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Small island nations can achieve food security benefits through climate-adaptive blue food governance by 2050

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ABSTRACT

Small island nations are highly dependent on food from aquatic environments, or *blue food,* and vulnerable to climate change and global food market price volatility. By 2050, rising populations will demand more food through various protein sources, including from the sea. This study identifies which small island nations can improve food self-sufficiency from the sea by implementing tailored climate-adaptive fisheries governance strategies that adapt to shifting marine resources. We combined projections of seafood demand and local catch under different future scenarios of global carbon emissions and local adaptive fisheries management to estimate potential seafood surpluses or deficits from by 2050 for 31 small island nations worldwide. We find that adapting fisheries management every 10 years could mitigate even worst-case projections of climate change impacts on locally available seafood, building a seafood surplus by 2050 in the Seychelles, Maldives, Cabo Verde, Bahamas, Antigua and Barbuda, Kiribati, PNG, Fiji, FSM, Tuvalu, and Marshall Islands. Strategic financial and capacity investments by the international community could help realize the full potential of food security from the sea for those nations. However, we project deficits in locally caught seafood by 2050 in Comoros, Sao Tome and Principe, Mauritius, Barbados, Dominican Republic, Cuba, Dominica, Jamaica, Grenada, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago, Haiti, Palau, Samoa, Nauru, and the Solomon Islands, regardless of adapting fisheries management. For those nations, we recommend international collaboration that strengthens food security from sources other than the sea coupled with investments in locally sustainable aquaculture. Overall, we find that climate-adaptive fisheries management can benefit a range of the studied small island nations, by supporting both food security goals as well as economic goals of productive fisheries for international trade

1. Introduction

The ocean is the primary source of protein for roughly 20 % of the world's population [1]. The tropics have especially high levels of dependence on the productivity of marine fisheries, yet have some of the lowest potential for maintaining fisheries into the future [2,3]. Climate change in these areas is also expected to generate the highest degree of marine fisheries productivity decline in the coming decades with associated threats to food supply and public health [4,5]. Small island nations, predominantly situated in the tropics, are at the forefront of many sustainable development challenges, all exacerbated by the threats posed by climate change [6]. Local food systems in island nations are limited; livelihoods are often constrained by high dependence on healthy natural resources, and food security is vulnerable to economic price shocks on the global market [7,8]. Small island nations are also prone to market and price volatility of imported foods due to their geographic isolation and high dependence on imports for food availability [9]. Such economic vulnerability is exacerbated by

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nutrition-related public health concerns, including high rates of non-communicable diseases linked to a diet of imported processed foods [10,11].

A growing human population, especially in resource-limited island nations, will increase the demand for access to nutritious food including seafood. By some estimates, global food demand could increase by up to 100 % by 2050 compared to 2005 levels [12]. Access to safe, nutritious, and sustainable food that meets local needs is often referred to as *food security*, while *food self-sufficiency* refers to a region's capacity to guarantee food security locally, and *seafood self-sufficiency* describes the capacity for a region to locally supply the amount of seafood its population demands [13–15]. The high dependence of small island nations on the ocean for food and the decline in wild marine fisheries harvests, coupled with anticipated population pressures and climate change impacts, compound to worrisome threats to seafood self-sufficiency and by extension, to food security [4,8]. With total seafood, or *blue food*, demand expected to nearly double globally by mid-century, meeting global blue food demand will depend on good governance of natural resources attentive to both environmental and nutritional consequences of ocean mismanagement [16].

This paper investigates how island nations can achieve blue food self-sufficiency through improved fisheries management. We explore under what conditions small island nations could achieve blue food self-sufficiency by 2050 because we believe that blue food provisioning is another motivation for good ocean governance in addition to sustaining economic opportunity in fisheries. We further investigate how fisheries management could mitigate climate change impacts on marine resources for small island nations that are typically highly reliant on marine resources. This research can improve our understanding of which island nations are likely to benefit most from climate-adaptive fisheries management, not only by way of maximizing local wild fisheries catch, but also by meeting future local food security and nutrition needs. In this study, we use the terms 'seafood' and 'blue food' interchangeably to mean food from the sea and underscore its importance to island nations' food policy.

This paper focuses on 31 small island nations and the potential that climate-adaptive fisheries management to meet these nations' anticipated seafood needs by 2050. We build on studies which focus on how climate change may affect national fisheries' yields and profits by adding the dimension of projected island seafood demand due to growing populations. The results offer new insights into 1) how the rate of adaptation of fisheries management to a changing climate can determine whether small island nations can maintain or achieve seafood self-sufficiency, and 2) which nations would be priorities for global cooperation to achieve their full blue food security potential by 2050 and which nations would need help securing food sources other than wild fisheries.

2. Methods

2.1. Overview

We use the 5-, 10-, and 20-year climate-adaptive fisheries management projections from Free et al. [17] to examine the extent to which adaptive management could meet 2050 seafood demands under climate change. We build upon the work of Free et al. [17] by focusing on the potential for different management and climate scenarios to affect island nations' ability to secure local blue food provisions.

