TRANSFORMATIONAL OPPORTUNITIES FOR PEOPLE OCEAN PLANET

FOOD & NUTRITION

Blue Climate Initiative

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This publication was commissioned by the Blue Climate Initiative (BCI), which accelerates ocean-related strategies, collaborating across a multidisciplinary global community towards a restored and healthy climate; an understood and protected ocean; and resilient, thriving and equitable communities. In 2020 the BCI initiated a holistic process to identify transformational opportunities at the intersection of people, ocean and planet, engaging over sixty world-class scientists and academics. These contributors compiled recommendations across six thematic areas: Health & Well-Being, Food & Nutrition, Marine Energy & Transportation, Mineral & Genetic Resources, Biodiversity & Nature-Based Solutions, and Sustainable Tourism. This publication is part of that series. The BCI is deeply grateful to its authors for their insights and collaboration.

A compendium synthesizing messages across the six Transformational Opportunities papers is available: Fries, L., Everett, J., and Davies, N. (eds.) 2021. Transformational Opportunities for People, Ocean, and Planet. French Polynesia: Blue Climate Initiative, Tetiaroa Society. https://doi.org/10.5281/zenodo.4540323.

For more information about the Blue Climate Initiative, please visit blueclimateinitiative.org or contact info@blueclimateinitiative.org.

The fiscal sponsor for the Blue Climate Initiative is Tetiaroa Society, a US 501(c)(3) nonprofit organization (tetiaroasociety.org).

Suggested citation for this publication:

> **Transformational Opportunities in Ocean-Based Food & Nutrition.** Christopher Costello, Lorin Fries, Steven Gaines, Amanda Kelley, Trisha Atwood, Manuel Barange, Thierry Chopin, Halley E. Froehlich, Ray Hilborn, Jane Lubchenco, Martin Quaas, James Sanchirico, Eric Schwaab, and Peter Tyedmers. French Polynesia: Blue Climate Initiative, Tetiaroa Society. https://doi.org/10.5281/zenodo.4549889

ISBN: 978-1-7368426-3-8 (Digital)

Cover photograph: © Ocean Era

Design by: Lauric Thiault / Moana Ecologic

Author Acknowledgements

We would like to extend our sincerest thanks to the Tetiaroa Society and the Blue Climate Initiative core team for their support, guidance, and leadership over the course of this project. We would also like to thank our colleagues from the other five Blue Climate Initiative Working Groups for their collaboration and thoughtful feedback throughout the development of this paper. Lastly, special thanks to Mauricio Collado, Masters Candidate at the University of California Santa Barbara's Bren School of Environmental Science and Management, for his analytical contributions to this paper.

CONTENT

Transformational Opportunities for Ocean-Based Food & Nutrition

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Executive Summary

The climate crisis and food production are closely linked. In the ocean, climate change manifests as warming ocean temperatures, ocean acidification, and increased storm frequency and severity, among other phenomena, impacting food and nutrition security and livelihoods in communities around the world. At the same time, food production—especially industrial, land-based animal protein production—exacerbates the climate crisis by contributing significantly to greenhouse gas emissions. As the global population increases to nearly 10 billion by mid-century, the climate and ecosystem impacts of current food production activities will intensify. This presents a two-fold problem: how can we meet the food and nutrition security needs of the future while dramatically reducing our impact on the climate?

We believe an important part of the solution lies in food from the sea. In this paper, we identify **Transformational Opportunities (TOPS)** that represent powerful options for urgent and effective climate mitigation and/or adaptation in the realm of ocean-based food and nutrition. Within these TOPS we have identified concrete interventions to actualize the full climate benefits, food and nutrition potential, and other co-benefits of each TOP. These include a range of pathways, from policy measures, market-based solutions, and community-based action to information provision. These TOPS are:

1. Expanding and enhancing mariculture operations
2. Motivating dietary shifts toward sustainable food from the sea
3. Restoring, expanding, and/or protecting critical ocean habitat
4. Managing wild fisheries to maximize economic yield

A key recommendation that crosscuts all TOPS is to put a price on carbon emissions. This would maximize the potential benefits of each TOP and allow for the implementation of solutions that might not otherwise be feasible.

