Secure local aquatic food systems in the face of declining coral reefs

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Coral reef social-ecological systems are at the forefront of change in the Anthropocene. In a recent article by Eddy and colleagues, long-term declines in reef fish catches are analyzed in the context of broader changes in reef condition. Catches are diverse, packed dense with essential nutrients, and are critical in many vulnerable geographies. We argue for policies that secure coral reefs as local food systems, to support some of the most vulnerable social-ecological systems globally.

Ecosystems globally are experiencing profound changes, driven by large-scale anthropogenic pressures. Although human caused, ecosystem change can undermine human wellbeing, reducing the availability of sufficient quantities of nutritious food and safe housing, and impacting environmental health and psychological wellness. Coral reefs are amongst the ecosystems most vulnerable to, and impacted by, anthropogenic pressures. Ocean warming has increased the frequency and severity of extreme weather, producing tropical storms and heatwaves that can cause mass coral mortality. Rapid decline in coral cover and associated biodiversity loss is now evident across vast areas.[1] Yet, communities living adjacent to coral reefs are often heavily dependent on their natural resources for their food, cultural, livelihood, and economic needs. Coral reef social-ecological systems are thus acutely sensitive to the impacts of ecosystem decline, presenting a necessary and valuable lens through which to understand and address contemporary sustainability challenges.

Contributing to the evidence for the declining condition of coral reefs and wider changes within this social-ecological system, Eddy et al. [2] have assessed global patterns of change in live coral cover, species-area relationships for coral reef associated organisms, and changes in attributes of reef fishery catches. Baselines in coral cover are uncertain, but long-term declines are evident, and the increasing frequency and spatial footprint of climate-driven coral bleaching events suggests more decline is inevitable.[1] Eddy et al. [2] further highlight the relationship between coral reef area and marine biodiversity. With many reef-associated species reliant on the structures built by live coral, declines in biodiversity are a challenging consequence of coral degradation, and winner and loser dynamics in how species respond are leading to a substantial reorganization of species compositions.

A major contribution from Eddy et al. [2] is to ask what changes in coral reef condition may mean for people that rely on these ecosystems. While catches of reef-associated species increased from the 1950s, they peaked in 2002 and are now in decline. Catch per unit effort- a measure of catch as a function of fishing pressure- has been in decline for longer, and the contribution of higher trophic level species in catches has become unbalanced. The authors identify geographies where reef fish consumption by Indigenous communities is particularly high, highlighting the need to understand how coral reefs support local food systems now, and how this may change into the future.

The incredible diversity of fish, invertebrates, and mollusks, supported by coral reefs, provide considerable nutritional benefits. Diets comprised of a greater diversity of species - whether aquatic or terrestrial - tend to have a higher nutrient adequacy.[3] This is due in part to increasing the likelihood of consuming complementary nutrients and in part because cultures pair species with different foods; increasing the overall diversity of food on the plate. Furthermore, fish and other animal source foods are rich in bioavailable micronutrients, such as calcium, iron, and vitamin A, which are often lacking in diets across the tropics.[4,5] Reef-associated fishes contain comparable concentrations of these nutrients to other animal-source foods, such as beef, pork, and chicken (Fig. 1A), but fish tend to be more affordable and accessible locally.[5] A 90g portion of an average reef fish would provide a child with an average of 33% of their recommended daily requirements across 6 micronutrients, in comparison to 134g of chicken or 74g of beef (Fig. 1A). However, unlike terrestrial animal-source foods, hundreds of species of coral reef fish are consumed, and micronutrient content varies considerably among these species.[6] Just 40g of the most nutritious species is needed to meet an average of 33% of recommended daily requirements, or 140g of the least nutritious species (Fig. 1A). Multi-species fisheries, such as from coral reefs, if sustainable, are thus capable of supporting diverse diets, and supplying the micronutrients needed to support human health in the tropics.[4]

Coral reefs have long been studied for their ecological, cultural, and economic contributions. However, the role of coral reefs within local food systems, although often implicit, is less well understood. This is in part because the discourse on food security takes a global or national focus, which can overlook the importance and role of diverse, local food systems and small-scale actors.[7] Coral reef fisheries often involve local and indigenous peoples, harvesting a diversity of species, using a variety of methods, under customary systems of rules and norms. Practices are thus culturally distinct and often differentiated by gender, identity, and age, which influences what species are caught, shared, prepared, and consumed.[8] More diverse species tend to be caught where more Indigenous languages are spoken (Fig. 1B), suggesting greater nutritional benefits associated with Indigenous food systems. Indigenous communities also tend to consume more fish than non-Indigenous communities. Yet, high rates of Indigenous reef fish consumption (>50kg $cap^{-1}yr^{-1}$) are not associated with higher catches.[2] Coral reef fisheries that support Indigenous food systems may thus be more sustainable, underscoring the importance of recognizing and supporting customary rules and norms.