We focused on 31 small island nations identified by the UN Sustainable Development Goals Knowledge Platform maintained by the United Nations Department of Economic and Social Affairs (UN-DESA) [18]. These include UN member states from the Caribbean (n = 13), Pacific (n = 11), and Atlantic and Indian Oceans (AIO; n = 7) (Fig. 1). We did not include Tonga, Cook Islands, Timor-Leste, and Niue due to lack of reliable data for both seafood consumption and local fisheries production; we excluded Singapore from this analysis due to its vastly different economic classification (i.e., it is considered a high-income nation by the World Bank and is not a target of international development support). For each island nation, we calculated potential fisheries yields in local waters under future climate scenarios to determine which countries will come short of or exceed the projected local need for seafood based on extrapolations from present-day seafood demand and future population growth.

We present model projections of anticipated seafood demand through 2050 for 31 small island nations. We then project the impact of climate change and alternative fisheries management actions on catch in each of these nations. The projections explore four different future climate change scenarios (RCPs 2.6, 4.5, 6.0, 8.5) and three fisheries management regimes and the ability of these nations to meet projected seafood demand under each scenario. The adaptation scenarios from Free et al. [15] assume perfect and instant adaptation to climate-driven changes in fisheries productivity and distribution at 5-yr, 10-yr, and 20-yr intervals. In short, these scenarios assume that economically optimal harvests are updated in response to current productivity and are coordinated across national boundaries on the specified interval (see details below). Depending on fisheries context, these reforms could be

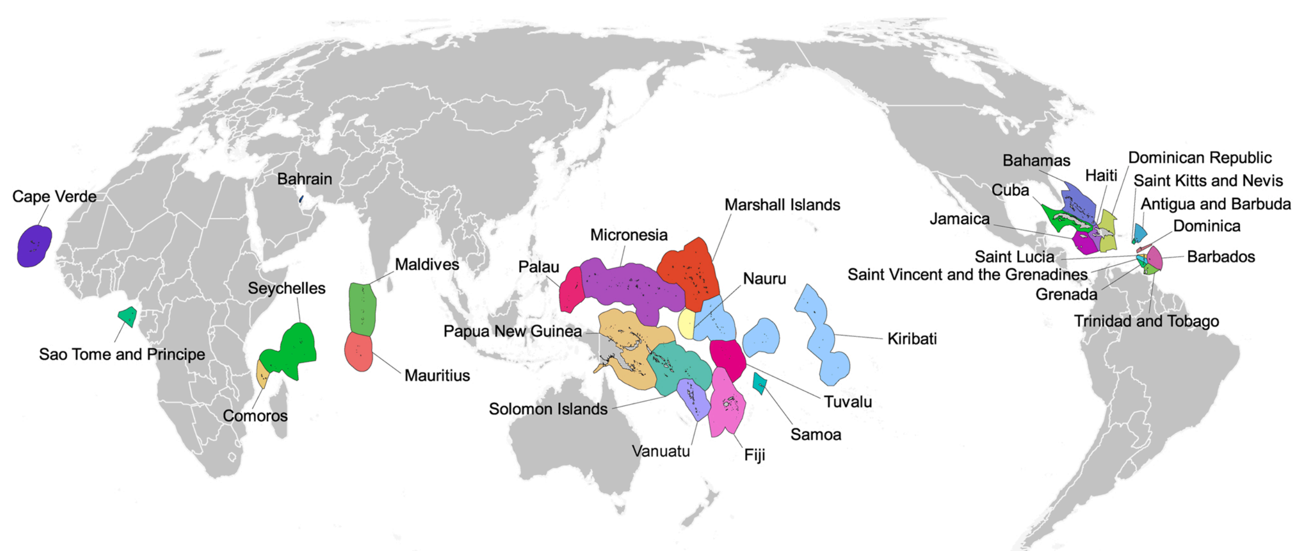

Fig. 1. Island nations considered in this study; colors for clarity of boundaries between neighboring exclusive economic zones (EEZs).

achieved through area-based conservation (e.g., seasonal or perennial no-take marine reserves), input measures (e.g., various gear restrictions for different species, number of fishing operations allowed for different fished species), and output measures (e.g., total allowable catch or size and bag limits).

2.2. Indicators

Indicators for this analysis are summarized in Table 1 and data sources and calculations are further described below.

2.2.1. Per capita annual seafood consumption (SC)

We estimated average annual seafood consumption for 2000–2009 from FAOSTAT Food Balance Sheets [19]. FAOSTAT lacked seafood consumption per capita data for Bahrain, Marshall Islands, Federated States of Micronesia, Nauru, Palau, Papua New Guinea, and Tuvalu. For these nations, average seafood consumption per capita was available for 2007–2009 from the U.S. National Oceanic and Atmospheric Administration [20].

2.2.2. Population growth (PG)

Population growth projections were obtained from UN DESA [21]. Three different scenarios from those projections were accessed from the UN database to offer an error envelope for the period from 2021 to 2050. 'No change" scenario A assumes constant fertility and constant mortality for the 2021–2050 period. Scenario B is a 'low fertility variant', assuming low fertility from 2021 to 2050, and scenario C is 'high fertility variant', assuming high fertility from 2021 to 2050.

2.2.3. Projected demand (PD)

Projected Demand (PD) refers to the average seafood demand per capita for each year from 2021 to 2050. We estimated PD for each of the 31 island nations in this analysis by multiplying the average annual seafood consumption per capita (SC) by the population projected (PG) for each year. The different population growth models served to provide an uncertainty envelope for the seafood demand projections, along with proper error propagation. We also estimated the projected percent increase in seafood demand nationally from 2021 to the period 2046–2050.

