on the feedstock and inputs for cell cultivation.[67]

At this early stage, it is difficult to predict how much land would be required to enable the mass production of cultivated seafood. However, unlike terrestrial agriculture and many types of aquaculture, cultivating seafood may require less extensive habitat conversion because existing infrastructure could be repurposed for seafood cultivation facilities. This would negate the need to convert carbon-sequestering forests, grasslands, wetlands, and other biologically diverse ecosystems.

3. Reduce greenhouse gas emissions and mitigate ocean acidification

Climate change and ocean acidification—the result of increasing levels of carbon in the ocean and atmosphere—are increasingly important drivers of biodiversity loss.[68, 69] As the ocean becomes more acidic, calcifying (shell-forming) organisms as well as larvae, many of whom form the base of the food chain, are vulnerable, threatening the stability of marine ecosystems. All seafood production, whether conventional or alternative, generates carbon emissions. A 2018 study estimated that fisheries consumed 40 billion liters of fuel in 2011 and generated a total of 179 million tons of CO_2-equivalent GHGs (approximately four percent of global food production).[70] Meanwhile, the GHG emissions associated with aquaculture production comprise approximately five percent of total agricultural GHGs[71] and 0.49 percent[72] of global GHG emissions.

Limit seabed disturbance and coastal habitat transformation.

However, emerging research indicates that these numbers may not tell the whole story. For instance, some bottom-tending modes of fishing may release as much as 1.5 billion metric tons of the aqueous CO_2 from the seafloor annually—equal to what is released on land through farming.[73, 74] The release of stored carbon into the water column likely contributes to ocean acidification and limits the ocean's capacity to buffer atmospheric CO_2—both of which can have negative effects on marine biodiversity.[75] Similarly, scientists are increasingly examining the impact of land use and conversion in evaluating the climate impacts of aquaculture production. Where land conversion occurs to make way for aquaculture production, particularly in coastal zones with high carbon sequestration and storage habitats such as mangroves, the carbon footprint can exceed conventional beef production.[76]

Comparing the emissions footprints of alternative and conventional seafood is challenging due to both the tremendous diversity of seafood species and production methods and the limited body of scientific literature comparing conventional seafood to alternatives. Existing analyses often rely on data for plant-based or cultivated terrestrial meat, assumed to be representative of plant-based and cultivated seafood, respectively. With these limitations in mind, current research indicates that alternative seafood produces equal or lower emissions than many forms of conventional seafood.

Generally, plant proteins produce significantly lower emissions than both conventional meat and seafood.[77] Santo et al. (2020) reported plant-based meat (a proxy for plant-based seafood) has an emissions footprint 34 percent less than conventionally farmed fish and 72 percent less than farmed crustaceans. However, they also found that scaled, efficient fisheries (such as purse seine tuna fishing) may remain less emission-intensive than plant-based seafood.[78] Even so, a lack of

transparency, poor oversight, and fraudulent and misleading labeling may make these products difficult to reliably identify in the market and less emission-intensive fisheries and farms may be confronting other sustainability challenges.

Scale seafood production with renewable energy.

Understanding future emissions from cultivated seafood is more complex. As with other dimensions of environmental sustainability, only limited research examines energy use and emission projections for cultivated seafood. Current analyses rely on cultivated meat as a proxy, but some experts note that cultivated seafood production may be less energy-intensive than cultivated meat production. Researchers and cultivated protein producers have observed that marine cell cultures may be more forgiving in terms of temperature, pH, and oxygen requirements compared to mammalian cell cultures, which may have implications for energy use and cost in mass production. Whereas mammalian cells need to be maintained at a certain temperature, room temperature is sufficient for most fish cells.[79]

The findings of Santo et al. (2020), Gephart et al. (2021), and Sinke et al. (2023) indicate that cultivated meat using conventional energy sources may have emissions greater than most wild and farmed seafood products but less than the most emissions-intensive conventional products.[80, 81, 82] Emerging forms of renewable energy will substantially decrease cultivated meat emissions, putting them on par with the footprints of the least emissions-intensive conventional seafood that use grid power/fossil fuels. (Life cycle analyses comparing impacts using renewables across both conventional and alternative modes of seafood production are not yet available.) Scaling emissions-efficient plant-based seafood and cultivated seafood produced with renewable energy may help reduce the pressure to expand the more emission-intensive modes of aquaculture and wild capture. (Please see *Building climate policy momentum for alternative seafood* for a deeper exploration of this topic.)