Ongoing global declines in reef systems highlight the challenge of securing local aquatic food systems.[1,2] However, data from climate-impacted coral reefs and models of reef degradation suggest that reef fish communities can have diverse responses to coral mortality, offering hope

for reef fisheries. Loss of coral cover is typically followed by increases in algal productivity, benefiting low trophic level fishes that feed on algal resources. These species, including parrotfishes and rabbitfishes that are targeted by fishers on many reefs globally, grow faster in response to algal growth, leading to higher fish biomass and productivity.[9,10] This emergence of novel reef ecosystems - rather than widespread population collapses - suggests that many reef fisheries may be able to adapt to short-to-medium term impacts of ocean warming. Although climate-impacted reefs will likely support less diverse fish communities and flatter food pyramids, many small-scale reef fisheries already target species that are resilient to coral loss. Local, culturally appropriate, and data-driven approaches to resource management have the potential to rebuild depleted fish stocks.[11] Such management systems could also be adapted to account for climate-driven shifts in stock productivity, for example by protecting long-term sustainable yields of macroalgal-feeding rabbitfish.[9]

What does this mean for local food policy? Like many aquatic food systems, coral reef fisheries are heavily influenced by regional and global drivers, such as markets, trade, and economics.[12] Given the important role coral reef fisheries can play in the nutritional security of some of the most vulnerable and culturally diverse geographies globally, safeguarding local aquatic food systems is critical. This will require firstly maintaining and supporting diverse local food systems to flourish and resisting their replacement with less nutritious alternatives.[13] Such policies could promote 'territorial' markets that prioritize local food over international trade[7] and bring Indigenous peoples and civil society to any negotiations on fisheries or trade agreements. Secondly, diverse approaches to ensuring sustainability of coral reef fisheries in the face of reef degradation and consumer demand will be necessary. Such policies could identify and co-design conservation strategies that recognize and work with customary rules and institutions,[8,11] prioritize nutritionally vulnerable populations, and promote traditional diets. Finally, adaptation of both the fishery to respond to the changes in composition and abundance of target species, and food system practices in terms of consumer preferences and practices, will be necessary to ensure local reef associated food systems can continue to flourish. Such policies could support gear based and dietary shifts to more resilient species and practices. All these adaptations will be context specific and may vary substantially from geography to geography, requiring place-based collaborations between scientists, resource managers, and stakeholders.

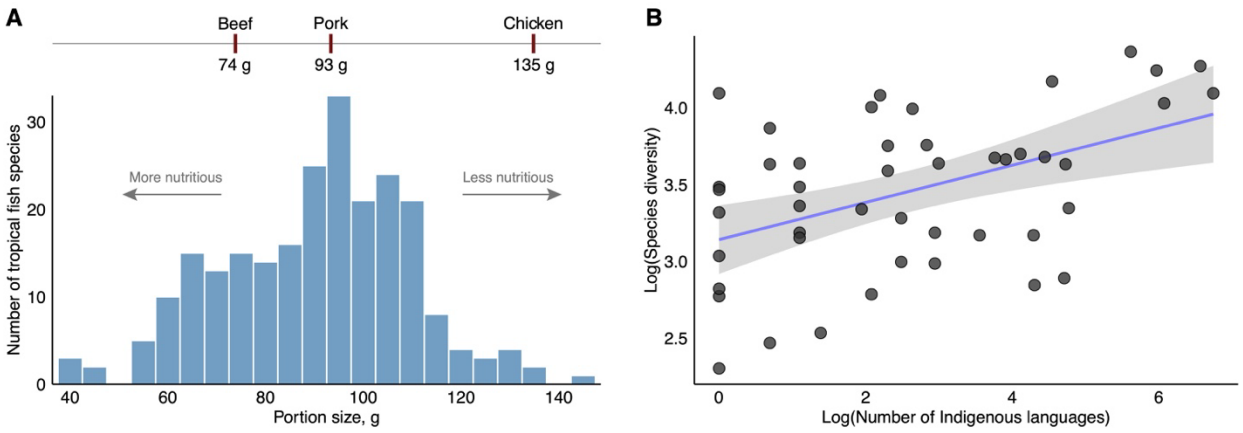

Figure 1. Nutrient content of coral reef-associated tropical fishes and their contribution to indigenous food systems.

A) The portion size required to reach an average of 33.3% of recommended daily intakes across 6 nutrients (calcium, iron, selenium, zinc, vitamin A, and omega-3 fatty acids) (following [5]), for 239 fish species in subsistence catches from coral reefs.[2] Equivalent values for terrestrial animal-source foods shown above,[14] recommended intakes are for children between 6 months and 5 years of age and f nutrient data from.[4] **B**) Relationship between the number of Indigenous languages (https://www.ethnologue.com/) and diversity of species caught (2010-2014).[2]

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Data and code availability

Data and code for FishBase micronutrient estimation are available at https://github.com/mamacneil/NutrientFishbase.