2.2.4. Projected catch (PC)

We used the Free et al. [17] climate-linked fisheries bioeconomic model to examine country-level changes in seafood production under four climate change scenarios and three fisheries management scenarios from 2021 to 2050 [17]. Free et al. [17] projected catch and profits of nearly 800 harvested marine fish and invertebrate fisheries which were separately evaluated within every exclusive economic zone (EEZ) from 2012 to 2100. Initial biomass statuses and fishing mortalities were determined based on Costello et al. [22]. To project changes in populations and geographical shifts, we updated annually the distributions using a bioclimatic envelope model [23]. We assumed fisheries productivity would change proportionately to changes in geographical range size, e.g., a 5 % growth in geographical range size would translate to a 5 % increase in productivity; Gaines et al. [24] provides detailed justification for this assumption. Finally, biomass and catch model estimates for 2021–2050 were then developed based on the above and an updated version of Costello et al. [22] bioeconomic model inclusive of selected adaptive fisheries management scenarios. We summed the catch across all species caught within a nation's EEZ to generate nation-wide outcomes.

We consider three of the "realistic" climate-adaptive management scenarios evaluated by Free et al. [17]. In these scenarios, productivity shift adaptations improve fisheries management by implementing a dynamic, economically optimal harvest policy given current productivity. Range shift adaptations result from international cooperation that effectively maintains management as stocks shift into new management areas. The realistic adaptation scenarios acknowledges that management rarely changes annually. Instead, these scenarios consider management that sets an economically optimal harvest rate based on current productivity at regular assessment intervals (5-yr, 10-yr, and 20-yr) and then maintain this rate until the next assessment. As mentioned above, economically optimal harvest rates could be achieved through input controls, output controls, area-based management, or other measures, depending on each country's unique fishery regulatory frameworks. Ecological connectivity and genetic rescue across coral reefs may boost climate resilience in some reefs that could support fish populations, but diverse and large adaptation networks are necessary to maximize the adaptive capacity of fish and coral species [25].

We acknowledge that every model has limitations. Our model is limited in that it only considers the impact of temperature on population dynamics and does not consider the impacts of other environmental stressors such as deoxygenation, acidification, and changing primary productivity or their interactions. It also does not consider important ecosystem interactions such as predation, competition, and changing phenology, which can have significant impacts on population dynamics. In attempting to be globally scalable, the model makes simplifications that may be overcome in future more detailed national or subnational analyses.

2.2.5. Projected Surplus

Having estimated a timeseries from 2021 to 2050 for projected total seafood demand for each island nation, we used the projected locally landed total wild fisheries catch in the above fisheries management scenarios under different climate change scenarios to determine the Seafood Surplus (SS). We defined surplus seafood as the projected percent available seafood in 2046–2050 above the projected seafood demand for 2046–2050. A negative surplus seafood value indicates a deficit and translates to a nation not being able to meet the seafood demand projected for the future. A positive SS implies the nation would be able to produce excess seafood beyond local projected demand. It is important to note that in these analyses, we assumed that taste and consumption preferences are such that locally produced and harvested seafood is also likely to meet the local seafood demand. In these analyses, we also assumed that the locally produced seafood (i.e., seafood caught by local fishermen in local waters) would first be used to satisfy local seafood demand, before exports were considered.

Table 1
Methods for future seafood indicators in this study.

Indicator	Equation	Inputs
Projected Demand (PD), in 1000 s kg per capita per person	$PD_N = SC \times PG_N$	SC = Per capita annual seafood consumption (mean 2000–2009) PG = population projected for a given year 2021–2050 N = year 2021–2050
Seafood Demand Increase (SDI), %	SDI (%) = $(PD_{2046-2050} - PD_{2021})/PD_{2021}$ * 100 %	$PD_{2046-2050}$ = the average projected demand for 2046–2050 period PD_{2021} = demand for 2021
Projected Catch (PC), in 1000 s kg	See Free et al. (2020) [17]	See Projected Catch paragraph in text below for details.
Surplus Seafood (SS), %	SS (%) = $(PC_{2046-2050} - PD_{2046-2050})/PD_{2046-2050}$ * 100 %	PC = projected catch for 2046–2050 period PD = projected demand for 2046–2050 period This was done for all 4 climate scenarios and 3 adaptive fisheries management scenarios.

3. Results

3.1. Projected potential fisheries catch

The standard deviation of 2050 projected seafood amount within any given RCP scenario across adaptive management interval options is much smaller compared to the standard deviation of 2050 seafood production estimates across different carbon emission scenarios (Fig. S1, Table S1). The analysis we highlight in the Supplementary materials is derived from Free et al. [17] and offers projections for 2046–2050 in wild catch estimates specifically for the 31 nations of interest in the present study, focused on 4 different RCP emission scenarios (2.6, 4.5, 6.0, and the worst one, 8.5) and 3 different adaptive fisheries management scenarios (5-yr; 10-yr; and 20-yr adaptive management cycles).

3.2. Projected mid-century island nation seafood demand

Although our models project that most island nations in this study would experience an increase in total seafood demand by 2050 (Fig. 2, Table S2), changes in total seafood demand between early 2020 s and mid-century range from −9–70 % growth. The total seafood demanded in all Pacific Island nations is expected to grow, but the small island nations in the Atlantic and Indian Ocean (e.g., Comoros and Saõ Tome and Principe) are anticipated to have the greatest growth in seafood demand at nearly 70 %. Five nations are projected to experience no change or declines in total seafood demand as a function of anticipated population decline, including Cuba, Dominica, Jamaica, Trinidad and Tobago, and Mauritius.