The values of inclusivity and accessibility underpin our analyses and recommendations. Educating and empowering women and girls, while not necessarily an "ocean-based" solution, has major implications for both

the climate and the future of food from the sea (FAO 2017, Project Drawdown 2020). Engaging women as independent economic actors, especially in the fisheries and aquaculture sectors where they commonly play crucial processing and post-processing roles, will be necessary to achieve the full potential of each TOP. Similarly, the leadership, decision-making, and engagement of Indigenous peoples and vulnerable communities, especially those most impacted by climate change, is a prerequisite for each TOP's success. Interventions must be implemented in a way that aligns with community needs, culture, and vision for the future.

Challenges in Focus

The global population is expected to increase by 32% (to 9.7 billion people) in 2050, placing enormous added pressure on the climate and natural resources involved in food production (FAO 2018). Under the additional stressor of climate change, many lands that were previously ideal for cultivation and raising livestock will become unsuitable, and the land available for food production will be reduced (Wiebe et al. 2015). Such a shift could have significant consequences for global food security and severe impacts on community diets and nutrition (Myers et al. 2017).

At the same time, agriculture, forestry, and other land uses are responsible for roughly 23% of annual greenhouse gas emissions (IPCC 2019). A combination of interacting market factors, including a growing global demand for animal protein as communities around the world become more wealthy, has driven these operations to expand and intensify in recent decades (Bereznicka and Pawlonka 2018). This presents a critical dilemma: the need to dramatically increase production of nutritious food, seemingly at odds with the need for urgent, significant reductions in emissions to combat the increasingly severe threat of climate change.

Marine food systems are uniquely positioned to address the challenge of meeting future food and nutrition demands while simultaneously mitigating and/or adapting to climate change impacts. Food from the sea has the potential to help meet the growing global protein demand (Costello et al. 2019), is associated with significantly fewer carbon emissions—or even the potential to sequester carbon—compared to land-based agriculture and livestock operations (Hoegh-Guldberg et al. 2019, Costello et al. 2020), and can supply nutrients that aren't readily available in land-based foods (Jayasekara et al. 2020). Below we describe our four Transformational Opportunity (TOP) areas and associated interventions.

Scope

This paper identifies climate change solutions rooted in ocean-based food systems. Several interventions we propose are not situated within the ocean, such as humans' dietary shifts, but have a profound influence on ocean food systems and potential climate impact such as through supply chains. In addition to representing significant climate and food and nutrition opportunities, these TOPS were selected for their ability to confer significant co-benefits, at low or mitigable risk, demonstrating the potential to address a range of complex, intertwined challenges. For illustrative purposes, we also include the results of light-touch, back-of-the-envelope calculations to ascertain the magnitude of potential climate and food provision impacts for each TOP.

Transformational Opportunity Areas

1. Expanding and enhancing mariculture operations

Expanding mariculture—the farming of marine organisms in the ocean—could produce an abundance of nutritious food with a significantly lower environmental impact and carbon footprint than most alternatives. This could reduce emissions substantially, especially if mariculture significantly displaces land-based animal protein production. Our calculations suggest a potential reduction of up to two gigatons of CO_2 emissions with a one-to-one replacement of beef with maricultured protein.

Benefits

Climate — Enhance low-carbon food production, promote carbon sequestration

There is vast, untapped potential for mariculture in suitable locations around the world to meet growing global food demand while helping to mitigate climate change (Costello et al. 2020). The current total global catch of all wild-capture fisheries could potentially be produced using less than 0.015% of the global ocean area, presenting an opportunity for countries to develop aquaculture in ways that align with their economic, environmental, and social objectives (Gentry et al. 2017). Mariculture can be expanded in environmentally sensitive ways that minimize or eliminate many of the negative externalities of land-based food production (Hoegh-Guldberg et al. 2019, Hilborn et al. 2018). Increased mariculture production may, in some cases, actually sequester carbon, though this will depend on the end use of the final product (Froehlich et al. 2019).

Food & Nutrition — Enhance food security and climate-resilient diets

Sustainable mariculture (which adheres to widely accepted protocols such as the European standards for sustainable mariculture) has the capacity to easily double production, from today's ten million metric tons (MMT) of food to well over 25 MMT, under policy reform and technology improvements (Costello et al. 2020).

Co-Benefits — Potential biodiversity and pollution remediation benefits

Expanding unfed mariculture, such as that of invertebrates and seaweeds, could help to support wild fisheries by creating artificial habitats and refuges from fishing, protecting wild species from overharvesting (Alleway et al. 2019, Gentry et al. 2019). Mariculture of similar unfed species could even help mitigate nutrient pollution in coastal waters (Chopin and Tacon 2020). As mariculture expands, its price could fall, motivating a shift away from some wild stocks, alleviating harvesting pressure on those wild stocks. There is also potential for the co-location of farming and offshore energy infrastructure, a win-win for renewable energy and food security (Abhinav et al. 2020).