4. Minimize biocide and antimicrobial use while scaling seafood production

By scaling alternative seafood to close the growing supply gap, we can minimize use of biocides (i.e., pesticides, fungicides, and herbicides) and antimicrobials, including antibiotics, for seafood production, helping protect microbial diversity and mitigate the risk of antibiotic pollution and antibiotic-resistant disease as seafood production grows.

Plant-based aquaculture feed, plant-based seafood inputs, and cultivated seafood growth media all rely on terrestrial plant agriculture, which commonly uses biocides. In addition to habitat loss and climate change, the use of biocides in agriculture has significant effects on biodiversity. These chemicals contaminate adjacent soil and water resources and cause collateral damage to non-target plants, animals, and fungi. Direct exposure to biocides can have toxic effects on organisms and harm beneficial insect populations that function as pollinators and natural pest controls. The bioaccumulation of these toxins—the build-up of contaminants inside the tissues of a living organism—can also lead to persistent long-term harm on higher trophic level species and ecosystem functionality. While agricultural advancements like integrated pest management and biological pest controls can mitigate biocide use, simply using every agricultural harvest as efficiently as possible is critical to minimizing biocide contamination—this is what alternative seafood enables.

Limit biocide use per calorie of food production.

Because only a fraction of feed is converted into edible meat, overall biocide use per calorie is generally higher for terrestrial animal protein production than plant protein production. While there is limited research comparing pesticide use in conventional meat and fish production to that of plant-based seafood, one study found conventional pork production used 1.6 times more pesticides per

unit of protein than the production of a pea-protein plant-based product.[83] Likewise, another study compared the biocide inputs for conventional meat protein to a soy-derived plant-based meat and found that conventional meat required six times more biocides.[84] While biocide use may be lower in plant-based products than terrestrial animal-based proteins, how plant-based seafood would compare to farmed seafood would vary depending on the use of plant-based feed versus fishmeal and fish oil for aquafeed. However, where fishmeal and fish oil are used for aquafeed instead, pressure on wild fish populations increases. Advancing more sustainable agricultural practices that reduce biocides and simultaneously maximizing efficient use of crops via plant-based seafood can help mitigate biodiversity loss on both land and sea.

Mitigate the acceleration of antibiotic-resistance.

Alternative proteins may also help reduce the spread of both antibiotic-resistant disease, a threat to public health, as well as antimicrobial pollution, a threat to terrestrial and marine ecosystems and biodiversity. To meet the growing demand for seafood globally, aquaculture production has increased by an average of 5.8 percent annually since 2001. The drive to increase production volume has, in many cases, come at the expense of biosecurity, good husbandry practices, and strong management standards. High stocking densities and the increasing incidence of aquatic pathogens are prompting producers to rely increasingly on the use of antimicrobials to stimulate growth and battle disease. These practices are leading to greater levels of antimicrobial resistance across a diversity of aquaculture species.[85] Research suggests that for some aquaculture species, the intensity of antimicrobial use exceeds the levels consumed by terrestrial animals and humans.[86] What's more, the use of antibiotics in aquaculture is particularly dangerous because drug residues and pathogens spread more easily and more consistently in water than in land-based systems.[87] The implications of increasing antimicrobial use in aquaculture are not insignificant as chronic exposure to antimicrobials can have deleterious effects on aquatic species, ecosystem functionality, and human health.[88]

> *Both plant-based and cultivated seafood offer the opportunity to scale seafood production with no or negligible antibiotics.*

Plant-based seafood production, on the other hand, does not require the use of antibiotics. Similarly, it is anticipated that antimicrobial use in cultivated seafood will be minimal, just as antibiotics are not typically used in biopharmaceutical manufacturing. Antibiotic use in cell cultivation can compromise proliferation, differentiation, and gene expression, and Good Cell Culture Practice mandates the use of aseptic techniques—such as those used in biopharmaceutical manufacturing—to avoid antibiotic use.[89] Both plant-based and cultivated seafood offer the opportunity to scale seafood production with no or negligible antibiotics.

