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Charting the systemic and cascading impacts of climate change on marine food systems and human health

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INTRODUCTION

Expected declines in global marine species and fish catch could increase climate change-related income, livelihood and food security risks, with consequences for seafood-dependent communities.[1] As one of the most biologically diverse and productive natural resources in the world, the ocean provides ecosystem services such as biomedical compounds derived from marine species; supports food provisioning, cultural practices and identity; and performs critical ecosystem functions such as protecting coastal zones, regulating the global climate system and facilitating carbon sequestration.[2–4] Globally, an estimated 3.3 billion people rely on 'blue' (aquatic) foods for nutrition, which accounts for almost 20% of the average per capita consumption of animal protein.[5] Seafood, in particular, is a nutritious source of protein, providing wide-ranging health benefits. Even with its significant contribution to the global food system, seafood is still largely undervalued and interest in 'seafood' security has only recently gained traction.[6]

Higher global warming levels and business-as-usual emissions continue to threaten marine biodiversity and undermine the ecological capacity of the ocean to provide important ecosystem functions and services. Golden *et al* stress that the effects of ocean warming, coral bleaching and ocean acidification will likely degrade coral reefs, disrupt marine and inland fishery productivity, and thus weaken social-ecological system resilience.[7 8] In effect, rising ocean temperatures are estimated to change the abundance, diversity and range of phytoplankton, zooplankton and fish stock that sustain ocean food webs.[4] While shifts in the spatial distribution of fish stock are predicted to affect the level of capture fisheries production and impact the dietary intake and nutritional status of local communities that are highly dependent on marine resources for food, particularly developing countries located at the equator.[9]

SUMMARY BOX

- ⇒ The ocean is integral to the production of nutrient-rich marine foods, however, shifts in productive fish species due to climate change represent a serious threat to food security.
- ⇒ Socioeconomic disparities within global food systems reinforce the case for food sovereignty, social-ecological resilience and the importance of harnessing indigenous knowledge to reframe the rights of local resource users.
- ⇒ Preserving and supporting diverse local food systems to thrive through locally relevant and adaptive fisheries management will become increasingly important.
- ⇒ The future of seafood contributions to global food supply will depend on effective, rapid, and sustained mitigation and adaptation actions and a combination of ecological, economic, policy and technological influences.

IMPACTS OF OCEAN WARMING ON ECOLOGICAL RESILIENCE, MARINE FOOD SYSTEMS AND NUTRITION SECURITY

Marine habitats, species composition and food-web structures are being threatened by global warming to varying degrees.[4] Research shows that for 142 countries, the average sea surface temperature (SST) in coastal waters rose on a global scale by almost 0·7o C in the 2019–2021 period relative to 1980–1982.[10] Subject to their ecological resilience, marine species have varied internal responses to changing ocean stressors that cause shifts in their patterns of productivity.[1] Once the resilience of natural ecosystems diminishes, a sudden reorganisation of their components may take place.[11] Complex ecosystem reorganisations also include the tendency of fish species to shift locations when conditions are no longer favourable.[4]

Typically, regional trends will determine to what extent local climate impacts on ocean ecosystems will occur.[1] The warming of oceans has already impacted fisheries catches and their composition in several regions by causing changes in the spatial distribution and abundance of fish stocks, which has steered tropical species to higher latitudes, and altered ecosystem structures.[1] For instance, rising SST is forecasted to increase primary production in polar regions, while decreasing primary production in tropical ones.[12] This has significant implications for global food supply, food stability and food security in some of the world's most impoverished regions including in Least Developed Countries (LDCs) and Small Island Developing States (SIDS).