Interventions

I. Introduce an emissions price for the food sector

A well-designed, sector-wide price on greenhouse gas (GHG) emissions (we focus here on a carbon price) would discourage production of high-emission foods and encourage production of carbon-neutral and/or carbon-negative foods. A carbon price would disproportionately increase the price of high-emission land-based protein, given its large carbon footprint, and improve the affordability of alternative, ocean-based protein—driving consumers to switch to the latter. As demand shifts, more mariculture operations will rise to meet it, possibly further reducing costs through learning. A carbon price would initially make food costlier, but to mitigate risks to food security, especially among low-income consumers, carbon revenues could be redistributed to reduce or eliminate the cost burden. Our calculations suggest that a well-designed, food-based carbon tax could reduce emissions up to 0.2 gigatons of CO2, or potentially even more, depending on the carbon price (Hoegh-Guldberg et al. 2019).

II. Permit mariculturists to participate in local carbon markets and/or nutrient (e.g., nitrogen and phosphorus) markets, awarding them credits

As first steps on the way towards a food-economy-wide carbon price, local efforts to put a price on carbon can incentivize mariculture. Many states and countries already have versions of a price on carbon (cap and trade or a carbon tax), but very few, if any, include mariculture in those markets. While it would require careful attention to design details to prevent leakage and other negative effects, incorporating mariculture into these carbon markets could provide incentives to expand while maintaining a low carbon footprint. Via gains from trade, it could also benefit other sectors already engaged in the carbon market. This concept could also be applied to nutrient (e.g., nitrogen and phosphorus) markets, wherein mariculture could remediate outflows and participate in trading with nutrient emitters (Chopin and Tacon 2020).

III. Remove political and regulatory barriers to production

Most mariculture operations are concentrated in only a few countries, such as China, Norway, and Chile. However, the countries with the highest potential—the top five being Australia, Indonesia, Argentina, India, and Mexico, followed closely by the USA and Brazil—are not currently producing large quantities of marine aquaculture (Gentry et al. 2017). Contributing factors include regulatory issues that drive up operational costs, lack of investment and infrastructure, and low consumer demand for species like invertebrates and seaweeds. Regulations may also inadvertently prevent the development of innovative aquaculture practices (such as integrated multi-trophic aquaculture) and become impediments to their evolution (Chopin 2019). Policy interventions could reduce or remove these barriers to facilitate the expansion of sustainable mariculture in these and other countries around the world. Concurrently, policy interventions can set standards for mariculture that curtail risks and address concerns associated with seafood farming: ecosystem damage, water pollution, and disease are all issues that plague inappropriately managed mariculture and aquaculture facilities, particularly with finfish production. Setting and enforcing standards for the design, operation, and monitoring of mariculture could mitigate or eliminate most of these concerns.

IV. Invest in feed innovations and value chain development

Expanding mariculture could lead to negative interactions with wild fisheries, such as the potential expansion of unmanaged wild fisheries for mariculture feed. Under current practices, most finfish aquaculture is fed using wild-caught forage fish. To prevent exacerbating overfishing and reduce constraints on growth, investing in feed innovations will be crucial to ensuring the sustainability of expansion. While soy and other crops have filled the “forage fish” feed gap over the last decade, new feeds such as seafood byproducts, microbes, and insects hold great promise in diversifying sources—with perhaps lower environmental impact—to reduce our reliance on catching wild fish to feed farmed fish (Cottrell et al. 2020).

V. Invest in animal health and therapeutics

Diseases (pathogens and parasites) have been cited as the most pressing issue in aquaculture, costing the global industry an estimated US$6 billion a year. Part of the solution is directly related to improved management and feed (e.g., One Health approach, Stentiford et al. 2020), but development and prudent applications of better vaccines, antibiotics, and probiotics will be critical as aquaculture expands, particularly because predicting disease outbreaks under a changing climate is a significant challenge (Lafferty 2015).

Risks

One crucial assumption for this TOP in the context of climate change hinges on the possibility that ocean-based protein will become a substitute for land-based protein, resulting in decreased livestock operations. Only under this scenario can significant climate mitigation benefits accrue. We explore this potential for substitution in the section below.