3.3. Projected mid-century island nation surplus seafood

We examined the relative percentage of surplus seafood projected to be available by 2050 under fisheries management scenarios adapting at 5-year, 10-year, or 20-year intervals (Fig. 3). We find that the frequency of adapting fisheries management matters. More frequent adaptive fisheries management regimes (at least every 10 years) can mitigate anticipated climate change impacts for marine resources and wild fisheries catch for many small island nations (Fig. 3, Table S2). However, when comparing how the frequency of adaptation of fisheries management practices, that we tested for, could affect the potential for future seafood available, in most cases, the scenario of adapting fisheries management every 5 years, yields the highest amount of projected locally available seafood. When we take the projections of seafood available by mid-century under scenarios of different fisheries management adaptation frequency (5-year, 10-year, 20-year) and subtract them from the projected seafood demand, we find that indeed the 5-year adaptation scenarios yield levels of wild catch that generate the greatest surplus seafood estimates or at least, the least deficit.

In eight nations (Fiji, Papua New Guinea, Kiribati, Vanuatu, Maldives, Seychelles, Bahamas, Saint Kitts and Nevis), adapting fisheries management every 20 years instead of every 10 years or 5 years could make the difference between being able to meet local seafood-dependent nutritional demands and not. Adapting management more frequently in these countries would increase the likelihood of securing seafood sources from local waters. However, in over half (n = 17) of the countries, seafood will be in deficit regardless of how frequently fisheries management is adapted: Comoros, Sao Tome and Principe, Mauritius, Barbados, Dominican Republic, Cuba, Dominica, Jamaica, Grenada, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago, Haiti, Palau, Samoa, Nauru, and Solomon Islands (Fig. 3).

4. Discussion

Our results show that blue food security and self-sufficiency could be

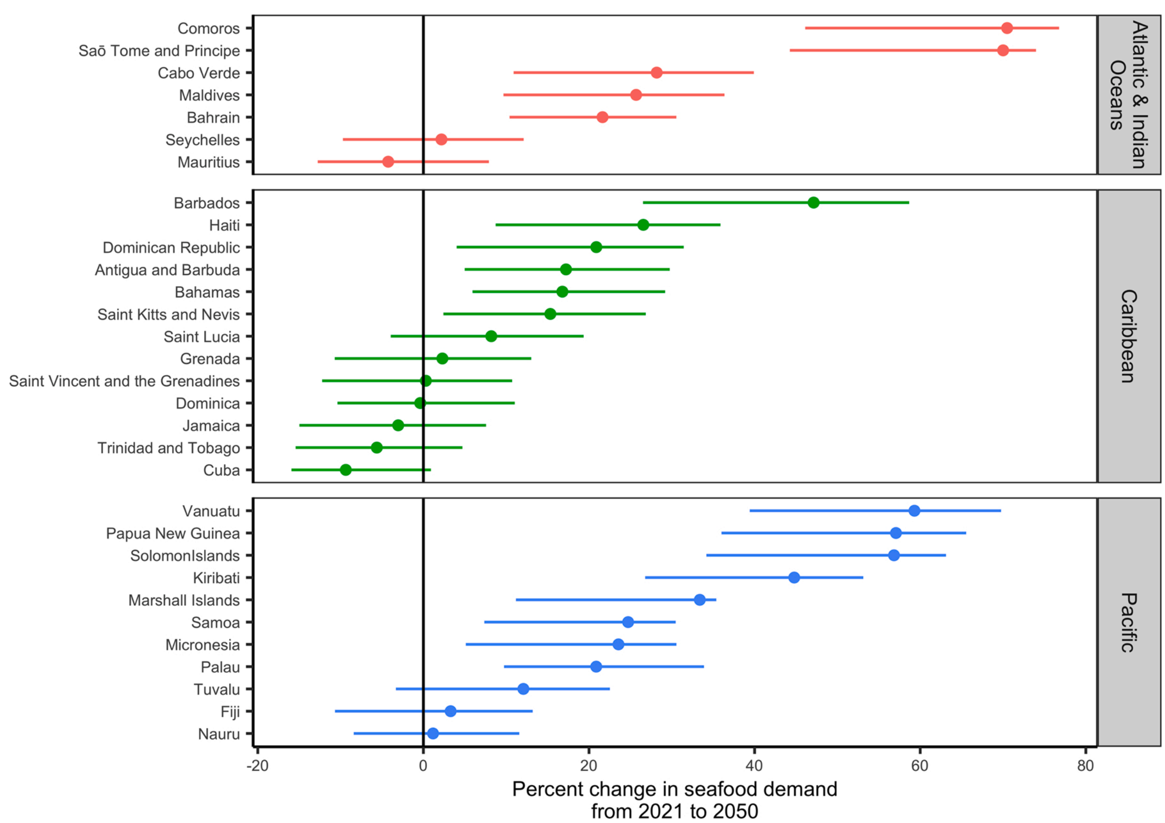

Fig. 2. Average percent change in total seafood demand projected between early 2020 s and mid-century for each nation in the Pacific, Caribbean, Atlantic, and Indian Oceans. The averages represent the mean based on population increase projections and present-day seafood consumption rates (Table 1). The error bars are derived from the range in UN national population growth models using variable fertility assumptions.