Coastal indigenous populations, for one, are highly dependent on seafood, with a per capita consumption rate equivalent to 15 times that of non-indigenous groups.[13] Seafood is also a source of nutrition in much of the Global South, delivering key micronutrients and vitamins, such as iron, zinc, vitamin A, vitamin B_{12} and fatty acids.[7] Moreover, it has significant health benefits for lowering the risk of cardiovascular diseases such as coronary heart disease, supporting normal fetal development and ensuring healthy brain function.[14] Owing to its diverse nutritional content and ability to avert, or to a lesser extent ease much of the environmental impacts resulting from terrestrial food production, seafood is well positioned to contribute to global food supply, and food and nutrition security.[15] Although, given the impacts of climate change coupled with unsustainable fishing practices that diminish the availability of and access to fish stock, coastal populations in certain regions that customarily rely on fish and shellfish as part of a balanced seafood-based diet, may turn to alternate sources of protein with lesser nutritional value.

HARNESSING INDIGENOUS KNOWLEDGE TO PROTECT BLUE FOOD SOVEREIGNTY

'Blue' foods constitute a critical part of the global food system and support sustainable, healthy and just food systems for billions of people.[16] That notwithstanding, 'green' terrestrial foods tend to dominate policy dialogues and decision-making on food systems, overlooking the vital role of 'blue' foods in supporting food and nutrition security. As the dialogue on food security is oriented towards the global or national perspective, this can often discount the importance of resource-rich local food systems.[17] For example—the role of coral reefs within local food systems traditionally managed by local and indigenous peoples—although lauded for its ecosystem benefits and cultural tenets, is not well understood in market-oriented spaces. Artisanal fishing communities therefore illustrate the complexity of food systems and the varying levels of food and nutrition insecurity that may not be ordinarily captured through national catch statistics[18] or national food security assessments.

The virtues of food sovereignty essentially lie in the ability to prioritise terrestrial and aquatic foods, including small-scale economic activities grounded on sustainability. Food sovereignty as a movement, underscores 'the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems. It offers a strategy to resist and dismantle the current corporate trade and food regime, and directions for food, farming, pastoral and fisheries systems determined by local producers. Food sovereignty promotes transparent trade that guarantees just income to all peoples and the rights of consumers to control their food and nutrition'.[19]

Going further, the concept of indigenous food sovereignty extends the focus of a rights-based approach that includes indigenous communities' bidirectional responsibility for environmental stewardship, while reviving food systems in line with their traditional practices and beliefs.[20] This paradigm is all important as severe climate change impacts and biodiversity loss reveal the unintended power redistributions to the disbenefit of indigenous and local fisher communities. Socioeconomic disparities within global food systems thus reinforce the case for food sovereignty, social-ecological resilience, and the importance of harnessing indigenous knowledge to reframe the rights of local resource users.[3]

THE ROLE OF BLUE JUSTICE IN SUSTAINING MARINE RESOURCES

Blue justice demands a paradigm shift with respect to unchecked blue growth and a reimagining of alternative economic growth models that prioritise human health and environmental protection.[21] As a starting point, fisheries are often depicted as the 'local' alternative to the global food system, producing less carbon emissions compared with terrestrial protein production.[22 23] Small-scale fishers, on the whole, produce less waste by capturing more fish per gallon of fuel compared with commercial fleets and discarding less fish.[24 25] Even so, the projected intensity of future blue growth—marked by the rapid and unregulated expansion of ocean-based economic activities—is expected to generate complex and quantifiable risks.[21] In particular, international demand for seafood has caused an influx of distant water fleets, which have appropriated fish stocks through legal access agreements and illegal means, diverting resources from local communities and small-scale fishers.[21 24 26 27] The predatory effects of unregulated commercial fishing vessels on local and indigenous food systems are especially concerning, as they accelerate the depletion of fishery resources and degradation of marine ecosystems.