2. Motivating dietary shifts toward sustainable food from the sea

Motivating a societal diet shift from land-based animal protein to ocean-based sources could reduce the emissions associated with industrial meat production and result in more nutritious diets. Under the assumption of a one-for-one shift from beef, we estimate reductions could be as high as 1.4 gigatons of CO2.

Benefits

Climate — Lowered carbon emissions from food production

By motivating a societal dietary shift from land-based to ocean-based protein, we can dramatically reduce the GHG emissions associated with food production. When raised or harvested sustainably, food from the sea has a much lower carbon footprint than land-based protein (Hallström et al. 2019, Kuempel et al. 2020). A worldwide, genuine shift from beef to fish specifically could result in massive reductions in GHG emissions (Aleksandrowicz et al. 2016, Hoegh-Guldberg et al. 2019).

Food & Nutrition — More nutritious, more diverse diets; improved food security

Food from the sea already plays an important role in consumption around the world, with fish being the most consumed animal protein in many developing countries, and the ocean could supply over six times more food than it does today (Costello et al. 2019). Food from the sea is highly nutritious, containing essential vitamins, minerals, and other nutrients—though there is variability in nutrition among fish species, both in wild and in farmed fish (Hallström et al. 2019). Seaweeds especially are rich in health-promoting molecules and materials such as dietary fiber, omega-3 fatty acids, essential amino acids, and vitamins A, B, C, and E—more so than terrestrial plants (Rajapakse and Kim 2011).

Co-Benefits — Potential workforce impacts and societal benefits

Increasing global demand for ocean-based foods would also boost income and employment, especially in developing countries with significant opportunity for aquaculture growth. Increases in wild fishing represent economic opportunity for coastal communities—many of which are in developing nations, where aquaculture's economies of scale can drive prices down. Careful and inclusive design of initiatives and policies can help to ensure that economic benefits accrue to the local community.

Interventions

I. Incentivize food from the sea for consumers through prices

TOP 1, above, suggests putting a price on GHG emissions to generate a supply-side shift in production away from high-carbon foods (especially animal-based proteins) toward low-carbon food from the sea. From the consumers' perspective, there is a risk that such a step could raise food prices, limiting economic access among poorer populations and potentially decreasing food and nutrition security. A well-designed carbon price would influence the differential costs of food products, making food from the sea more economically attractive than alternatives. This can incentivize the purchase of such foods over options like red meat within consumers' food baskets without significant impact on the total cost of a healthy diet. Notably, studies show a relatively low rate of substitution from land-based meat toward fish: a 1% increase in the price of terrestrial meat results in only a 0.04% increase in fish consumption in low-income countries (Cornelsen et al. 2015). However, even a 10%–15% shift in diets would yield significant global impact (Hoegh-Guldberg et al. 2019). This represents a vital opportunity, as current global food production is the largest pressure caused by humans on earth (Willet et al. 2019). Lastly, although a carbon price would help to correct price distortion, other sources of distortion would also need to be addressed, such as subsidies for land-based production that don't exist for ocean-based production.

II. Increase consumers' preference for food from the sea through social marketing

Consumer demand—especially in higher-income economies and importing regions—will continue to influence what is fished and farmed from the sea. In complement to the price-focused intervention above, and especially noting the varying levels of embodied carbon among fish species, a key intervention lever is influencing consumer demand. The science is clear that a low to moderate consumption of seafood (and poultry), and a zero to low consumption of red and processed meat, is preferred for a "healthy reference diet" that supports human nutrition and planetary health (Willet et al. 2019), and seafood fits well within dietary trends toward health and wellness (FAO 2020).

Influencing consumption choices is challenging, particularly around behaviors as culturally and personally situated as food consumption, but there is opportunity to build on lessons from other global examples—such as tobacco controls and energy-sector shifts from fossil fuels and toward renewables—to enable effective, large-scale behavior change. Insights emerging from such examples include the need to accompany awareness-raising with specific calls to action; the imperative of careful targeting of messages; the contributions of behavioral science to understand what people are likely to do with a given piece of information; and the need to anticipate backlash—in this case, from entrenched interests who would "lose" in this shift (Christiano and

Neimand 2017). Importantly, such campaigns should avoid framing a desired choice (i.e., greater consumption of food from the sea) as a sacrifice. As shown by the contrast between Michelle Obama's "Let's Move" campaign and Nancy Reagan's "Just Say No" campaign in the US, emphasizing a positive set of actions such as drinking water and exercising proves more effective than cautioning against prohibited behaviors like drug use (Christiano and Neimand 2017, Lilienfeld and Arkowitz 2014). Finally, while social marketing is likely a necessary intervention, it will not be sufficient alone.