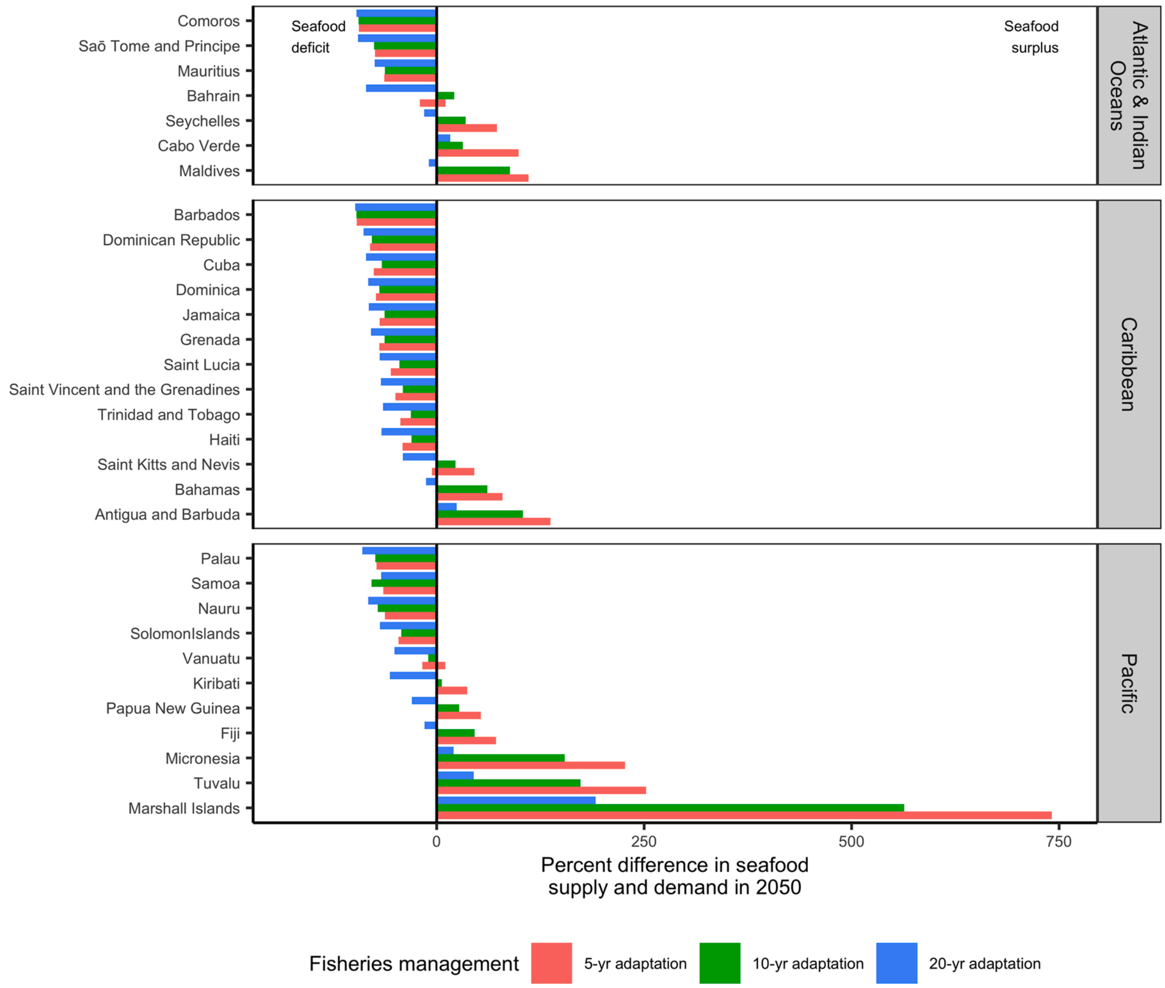

Fig. 3. Mid-century seafood surplus, shown as 2046–2050 projected catch exceeding projected demand for the same period, in three fisheries management scenarios assuming 5, 10-, or 20-year intervals of management adaptations to a changing ocean.

key motivators for achieving climate-adaptive adaptive fisheries management. Further, these results point to potential geographical priorities for investments to support the implementation of climate-adaptive fisheries policies specifically supporting local food sufficiency.

We find that adapting fisheries management makes a more significant difference to potential local catches in the future in most nations in this study when compared to the different level of impact of climate change scenarios on wild fisheries catches. Adapting national fisheries management plans every 10 years could mitigate even worst-case projections of climate change impacts on locally available seafood, building a seafood surplus by 2050 in the cases of Seychelles, Maldives, Cabo Verde, Bahamas, Antigua and Barbuda, Kiribati, Papua New Guinea, Fiji, FSM, Tuvalu, and Marshall Islands. Strategic financial and capacity investments by the international community can help realize the full potential of food security from the sea for those nations.