This ties in with the issue of 'ocean grabbing', which involves obscure access agreements that threaten local food security and well-being of small-scale fishers by (1) encroaching on marine protected areas; (2) facilitating the illegal harvesting of fishery resources; (3) redirecting

marine resources away from coastal communities; (4) forcibly relocating coastal communities; (5) undermining historical access to marine areas and/or (6) enabling the loss of spatial tenure rights.[24 26] Although, the intrinsic motivations behind development activities such as the reallocation of marine spaces and resources are not always insidious or clear-cut. Contrary to opportunity-seeking behaviours or exploitative interests, ocean grabbing—specifically the dispossession of marine spaces—can also take place to promote marine protected areas aimed at biodiversity conservation, leading to the displacement of local resource user groups.[26] Bennett *et al* theorise that claims of ocean grabbing are implausible if initiatives promote local livelihoods, refrain from undermining human security and generate positive social-ecological effects.[26] The spatial competition of marine areas between renewable energy and fishery activities is also expected to yield a complex mix of undesirable and positive social influences for various communities, further amplifying this issue.[21] According to Farmery *et al*, blue food-related activities are seldom emphasised in global discourses on the blue economy and marine spatial planning exercises,[28] resulting in a lower level of prioritisation among ocean-based economic activities.

Equally important is the role that blue justice plays in promoting the sustainable and equitable governance of marine resources, protecting local livelihoods by securing formal access and harvesting rights of indigenous and local resource user groups, and ensuring social-ecological well-being.[21] That notwithstanding, the idea that people—and in particular fisherfolk—need to be 'managed' to avert ecological crises is recurring theme in natural resource debates.[29] Historically, this can be traced back to the introduction of indigenous fishing rights and access in North America. To give an example, policy-making and state-indigenous relations in the state of Alaska in the U.S. have led to the disenfranchisement of indigenous fisher communities and the attenuation of their fishing rights due to limited-entry permit systems, created in the interest of developing the fishing economy.[29 30] According to Cohen, the prevailing Westo-centric narratives at the time suggested that alternative fisheries management systems, in the absence of state control, were unsustainable despite the 'sophistication' of existing traditional systems.[29 30]

Fast-forward to present day, persistent and proximal threats to marine ecosystems linked to the blue growth agenda still need to be acknowledged and judiciously addressed to offset the unequal distribution of benefits to coastal communities and small-scale fishers, and to mitigate social harms as a result of exclusionary practices.[21] To a large degree, this calls for policy-makers and state legislators to recognise the legitimacy of indigenous knowledge, customs, traditional livelihood practices and diets in order to effectively engage in dialogues around fisheries comanagement and policies incentivising local preservation of small-scale fisheries for whom the protection of common resource pools is vital.[29 31] Another point of note with respect to blue justice is the nefarious human rights abuses that seek to exploit vulnerable labourers, so as to lower fishery production costs.[32] Global supply chains, for example, are complex and murky, adding to the varied considerations of consumers when determining environmental impacts and labour abuses in production.[31] Tickler *et al* suggest that the absence of transparency and product traceability, which enable illegal and unreported fishery products to enter supply chains, also facilitates the global trade of slave-caught and handled seafood.[32]

Blue food dialogues have more or less overlooked critical aspects of food and nutrition security, especially as it relates to access, affordability and utilisation of food resources.[28] According to Chuenpagdee *et al*, the concept of food security at the local level is complex with myriad interacting influences such as livelihoods, climate change, community infrastructure and tenure systems—which shape the ways in which individuals access nutritious and traditional foods.[22] For example, socially and economically vulnerable fisherfolk may relinquish the concept of 'fish as food' in favour of livelihood strategies focused on fish trade, which indirectly contributes to food security.[25] Isaacs posits that protecting fish species with high nutrient profiles—such as small pelagic fish, which include sardines, mackerels, anchovies—for local consumption instead of diminishing it to fishmeal for cultured fish, animal feed and crop fertiliser is integral to tackling malnutrition in Africa.[25]

MAINTAINING HEALTHY OCEAN ECOSYSTEMS TO ENSURE BETTER HEALTH OUTCOMES

Local, traditional and indigenous diets constitute a high diversity of species and tend to have a high nutrient profile. And despite the fact that indigenous communities are inclined to consume more fish than non-indigenous communities, their consumption of reef fish is not measurably correlated to higher catches.[17] This demonstrates how locally sourced, sustainably produced marine-source foods not only support better nutrition and health outcomes but sustain healthy ocean ecosystems.