III. Gamify sustainable lifestyles and diet choices

Food preferences are highly influenced by an individual's consumption patterns in childhood and adolescence (De Cosmi et al. 2017). At the same time, Gen Z ranks climate change as its top priority issue (Amnesty International 2019). There is a vital window of opportunity to influence the food choices of the next generation of consumers toward more climate-friendly options. We hypothesize that this is an area for creativity and technological innovation, tapping into digital channels of entertainment and influence. This could include gamification and experiential learning and action such as through virtual and augmented reality, especially given the profound shifts toward online education necessitated by the SARS-CoV-2 pandemic.

Risks

Motivating behavior change is difficult, and results are uncertain, but in combination with market mechanisms and other interventions, it can prove successful and powerful. As mentioned in the previous TOP, there is potential for negative ecological impact, but with proper design and monitoring, these risks can be mitigated.

3. Restoring, expanding, and/or protecting critical ocean habitat

Strategically improving and carefully managing marine and coastal habitats can provide multiple benefits to fisheries, moderate levels of carbon sequestration, and other ecosystem services. According to existing literature, an estimated range of 0.5 to 1.4 gigatons of CO2 emissions could be reduced through this TOP.

Benefits

Climate — Improved coastal resilience, some mitigation benefit

Restoring and enhancing vulnerable ocean habitats (e.g., seagrass, mangroves, and tidal marshes) has the benefit of protecting wild species from the combined impact of overharvesting and climate change by increasing nursery habitat and refugia (Taylor et al. 2017). Despite their small spatial extent, mangroves, salt marshes, and seagrass account for 47% of the total carbon burial in coastal ocean sediments (Duarte et al. 2005). Their high sequestration rates, combined with their ability to store carbon for tens of thousands of years, make vegetated coastal habitats the ultimate natural carbon sink (Mcleod et al. 2011). Furthermore, mangroves, salt marshes, seagrasses, and seaweeds provide shoreline stabilization and act as natural buffers to climate impacts like sea level rise and increased storm intensity (Arkema et al. 2017, Rogers et al. 2019).

Food & Nutrition — Enhanced long-term food security

Restoration, expansion, and protection of nursery habitat for key fishery species can help to protect some species from overfishing and can even increase productivity in well-managed fisheries (Taylor et al. 2017). However, habitat protection interventions in particular may result in short-term costs to the fisheries sector, and reduced access to fish protein in the short term as well. These costs could be mitigated through a combination of careful stakeholder-informed design of interventions and market mechanisms.

Co-Benefits — Ecosystem and biodiversity benefits, sustainable tourism

Investing in the enhancement and protection of vulnerable habitats would benefit biodiversity for many marine species, including some endangered species. Protecting and restoring these same habitats would confer other non-extractive values that could be partially captured through increased opportunities for eco-tourism.

Interventions

I. Incentivize restoration and protection via market mechanisms

Market-based incentives can effectively price natural assets and thus incentivize their protection. If market incentives are limited to carbon (via a REDD-like mechanism), then carbon reductions will result and some co-benefits to other ecosystem services may also arise. More complete markets would also price other ecosystem services. For example, a nutrient trading mechanism would directly incentivize the protection and restoration of ecosystems, or the cultivation of organisms (e.g. seaweeds), that mitigate nitrogen and phosphorus pollution while also conferring nontrivial carbon-sequestration benefits.

II. Allocating rights and responsibilities

A complement to pricing ecosystem services in markets is allocating rights and responsibilities for ecosystem stewardship to various parties. For example, allocating fishing rights to a particular village can often provide incentives for long-term stewardship of the fish stocks and the habitats on which they depend (Costello and Kaffine 2017). This principle of the allocation of rights can be used for the dual purposes of improving ecosystem outcomes (if rights are defined in a way that provides these incentives) and broadening ownership and empowerment among historically disenfranchised peoples by, for example, allocating property rights to women or Indigenous groups.

III. Information provision with big data

One reason marine habitats are perennially undersupported is that it is hard for agencies and the general public to witness (possibly illicit) habitat conversion (Luque et al. 2018). A possible intervention is to increase the transparency of coastal habitat conversion. One could imagine a real-time big-data platform like Global Forest Watch or Global Fishing Watch, but focused on activities in the coastal zone that affect habitat.