Opportunities to advance alternative seafood in ocean conservation policies and programs

Just as alternative seafood can advance ocean conservation, so too can the ocean conservation community accelerate progress on alternative seafood to fully realize the benefits sooner. While many view alternative proteins as a way to mitigate the environmental impacts associated with conventional animal protein production, governments are beginning to embrace alternative proteins, and in particular cultivated meat and seafood, as a global solution that can reduce emissions, strengthen food security, improve public health, and provide economic development opportunities.

Singapore, the first country to approve cultivated meat, is poised to become the hub for cultivated meat protein production in Asia. Because Singapore imports more than 90 percent of its food, it is particularly vulnerable to supply chain disruptions—like those caused by COVID-19. Cultivated proteins, which can be produced locally, may offer a more reliable, sustainable, and accessible protein source for the small city-state. Likewise, Israel's leaders have been publicly outspoken about support for the sector and have invested $18 million in a cultivated meat research consortium. The Israeli government has also funded start-ups, built pilot plants, and taken steps to ensure a robust regulatory framework.

Currently, the United States has more companies and higher levels of private investment in this sector than any other country in the world. However, the United States lags behind countries like Singapore and Israel in terms of public sector support for plant-based and cultivated products. Leveraging alternative seafood to address the mounting biodiversity crisis will require: (1) policies that enable a clear path to market and a level playing field for these products to compete with conventionally produced proteins; and (2) government investments to advance the science, scale alternative seafood production, and ultimately meet consumer expectations on taste, price, and convenience.

Multiple stakeholder and multi-sectoral support will also be critical to mainstreaming alternative seafood and realizing its potential to enhance marine biodiversity. Given the cross-cutting nature of alternative seafood, advocates of biodiversity, climate resilience, and food security can add plant-based and cultivated seafood to their toolbox of solutions to accelerate progress. Indeed, an overhaul of our food system will require fundamental changes to our consumption habits as well as a redesign of how food production systems utilize natural resources. While alternative seafood complements and reinforces existing efforts to change consumer behavior and improve the sustainability of fishing and farming

practices, diversifying our food system and mainstreaming alternative seafood will require collaboration at both a domestic and international level. That collaboration will need to focus on various strategies, from governance reforms and public financing to public education and market incentives. Below is a partial list of engagement opportunities around alternative seafood that aligns with many of the conservation community's existing priorities.

1. Recognize alternative seafood as a biodiversity and climate solution.

Climate change exacerbates the biodiversity crisis. It can alter the abundance, distribution, and diversity of marine species and disrupt natural behaviors such as feeding, development, reproduction, and predator-prey relationships. Trends in biodiversity loss cannot be reversed without also addressing climate change. Conversely, protecting biodiversity can mitigate the negative effects of climate change. Protecting and restoring coastal blue carbon habitats can be a powerful carbon-sequestration and storage strategy. Biodiversity is also critical to achieving the goals of the Paris Agreement under the United Nations Framework Convention on Climate Change. António Guterres, the UN Secretary-General, noted in the foreword to the 2020 UN Global Biodiversity Outlook 5 that "climate change threatens to undermine all efforts to conserve and sustainably manage biodiversity, and that nature itself offers some of the most effective solutions to avert the worst impacts of a warming planet."[90]

Approximately one-third of the net reductions in GHG emissions required to meet the goals of the Paris Agreement could come from nature-based or natural climate solutions.[91] Our ocean and coasts offer a host of nature-based solutions to the climate crisis, including maintaining or increasing natural habitats for sequestration purposes. Blue carbon ecosystems such as mangroves, seagrass beds, salt marshes, estuaries, and other coastal wetlands can sequester and store ten times more carbon than tropical rainforests.[92] In addition to their sequestration capacity, these ecosystems play a critical role in supporting both terrestrial and marine biodiversity, acting as nurseries and providing habitat for a range of species at different life stages.