Notwithstanding the myriad health benefits of nutrient-dense aquatic foods, there are underlying adverse health effects from both naturally occurring and introduced toxicants in seafood.[33] From a public health lens, microbial illness from seafood is acute, persistent and poses a high risk. Maintaining ecosystem resilience, in no small measure, helps lower the risk of exposure to environmental pollutants such as dioxins, polychlorinated biphenyls and pesticide residues, which can produce carcinogenic, immunotoxic, embryonic and hepatotoxic effects with prolonged exposure.[34]

Beyond this, the risk of contamination is greatly reduced by limiting seafood consumption to suitable harvest locations, paying heed to the appropriate fishing season and the age of fish catch, and selecting fish species with archetypally lower levels of contamination.[34] In

particular, determining harvest strategies that support seafood production is vital in meeting the dietary needs of a growing population in the face of compounded climate risks.[35]

MEANS OF IMPLEMENTATION FOR CLIMATE ADAPTIVE AND INTEGRATED FISHERIES MANAGEMENT

Climate impacts combined with unsustainable fishing practices could lead to reduced levels of capture fisheries production that, if sustained, could cause local fishery collapses. Which is why, climate adaptive and integrated fisheries management stand to reinforce ecosystem-based approaches through the maintenance of ecosystem services and the use of flexible, participatory, climate-adaptive responses in the fisheries sector.[36] Beyond the virtues of adaptive and integrated fisheries management, Golden *et al* theorise that along the chasm of food production and nutritional security, lie many governance and market institutions that determine varying access to food including the distribution of benefits to marginalised, poor and vulnerable resource user groups.[7] Paradoxically, countries with persistently high levels of undernourishment and weak governance are typically net exporters of seafood to countries with well-nourished populations and strong governance structures.[9 37 38] This illustrates a focus on profit maximisation in many countries around the world, characterised by high-priced products and export orientation in fisheries and aquaculture management.[31]

In effect, the global seafood trade has sustained systems of inequity whereby low-income countries export high-value seafood in exchange for low-cost and lower-quality seafood to meet their dietary needs.[28] In response to this, the UN Special Rapporteur on the Right to Food, has advocated rebuilding local food systems through a bottom-up approach and shifting from a reliance on food imports.[39] This further highlights the importance of strengthening systemic, governance and institutional capacities within integrated fisheries management, which creates greater efficiency and productivity to meet the demands of food production. For instance, adaptive and integrated fisheries management grounded on a rights-based approach could (1) support the identification and prioritisation of policies that champion the rights of artisanal fishers; (2) address the threats, risks and prospects of female fish traders, who make up a significant part of the postharvest sector; (3) impose greater restrictions on commercial fishing vessels; (4) moderate postharvest loss and increase food quality and safety; and (5) encourage the engagement of local fishers in decision-making processes across civil society, public and private sector institutions, at all governance levels.[31 40]

International cooperation is equally important for the management of shared fish stocks, as climate-induced shifts in productive fish species add to the existing fishery challenges by violating 'the 'clear boundaries' principle for sustainable governance of common pool resources'.[41] Pinsky *et al* posit that future geographical shifts could continue to breach national boundaries making it difficult to maintain fish stocks within state-level jurisdiction. At the same time, current scholarship argues that managing the 'boundary paradox' entails reintegrating, rescaling and redefining boundaries on an ecological rather than anthropogenic basis.[42]

On another point of note, a weak enabling environment; lean public and private investment in the blue economy; and the comparatively high-risk nature of ocean economic sectors comprise key barriers that limit sustainable financing of ocean ecosystems.[43] Access to finance is a critical component that drives adaptive management of marine resources. The Global Fund for Coral Reefs, for example, supports the development and acceleration of revenue-generating activities that sustainably finance the mitigation of the underlying drivers of coral reef degradation.[44] Other financial mechanisms include blue bonds, debt-for-nature swaps and biodiversity offsets.[45]