The frequency of fisheries management adaptation also makes a difference for some nations' potential to meet food security needs from the sea by 2050. Rapid adaptation of management commensurate with climate change impacts can best help secure the highest likelihood of healthy fisheries for local food security. For example, for Bahrain, Bahamas, Saint Kitts and Nevis, Fiji, Kiribati, Maldives, and Papua New Guinea, a 20-year adaptive management regime would not meet the seafood demand, while adapting every 10 years would result in a surplus (Fig. 3). Importantly, in some cases a 10-year frequency of recalibrating the adaptive management can lead to exceeding local seafood needed many times over (Fig. 3). For example, focusing on the seafood surpluses projected under the 10-year adaptive management scenarios, the Marshall Islands, Federated States of Micronesia, Tuvalu, Maldives, and Antigua and Barbuda can exceed their projected seafood demand by 2050. Exceeding food self-sufficiency need from marine sources could add economic and development opportunities for island nations via strengthening export markets. With many island nations currently exploring potential sources of economic activity from the ocean as part of national blue economy planning exercises, this result provides a sound economic case for adopting climate-adaptive fisheries management.

The potential for 2050 seafood surpluses (i.e., locally caught seafood exceeding project local demand) under frequent climate-adaptive fisheries management appears to hold for both island nations that are heavily dependent on local marine resources for nutrition and those without a high dependence. Kiribati, Maldives, Federated States of Micronesia and some Caribbean nations are highly reliant on the health of local marine resources for their nutrition [e.g. 21]. Other island nations, namely Antigua and Barbuda, Bahamas, St. Kitts and Nevis, Fiji, and Cabo Verde, may be capable of producing a seafood surplus locally but do not have a high dependence on seafood for local nutrition. This difference suggests that climate-adaptive fisheries management can benefit a range of the studied small island nations here, both by supporting food security goals as well as economic goals of productive fisheries for international trade.

In terms of the geographical focus of seafood deficits by 2050, our results suggest that Comoros, Sao Tome and Principe, Mauritius, Barbados, Dominican Republic, Cuba, Dominica, Jamaica, Grenada, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago, Haiti, Palau, Samoa, Nauru, and the Solomon Islands, would not be able to meet projected seafood demand by mid-century regardless of adaptation intervals. For those nations, our results indicate that additional tools beyond climate-adaptive fisheries management are needed for ensuring food security locally. We recommend international collaboration that strengthens food security from land-based sources, trade, coupled potentially with investments in locally appropriate sustainable aquaculture.

These nations with projected seafood deficits (i.e., locally caught seafood which comes short of projected demand) will need to consider tools other than sound fisheries management to develop more durable food self-sufficiency in the context of climate change and rising populations. Some additional tools could include improving the national and regional regulatory environment, foreign fleet fishing agreements, strengthening enforcement, and managing the supply chain through market regulations and trade policies [26,27]. These nations may need significant alternative food source investments, for example, investments in their sustainable aquaculture sector for both local markets as well as export markets. The role of aquaculture in humanity's aquatic food supply has markedly increased [28], and therefore there may be appropriate forms of small-scale aquaculture in some geographies that meaningfully support local food security in a way that results in climate resilience by diversifying stressed food systems. It is important to note that small-scale or large-scale aquaculture may not be equally appropriate for small-island nations everywhere due to specific environmental conditions, cost, local preferences, and other factors.

However, for both economic and food security needs, it would be prudent for researchers to further study the potential for cost-effective and productive aquaculture options, for example, in Caribbean small island nations which tend to have less healthy marine ecosystems than many Pacific Islands and not much arable land for home-grown animal protein. In fact, FAO has a strategic plan Climate Change Adaptation and Disaster Risk Management in Fisheries and Aquaculture in the CARICOM and Wider Caribbean Region, discussed in FAO (2018) [1], which emphasizes the need for cooperation and development of climate-smart small-scale aquaculture and fisheries management in the Caribbean, in order to avert fisheries disasters and strengthen the aquaculture sector for food security goals and local livelihood goals.

How do we support the '2050 seafood surplus' nations above to realize their potential?

To achieve blue food self-sufficiency and even a seafood surplus, island nations may consider embracing localized, collaborative management involving participatory decision-making, power-sharing, and integration of traditional, customary, and Western fisheries management tools for achieving sound environmental governance and livelihood sustainability [27,29–31]. Embedding blue food in national food policies would be critical, meaning explicitly addressing food production from the sea in national nutrition goals while acknowledging that this nutrition source is threatened by climate change [32]. These governance arrangements would be driven by national commitments to the transformation of national food systems [6,16], as well as local-scale understanding of social vulnerability and resilience linked to the adaptive capacity of individuals, their access to capital, flexibility in fish gear use, available alternative livelihoods, and other factors that often can extend to local coastal communities [33–35].

Embedding blue food in national food policies can lead to managing fisheries from a food security perspective with potentially positive outcomes for oceans and people, specifically reducing fisheries conflict and vulnerability from foreign fleets catching too much fish in poor ocean-resource dependent nations [36]. Blue food policy could provide greater incentives for managing local natural capital with a greater focus on sustainability, because of clear connections between natural resources, public health, social stability, and conflict. We need only look to the Arab Spring of 2011 for a classic example of how food insecurity and lack of robust national food policies broadly can disrupt socio-political stability and also lead to forced migration [37]. Further, concerted blue food policies in line with ocean sustainability can improve human health by reducing the burden of disease associated with inadequate nutrient intake [38].