Scientists estimate that the total coastal wetland loss due to human activities is greater than 67 percent of its original area.[93] The conversion of mangrove forests and other coastal blue carbon ecosystems to make way for aquaculture production and other human developments not only removes important carbon sinks but can release large reservoirs of previously sequestered carbon. Likewise, protecting the carbon-rich seabed from destructive bottom trawling may mitigate climate change and ocean acidification.[94] Diversifying modes of seafood production to include alternative seafood and shifting seafood production away from these critically important ecosystems could not only help restore biodiversity but also ensure that these areas maintain their value as important carbon sinks.

In addition to enabling more nature-based solutions to climate change, alternative seafood may help lower GHG emissions. While conventional seafood production is comparatively less carbon-intensive than terrestrial animal agriculture,[95] plant-based products generally generate fewer GHG emissions than both terrestrial meat and seafood.[96]

Diversifying modes of seafood production to include alternative seafood and shifting seafood production away from these critically important ecosystems could not only help restore biodiversity but also ensure that these areas maintain their value as important carbon sinks.

Organizations involved in climate and biodiversity advocacy can join calls to reform food systems and reduce carbon emissions by investing in alternative protein innovation.

Cultivated seafood, on the other hand, is still in its nascent stages so projections for energy use and GHG emissions associated with cultivated seafood are still hypothetical, and most studies do not reflect the anticipated shift to less carbon-intensive energy sources. Decarbonization of the cultivated seafood production process will be critical to mitigating its potential impacts on biodiversity.

Organizations involved in climate and biodiversity advocacy can join calls to reform food systems and reduce carbon emissions by investing in alternative protein innovation. Several domestic and international initiatives seeking to transform food production would benefit from broader stakeholder support. For instance, the Agriculture Innovation Mission for Climate (AIM4C), a joint initiative created by the United States and the United Arab Emirates, seeks to address the climate crisis by increasing and accelerating climate-smart agriculture and food systems innovation. Private entities are stepping up to fund alternative proteins as part of AIM4C. In the U.S., organizations should call upon Congress and the executive branch to prioritize open-access research on alternative seafood as a central component of the government's and NOAA's climate change agenda.[97]

2. Advocate for public investment in open-access science

To better understand the role that alternative seafood can play in mitigating the biodiversity crisis and accelerate the integration of alternative seafood into our diets, sustained public investment in open-access collaborative research is needed. To date, much of the research around alternative proteins has been industry-funded, and focused on financial returns rather than conservation outcomes. Rather than focus on short-term financial returns, publicly funded, open-access science can benefit long-term environmental, social, and economic outcomes and ensure that the results are accessible, credible, and transparent. Public investment in early-stage, precompetitive research focused on solving technological, operational, and impact-related challenges experienced across the industry can accelerate the development of the entire sector. Likewise, public research can connect

and strengthen the currently fragmented research ecosystem by enabling researchers to co-prioritize issues, avoid duplication, and facilitate collaboration among industry, academia, government agencies, nonprofit organizations, and other relevant stakeholders.

Public funding can also strengthen our understanding of the environmental impacts associated with different modes of seafood production. Public support for independent third-party LCAs and a voluntary standard framework to enable comparisons between conventional seafood and alternative seafood products are vital. Additionally, targeted research to evaluate the biodiversity impacts of agricultural expansion or infrastructure development can help alternative seafood fully meet its promise to advance biodiversity.

In addition to enhancing our collective scientific knowledge,[98] ensuring a sustainable and equitable food system transition requires behavioral and structural changes. Public research can identify appropriate pathways and strategies for advancing alternative seafood (e.g., policies, industry performance standards, taxes, subsidies, labeling, and public awareness campaigns). This interagency research could be coordinated by the White House's Office of Science and Technology Policy.[99]

3. Support alignment of economic incentives to level the playing field for alternative seafood production.

Ensuring fair competition so alternative seafood can compete with the conventional seafood industry will require policy reforms to help achieve economies of scale and ensure that government subsidies support seafood production processes that safeguard biodiversity. While not all subsidies are harmful (e.g., support for gear innovation to mitigate bycatch and habitat damage), as much as $20 billion of the $35 billion in total global subsidies directly contributes to overfishing.[100] Indeed, subsidies in the United States tend to be dominated by fuel subsidies, which many in the conservation community view as problematic given that the total value of subsidies equates to approximately one-fifth the value of the catch itself.[101] Harmful subsidies can encourage less sustainable practices, artificially deflate prices, and put the emerging plant-based and cultivated seafood sectors at a competitive disadvantage.