Considering that climate-impacted reefs tend to support less fish biodiversity and flatten food pyramids, preserving and supporting diverse local food systems to thrive through locally relevant and adaptive fisheries management will become increasingly important.[17] According to Free *et al*, climate-adaptive fisheries reforms would support the health of world fisheries and sustain future harvests and financial gains for all scenarios except the high-emissions RCP 8.5.[46] Under extreme conditions, the most severe climate change impacts would occur when soft and hard limits are reached. To minimise loss and damage to ecosystem services, adaptation and mitigation options in the present will need to consider the potential long-term impacts of climate shocks to socio-ecological systems, depleted fisheries and degraded coral reefs.

CONCLUSION

Climate change is driving the reorganisation of marine food systems, displacing wild fisheries, disrupting food production and nutritional security.[7] For all that, only a limited number of public health practitioners are aware of the systemic approaches to planetary health that consider the economic growth, environmental degradation and human health nexus.[47] Seafood in the latest food security literature remains poorly researched relative to terrestrial animal and plant production.[6] Furthermore, current scholarship on the role of blue foods and the blue economy offers limited insights into the pathways that link production and consumption.[28] Observing low-income countries that benefit from seafood exports shows that profits rarely trickle-down to the local level.[28 48] In the absence of social, food and nutrition security for local and indigenous fisher communities, the most vulnerable are at risk of being rendered worse off due to the global seafood trade.[28 48] On par with this supply-side theory, lessons drawn from the green economy reveal that prioritising growth and technology does not necessarily cause declines in hunger and malnutrition.[28] As a first step, governments can promote a systems approach to blue

foods that will ensure equitable participation in production, access to blue foods for consumption and inclusive representation in decision-making.[31] Taking this into account, interdisciplinary research will be paramount in addressing the systemic policy and market-level conditions linked to food and nutrition security among local and indigenous resource user groups.

Bearing in mind the role and importance of blue food systems within complex social-ecological networks, policymakers should prioritise the needs, cultural values and health of local and Indigenous fishing communities.[3] In the event that traditional diets become unsustainable, the nutrition transition to mixed diets (of traditional and market-based foods) may become pronounced.[6] Disruptions in coastal food systems, particularly in places with higher market integration and prohibitively priced import substitutes could prompt a transition to farm-based fish products or other animal-source proteins, which may cause nutritional challenges due to the low diversity of fish, worsening existing micronutrient deficiencies.[9 49 50] For example, Heilpern *et al* suggest that in the Peruvian Amazon, where people suffer invariably from high malnutrition rates, substituting wild catch with farmed fish could satisfy specific nutritional needs.[50] Yet, due to differences in iron and omega 3 fatty acids that capture fisheries provide, transitions to farm-based fish alternatives could largely undermine nutrition.[50] Going further, when fisheries and aquaculture are managed independently of each other, policy-makers forgo possibilities to enhance their nutrition, livelihood and sustainability goals, and instead make unintended trade-offs.[31] Most important is that aquaculture, and by extension mariculture, complement rather than displace fish harvested by wild-capture fisheries, particularly small-scale fisheries.[28]

In the short term to medium term, climate change adaptation interventions should ensure that marginalised, poor and resource-dependent groups have sufficient capacities to cope with ecosystem and market-based disruptions. Such considerations could include the integration of indigenous and local communities in negotiations on market-oriented production of fisheries and trade agreements.[20] In the long-run, climate change mitigation actions will be critical to ease carbon emissions and the associated effects of ocean warming. Indeed, scientific uncertainties and risk perceptions on the effectiveness of ocean and fisheries governance has been described in literature, emphasising the importance of timely mitigation and adaptation responses.[1] As climate change tests the ocean's ability to meet the growing demand for food, the future of seafood contributions to global food supply will depend on effective, rapid, and sustained mitigation and adaptation actions and a series of ecological, economic, policy and technological influences.[15 46]

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