Adaptation and cooperation between national and regional fishery management institutions is also required to build capacity for climate-adaptive fisheries management in collaboration with food policy implementers, especially for many small island nations with limited management and human resources. Regional Fishery Management Organizations (RFMOs) already represent management institutions for facilitating international cooperation. They can foster climate-adaptive fisheries solutions for some fisheries, potentially through investing resources in tracking climate change impacts, facilitating data-sharing in often data-poor environments, improving the equity in foreign fleet vessel day lease negotiations, and enhancing maritime enforcement [39,40].

The capacity to adapt island fisheries can be examined through several lenses, e.g., through individual fisher, community, national, and regional responses [35,41–43]. While the literature is rich with studies of the adaptive capacity of individuals and communities to climate change and fishery regimes, particularly in small island contexts in the Pacific and Indian Oceans [27,44,45], few studies have examined the pathways for national governments to cooperate at the international level on blue food security and sustainable fisheries. With globalized seafood markets, the footprint of global fisheries has increased in the last several decades far beyond coastal waters, deeper into the sea, and far from effective enforcement control [46]. As a result, the vast marine resources in national jurisdiction of capacity-constrained small island nations are often overexploited due to illegal, unreported, unregulated (IUU) fishing linked to profitability that stems from global seafood demand [47,48]. The benefits of international cooperation will be greatest for nations with high ecological connectivity and for species with high adult mobility and/or larval dispersal. The benefits will be more limited for remote nations and species with strong habitat associations and/or limited mobility.

Distant-water fishing contracts, wherein foreign fishing fleets buy or lease the rights to fish in the waters of developing nations, often small island nations with large EEZs, have presented a legal instrument for foreign fleets to fish out other nations' waters, and have often led to overexploitation and essentially a displacement of seafood demand footprint [49]. However, the Parties to the Nauru Agreement (PNA), which encompassed the Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea, Solomon Islands, and Tuvalu, are a good example of how arrangements with distant water fleets can be made with a climate strategy in mind and leveraged for climate adaptation [50,51]. The PNA allows the trading on a quota of fishing days to sell to distant fleets based on how highly migratory tuna stocks move during El Niño or La Niña events [52,53]. By embracing a highly adaptive management strategy, the PNA is often presented as a best practice model for climate-adaptive regional fisheries management [54]. To protect from potentially escalating inequities associated with availability of tuna in signatory nations' EEZs, the PNA could go further in transboundary cooperation by establishing dynamic temporary no-fishing zones for several months or years at a time, which would act as climate refuges buffering some of the stochasticity in the fishery response to climate impact on the environment and the fish [55]. It is possible that such tactics may also reduce risk from fisheries conflict and secure higher locally landed catches for these island nations, helpful for local food security.

International aid, donor funding, support from non-governmental organizations (NGOs), and increased cooperation and collaboration could support the improved governance required for small island nations to maintain healthy marine resources for their own development and food security goals, including the UN Sustainable Development Goals [56,57]. Our results indicate that systematic fisheries management and food policy investments in capacity-building, sustainable financing, and institutionalized science-based adaptation, potentially through climate financing mechanisms, would be highly productive in the island nations exhibiting high potential to generate seafood surpluses, including Federated States of Micronesia, Kiribati, Maldives, Tuvalu, and Antigua and Barbuda. Our results indicate that these six nations are highly dependent on healthy marine resources for their prosperity and food availability, and with improved capacity to adaptively respond to environmental change, these nations may be quite successful in supporting their islanders' nutritional needs, as well as those of trading partners.

Seafood is the most traded food commodity in the world, and 35 % of all the seafood produced is traded internationally [58]. Many developing nations export high-value seafood to developed nations while importing lower value seafood to feed local citizens [49]. National food security relying on seafood supply chains are also vulnerable to demand-side market shocks or supply-side environmental shocks. During the COVID-19 pandemic, for example, disruptions to fishermen and seafood markets led to significant food security and livelihood implications throughout many island nations [59,60]. Food self-sufficiency for small island nations will continue to be important, especially as supply and demand shocks such as the COVID-19 pandemic continue to introduce volatility in food supplies globally [22]. This can cause a net export of nutrition and may threaten the ability of these nations to support their populations [61,62]. In the case with tuna in the Pacific and other similar examples, species have been used for national government revenue via foreign fishing fleet leases rather than kept locally to benefit national food security benefits. But one potential adaptation in the future, consistent across food policies and fisheries management could be the prioritization of such important species for local food security; this would also necessitate an economic diversification and international development support to substitute the role of fishing leases' contributions to government revenue [63,64].

5. Conclusion

This study, built on previous modeling efforts, evaluates how effectively the seafood security gap for small island nations could be filled by 2050 via climate-adaptive ocean governance and better fisheries management. Our work shows that food security and food self-sufficiency could be important motivators for achieving climate-adaptive fisheries management for many small island nations. The results identify which small island nations stand to benefit from fisheries management to address blue food security and blue food self-sufficiency. The models further identify nations where investment in fisheries management alone may not be able to address prior environmental degradation of marine resources or the anticipated climate change impacts on fisheries catch, pointing to a need for them to consider alternative pathways in securing local food self-sufficiency (Fig. 3). This implies that island nations with the largest deficits are at the greatest peril in achieving food self-sufficiency from marine sources and are most likely to experience overall national food insecurity if no action is taken.