Risks

If habitat protection measures are implemented incorrectly or out of sync with fisheries management measures, they may result in short-term costs to the fishing sector, reducing economic and food security. The potential costs of restoring and/or protecting these ecosystems could be relatively high, especially in places where the physical infrastructure is weak and political will is low or uncertain. There is also a time lag between the urgency of mitigation action and the realization of carbon sequestration benefits over the coming many years—a lag that complicates businesses' and politicians' ability to claim measurable, linear impact from their decisions. Climate adaptation benefits in the form of long-term food security through protected habitats would also take many years to be fully realized. Allocation of rights is always contentious, and the proposition to allocate to historically disadvantaged groups is sure to meet resistance from incumbents.

4. Managing wild fisheries to maximize economic yield

Most fishery management approaches seek to maintain a target biomass of fish in the ocean at a benchmark level. Raising this benchmark level of biomass will leave more fish in the ocean, lowering the effort and therefore cost of fishing while modestly reducing carbon emissions from vessels relative to the traditional benchmark. According to our calculations, managing wild fisheries to leave more fish in the ocean could reduce carbon emissions by 0.9 gigatons of CO2, while also potentially increasing fish production by 3.7 million metric tons compared to today's catch.

Benefits

Climate — Lowered emissions from fishing fleets

In managed fisheries, the target is typically the "Maximum Sustainable Yield"—that is, to catch the largest number of fish that can be sustained by a given fish population over time. This level of biomass, called the BMSY, is typically about 40% of the "pristine" or unfished biomass. But to maximize the economic value of the fishery, the target biomass of fish left in the water is higher—around 60% of the unfished biomass. This is the Biomass at Maximum Economic Yield, or BMEY. BMEY is larger than BMSY, because when the biomass of fish in the water is larger, the effort and therefore cost of catching them goes down. The reduced effort also results in lowered carbon emissions from fishing fleets (Farmery et al. 2014).

Food & Nutrition — Enhanced long-term food security

The immediate impact on food security will be case-specific. In currently poorly-managed and/or unmanaged fisheries, using BMEY will increase food security in the long term, but will come at some short-term cost to food supply while depleted fisheries rebuild (Dueri et al. 2016). The increased productivity of wild-capture fisheries will help to replace more carbon-intensive land-based food, complementing TOP 2, above. In already well-managed fisheries, the food cost implications will be modest in both the short and the long run. In all cases, livelihoods will improve in the long run.

Co-Benefits — Ecosystem and biodiversity benefits, sustainable tourism

Rebuilding fish stocks to BMEY will require short-term reductions in fishing activity, which could lead to short-run losses to fishers. But in the long term, as stocks rebuild, there will be increased biodiversity and abundance of fish, which will bring additional ecosystem services and tourism benefits (IPBES 2019). The total economic upside of moving toward BMEY-based management is around US$50 billion per year (World Bank 2017, Costello et al. 2016). Non-target species (like sharks, turtles, birds, and other protected species) that are inadvertently caught by fishing will also benefit from this TOP.

Interventions

I. Country-level analysis of the economic benefits of moving to BMEY management

Many countries face a difficult tradeoff with fishery management. They could manage to BMEY, which confers long-term economic benefits, or fish hard today, which confers immediate benefits at the expense of future profits. By illuminating the economic benefits of BMEY, and the path to achieving it, we can equip countries to more rationally make this tradeoff. Even for "well-managed" fishing countries, understanding the economic implications of moving from BMSY to BMEY could help motivate the transition.

II. Permit the fishing industry to participate in local carbon markets

If fishers owned property rights over fish stocks, and if they were able to participate in local carbon markets, they could potentially sell carbon credits as the stock of fish grew. While many design challenges will emerge that must be addressed, this intervention has the potential to provide an even greater financial incentive to increase the fish stocks to BMEY.

III. Implement a sector-wide carbon price

Suppose the entire fishery sector had a carbon market, so fuel use, carbon sequestered by fish, and other sources and sinks of carbon were measured and monitored. This would incentivize behavior that reduced emissions and increased sequestration. This intervention could help financially motivate a shift toward BMEY management.