In 2015, the UN Sustainable Development Goals established a target of prohibiting harmful fisheries subsidies that contribute to overcapacity and overfishing.[102] This effort was echoed by the UN Convention on Biological Diversity's new global biodiversity framework which calls upon member states to "redirect, repurpose, reform or eliminate incentives harmful for biodiversity, in a just and equitable way" by 2030.[103] Recalibrating subsidies to encourage practices and production processes that support biodiversity should include ensuring that alternative seafood production qualifies.[104]

A number of U.S. nonprofits are working with decision-makers to eliminate harmful fisheries subsidies and the perverse incentives that undermine efforts to end overfishing, rebuild depleted fish stocks, and protect marine biodiversity. Proposals to repurpose public funding to protect and restore the marine environment often accompany these calls. Organizations making such proposals should highlight how alternative seafood, as part of the blue economy, can contribute to domestic economic development, job creation, food security, and marine biodiversity to help attract more government support for this burgeoning industry.

4. Ensure a clear and efficient regulatory process and labeling rules for alternative seafood.

Given its potential biodiversity and climate benefits, alternative seafood should not be subject to regulatory requirements that exceed the norms for conventional proteins. This is especially important for cultivated seafood, which has not received regulatory clearance as of June 2023 in the United States. The Food and Drug Administration (FDA) should exert its regulatory authority fairly and ensure that safe, properly labeled cultivated seafood can come to market without unduly onerous regulatory requirements. Likewise, the United States can provide leadership in the Codex Alimentarius ("Food

Code") Commission to help develop guidance or model regulations for cultivated seafood that assists other nations in developing their own fair regulatory frameworks. Simultaneously, the two multilateral organizations that convene the Codex—the UN Food and Agriculture Organization and the World Health Organization—should continue to encourage regulators and subject-matter experts to share information about bringing alternative seafood to market safely.

Further, FDA, which regulates the labels of seafood and most other foods in the United States, including plant-based seafood, should continue to support fair labeling rules for plant-based seafood products to allow producers to communicate to consumers that these foods have the taste and texture of familiar seafood products and are made from plants.[105]

5. Combat seafood fraud and mislabeling with domestic production of alternative seafood.

A movement toward more conscious seafood consumption requires detailed and accurate information on seafood products. However, fraud and mislabeling of conventional seafood is widespread. An analysis conducted by *The Guardian* of 44 recent studies found that 36 percent of more than 9,000 samples from restaurants and retailers in more than 30 countries were mislabeled.[106] By obscuring the source and/or species, seafood fraud enables IUU fishing and causes global biodiversity loss. As commercially and ecologically valuable fish stocks decline, the economic incentives for intentional fraud increase, creating a vicious cycle of depletion and causing annual economic losses to the global economy of $26 to 50 billion.[107] While NGOs and policymakers are working to curb fraud and enable greater transparency and traceability into the seafood industry, the complexity and opacity of the global seafood supply chain makes this a daunting task.

Enabling more domestic seafood production shortens the seafood supply chain and mitigates the risk of fraud. Alternative seafood presents an opportunity to establish more domestic plant-based and cultivated seafood production facilities for species that are traditionally imported and/or are the subject of fraud and mislabeling. Plant-based seafood alternatives can capitalize on existing agricultural infrastructure, and both plant-based and cultivated seafood production facilities can be established almost anywhere in the United States, including inland and more economically depressed areas. Local producers could cater to regional demands, simplify supply chains, and contribute to economic growth and job creation—all while reducing pressure on vulnerable fish and wildlife populations and ecosystems. The conservation community and policy makers can encourage domestic production of alternative seafood along with clear, robust, and equitable labeling and traceability requirements to de-incentivize seafood fraud and mislabeling and meet the demand for more socially and environmentally responsible seafood.