Risks

Implementing this TOP could be challenging due to political barriers and variability in governance. It would require active monitoring and potentially resource-heavy management in a sector that already suffers from significant illegal, unreported, and unregulated fishing. It may also be challenged by stakeholders who would not find justification in the short-term loss of sustainable catch. A price on carbon could help offset the losses in catch as fish biomass in the water builds, while the establishment of property rights in more fisheries would tend to create an incentive to maximize profits, consistent with BMEY. Another pathway is the introduction of legislation that focuses on balancing social, economic, and environmental considerations, rather than just catch. Currently, only about 25% of the world's fish catch comes from fisheries that have implemented explicit rights-based fishery management. Thus, ample opportunities exist to capture benefits with an investment in the other 75%.

Conclusion

Tackling the climate crisis demands the implementation of bold, creative, and inclusive solutions. The ocean, while often framed as a casualty of climate change, has strong potential to mitigate the harm of this global crisis. Harnessing the potential of marine food systems through strategic interventions could reduce greenhouse gas emissions, secure healthier oceans, enhance food and nutrition security, and provide equitable economic opportunities.

The Transformation Opportunities we have presented represent viable, meaningful pathways for carbon-negative, climate-positive food and nutrition from the sea. It is imperative that such TOPS be implemented through inclusive, thoughtful design. Though the need for climate action is urgent, strategies must embody a long-term perspective, risk mitigation, and foresight to avoid unintended consequences. Most of the interventions proposed here will require large-scale collaboration. Overcoming the climate crisis will require myriad interventions from diverse angles and players. Sustainable food from the sea can be among our collective success stories in the collaborative effort to address climate change.

Annex

Back-of-the-envelope calculations

To develop and estimate the magnitude of impact each of these TOPS could have on food provision and carbon emissions, we completed the series of rough estimations outlined below:

1. Expanding and Enhancing Mariculture Operations

We take the high aquaculture growth scenario from the Costello et al. 2020 Nature paper, which estimates that 35 million MT more food can be produced from mariculture than is produced today. For a very simple and uncluttered calculation of the potential carbon implications, we simply assume a one-for-one offset with beef production. Producing 1 kg of beef results in 59.6 kg of CO2 emissions, while 1 kg of farmed fish produces 5.1 kg of CO2; thus the difference is 54.5 kg of CO2 per kilogram of food. Multiplying 54.5 kg of CO2 emissions by the 35 million MT of potential additional production in mariculture under the one-for-one offset with beef leads to a net reduction in emissions of 1.9 Gt.

2. Motivating Diet Shifts

Oceania has the world's largest fish consumption per capita (24.2 kg/person/year). To roughly estimate the potential impact of motivating diet shifts, we assume that diets around the world shift to Oceania's level of consumption, with that shift offsetting the consumption of beef. Thus, the replacement of kilograms of beef per capita by region is as follows: 4.1 in Africa, 1.8 in North America, 13.7 in Latin America and the Caribbean, 0.1 in Asia, and 2.6 in Europe. For a simple calculation of the carbon implications, we again assume a one-for-one offset with beef. Producing 1 kg of beef yields about 59.6 kg of CO2 emissions, producing 1 kg of farmed fish yields 5.1 kg of CO2, and producing 1 kg of wild-caught fish results in 3 kg of CO2. Between the wild-caught and farmed fish, we assume an average emission from 1 kg fish is ~4 kg of CO2. Thus, the difference in emissions between beef and fish is about 55.6 kg of CO2 per kg of food. Working continent by continent, multiplying the consumption changes by the population of each region, we estimate a net emissions reduction of 1.39 Gt.

3. Restoring, Expanding, and/or Protecting Critical Ocean Habitat

Hoegh-Guldberg et al. (2019) recently estimated the potential for carbon sequestration that could come about through marine ecosystem conservation and restoration. They do not estimate the food implications of these changes, so we also omit that here. We adopt their estimated range of a 0.5 to 1.4 Gt reduction of CO2 emissions.

4. Managing Wild Fisheries to Leave More Fish in the Water

Several authors have previously estimated the global fishing pressure relative to Maximum Sustainable Yield (MSY) or Maximum Economic Yield (MEY). We assume that fishing pressure is proportional to fishing effort, which is then proportional to carbon emissions. Thus if global fishing pressure were reduced by X%, the carbon emissions from the global fleet would also be reduced by X%. Changes in fishing pressure have implications for food provision as well; food production under MSY should go up (relative to today), and food production under MEY could go up or down relative to today, but will be smaller than under MSY. Based on the literature and our own calculations, suppose fishing pressure is reduced by about 20% (for MSY) and 35% (for MEY), relative to today. A simple model suggests that this leads to an increase in catch of 12% (for MSY) and 5% (for MEY), relative to today. The resulting changes in carbon emissions are reductions of 0.06 Gt CO_2 under MSY and 0.9 Gt CO_2 under MEY. In terms of food provision, under this scenario we estimate a 8.8 million MT increase under MSY and a 3.7 million MT increase under MEY, compared to today's catch.

Carbon Price on Food

If all food were taxed for its carbon content, then the price of all food would increase. This could be designed in a revenue-neutral manner so that effectively the prices of low-carbon foods decreased while the price of high-carbon foods increased. We assume that a carbon tax designed as such is implemented. For illustrative purposes, we assume that these carbon taxes raise the price of beef by US$0.105 per pound (which amounts to a 5% increase in price) and lower the price of fish by $0.346 per metric ton (which amounts to a 5% decrease in price). The resulting changes in quantity produced depend on elasticities. Using elasticities of ~0.382 (for fish), ~0.076 (for beef), and 0.04 (for cross-price), we conclude that fish consumption will increase by 2% and beef consumption will decrease by 3.5%. Converting these figures to changes in emissions, we conclude that this kind of food-based carbon tax could reduce emissions by between 0.005 and 0.191 Gt of CO_2.

Transformational Opportunity	Food Implication	CO2 Emission implication
1. Expand/Enhance Mariculture	+185%	−1.9 GT CO2
2. Diet Shift	+21.8%	−1.39 GT CO2
3. Habitat	—	−0.5 to -1.38 GT CO2
4. Fisheries Mgmt.	+7.2% to +17.5%	−0.06 to -0.9 GT CO2
Intervention - C Price for food	-1.9% to + 2.0%	−0.005 to -0.191 GT CO2

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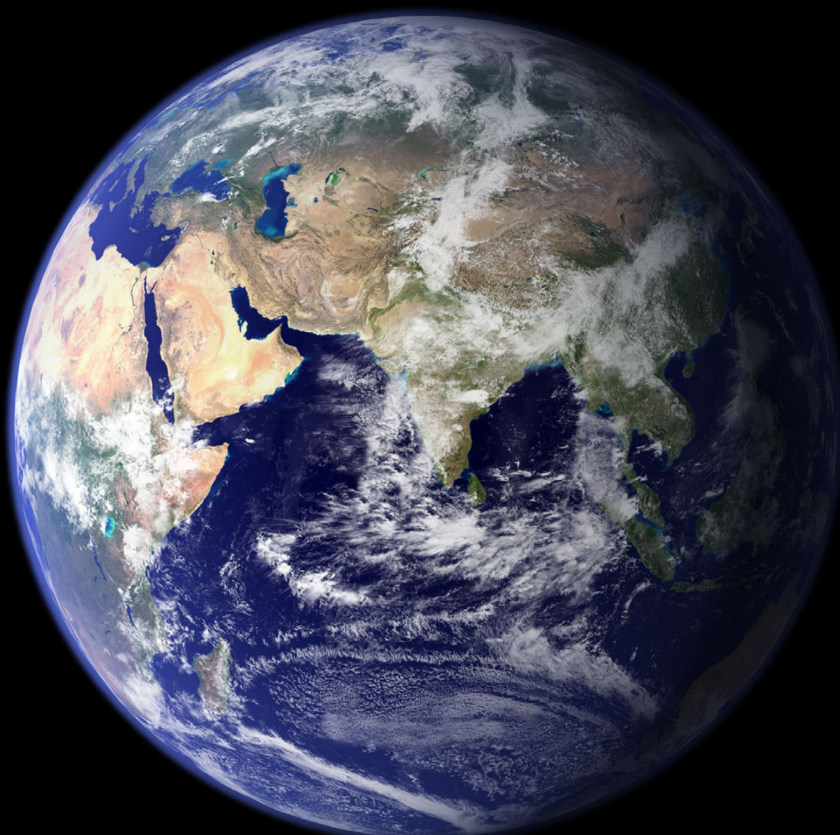
WHAT WILL YOU DO?



Blue Climate Initiative

The Blue Climate Initiative accelerates ocean-related strategies, collaborating across a multidisciplinary global community towards a restored and healthy climate; an understood and protected ocean; and resilient, thriving and equitable communities. The fiscal sponsor for the Blue Climate Initiative is Tetiaroa Society, a US 501(c)(3) nonprofit organization (tetiaroasociety.org).