Plant-based seafood alternatives can capitalize on existing agricultural infrastructure, and both plant-based and cultivated seafood production facilities can be established almost anywhere in the United States, including inland and more economically depressed areas.

6. Enhance consumer awareness to influence demand for alternative seafood.

American consumers are becoming increasingly aware of the inextricable link between ocean health and human health. Recent surveys show that consumers are increasingly concerned about the nutrition and sustainability profiles of their protein choices. As such, more and more consumers are

seeking alternatives to red meat and turning to seafood, both wild and farmed. Yet even as the demand for seafood grows, declines in ocean health are prompting many to reconsider their preference for wild-capture fish.[108] However, consumers are currently more concerned about the health-related risks of seafood consumption (e.g., plastic, heavy metal, and chemical contamination) than they are about the biodiversity impacts of wild-capture fisheries and aquaculture.

Notably, younger consumers are more concerned about sustainability and ocean health issues than older generations and are open to alternative production methods like cultivated seafood. In fact, 45 percent of Millennials already know about cultivated seafood, and 43 percent of Americans are willing to replace some or all their current seafood consumption with cultivated products.[109] The growing American demand for seafood is likely to increase pressure on global fish stocks and the ecosystems that support both wild-capture fisheries and aquaculture production. However, younger consumers' interests in healthy and sustainable protein choices offer an opportunity to engage people on issues related to ocean health and to diversify seafood production to include alternative seafood.[110]

While the industry is actively working to communicate with and appeal to consumers, the conservation community—including seafood certification and rating programs—can start to familiarize the public, industry partners, and decision-makers with the potential benefits of alternative seafood.

The challenge of increasing alternative seafood acceptance is as much about accessibility, affordability, and taste as it is about biodiversity, health, and other societal benefits. While the industry is actively working to communicate with and appeal to consumers, the conservation community—including seafood certification and rating programs—can start to familiarize the public, industry partners, and decision-makers with the potential benefits of alternative seafood. At the same time, for alternative seafood to yield real conservation benefits, consumers must embrace it. One study that looked at the potential environmental benefits of cultivated seafood observed that after developing a viable product, securing regulatory approval, and introducing it to the market at a competitive price point, companies will need to capture a significant proportion of conventional seafood market share to realize the conservation benefits, and encouraging adoption of alternative seafood will help.[111,112] Thus, a coordinated campaign that elevates consumer awareness, modifies choice settings such that the more sustainable choice is the more affordable and accessible choice, and advocates enabling policies will be critical to advancing alternative seafood development and adoption as a strategy to protect biodiversity.

Conclusion

Biodiversity is the foundation of a well-functioning food system, and yet food production today is one of the leading causes of global biodiversity loss both on land and at sea. Reimagining seafood production represents a significant opportunity for biodiversity restoration. Seizing this opportunity will require transformative changes to our food system and a more expansive understanding of sustainability.

Whereas seafood sustainability was once narrowly construed as whether a specific target species was overfished or not, our collective vision for sustainability is evolving to include dimensions such as biodiversity, ecosystem health, climate change, and social equity. Plant-based and cultivated seafood challenge us to think even more broadly and explore how these novel products compare with conventional seafood, what role they can play in transforming the broader food system, and how they align with changing consumer values and the growing demand for sustainable and delicious food.

We need innovative, equitable, and sustainable diversification of the global food system to restore and protect biodiversity, mitigate climate change, and feed a growing population. Whether plant-based and cultivated seafood can help meet this need will depend on sustained support from policymakers and the conservation community. Advancing workable solutions will require a commitment to multi-sectoral collaboration, information sharing, capacity building, and funding for open-access science. Mainstreaming alternative seafood will also require a transparent and equitable governance framework that levels the playing field for alternative seafood, incentivizes innovation, and facilitates a transition towards a more sustainable, diverse, and resilient food system that protects and enhances biodiversity.

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