Aquaculture will become more and more important as a low-carbon footprint protein source particularly for small island nations for whom no amount of sustainable fisheries management can support local seafood demand into the future. Local pilot projects and significant national and foreign investments for aquaculture will continue to be critical for many parts of the Caribbean and several islands in the Pacific Ocean characterized by already historically beleaguered fisheries. As climate change and other threats increasingly affect global food production systems, the ability of vulnerable small island nations to sustainably harvest food from within their own marine waters via wild fisheries and aquaculture will be crucial to feed future populations and achieve sustainable development goals. Embedding these *blue foods* into national food policies will be a critical piece of improved ocean governance and food system transformation for a climate-smart future.

CRediT authorship contribution statement

Lida Teneva conceived of the study. Chris Free performed the climate and fisheries management scenario generation. Reg Watson and Carissa Klein contributed curated FAO seafood consumption and fisheries catch datasets. Andrew Hume, Vera Agostini, Steven Gaines contributed interpretation of the analysis. Andrew Hume and Chris Free contributed to the making of figures and graphics for this manuscript. Lida Teneva led the writing, with contributions from everyone else on specific sections.

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2023.105577.

References

[1] FAO, The State of World Fisheries and Aquaculture - Meeting the sustainable development goals, Rome, 2018.
[2] W.W.L. Cheung, R. Watson, D. Pauly, Signature of ocean warming in global fisheries catch, Nature 497 (2013) 365–368, https://doi.org/10.1038/nature12156.
[3] V. Lam, W. Cheung, G. Reygondeau, U. Sumaila, Projected change in global fisheries revenues under climate change, Nat. Sci. Rep. 6 (2016) 32607, https://doi.org/10.1038/srep32607.
[4] C. Golden, E. Allison, W. Cheung, M. Dey, B. Halpern, D. McCauley, M. Smith, B. Vaitla, D. Zeller, S. Myers, Nutrition: fall in fish catch threatens human health, Nature 534 (2016) 317–320, https://doi.org/10.1038/534317a.
[5] L. Thiault, C. Mora, J. Cinner, W. Cheung, N. Graham, F. Januchowski-Hartley, D. Mouillot, U. Sumaila, J. Claudet, Escaping the perfect storm of simultaneous climate change impacts on agriculture and marine fisheries, Sci. Adv. 5 (2019) eeaw9976, https://doi.org/10.1126/sciadv.aaw9976.
[6] M. Tigchelaar, W. Cheung, E. Mohammed, M. Phillips, H. Payne, E. Selig, C. Wabnitz, M. Oyinlola, T. Frölicher, J. Gephart, C. Golden, E. Allison, A. Bennet, L. Cao, J. Fanzo, B. Halpen, V. Lam, F. Micheli, R. Naylor, U. Sumaila, A. Tagliabue, M. Troell, Compound climate risks threaten aquatic food system benefits, Nat. Food 2 (2021), https://doi.org/10.1038/s43016-021-00368-9.
[7] B. Belton, S. Thilsted, Fisheries in transition: food and nutrition security implications for the global South, Glob. Food Sect. 3 (2014) 59–66, https://doi.org/10.1016/j.gfs.2013.10.001.
[8] FAO, IFAD, UNICEF, WFP, WHO, The State of Food Security and Nutrition in the World, Rome, 2019.
[9] J. Connell, K. Lowitt, A. Saint Ville, G. Hickey, Food security and sovereignty in small island developing states: comtemporary crises and challenges, in: J. Connell, K. Lowitt (Eds.), Food Secur. Small Isl. States, Springer, Singapore, Singapore, 2020, pp. 1–23.
[10] K. Charlton, J. Russell, E. Gorman, Q. Hanich, A. Delisle, B. Campbell, J. Bell, Fish, food security and health in Pacific Island countries and territories: a systematic literature review, BMC Public Health 16 (2016) 285, https://doi.org/10.1186/s12880-016-2953-9.
[11] J. Santos, B. McKenzier, K. Trieu, S. Farnback, C. Johnson, J. Schultz, A. Thow, W. Snowdon, C. Bell, J. Webster, Contribution of fat, sugar, and salt to diets in the Pacific Islands: a systematic review, Public Health Nutr. 22 (2019) 1858–1871, https://doi.org/10.1017/S1368980018003609.
[12] H. Valin, R. Sands, D. van der Mensbrugghe, G. Nelson, H. Ahammad, E. Blanc, B. Bodirsky, S. Fujimori, T. Hasegawa, P. Havlik, E. Heyhoe, P. Kyle, D. Mason-D'Croz, S. Paltsev, S. Rolinski, A. Tabeau, H. van Meijl, M. von Lampe, D. Willenbockel, The future of food demand: Understanding differences in global economic models, Agric. Econ. 45 (2013) 51–67, https://doi.org/10.1111/agec.12089.
[13] FAO, An Introduction to the Basic Concepts of Food Security, Rome, 2008.
[14] J. Clapp, Food self-sufficiency: making sense of it, and when it makes sense, Food Policy 66 (2017) 88–96, https://doi.org/10.1016/j.foodpol.2016.12.001.
[15] L. Teneva, E. Schemmel, J. Kittinger, State of the plate: assessing present and future contributino of fisheries and aquaculture to Hawai'i's food security, Mar. Policy 94 (2018) 28–38, https://doi.org/10.1016/j.marpol.2018.04.025.
[16] R. Naylor, A. Kishore, U. Sumaila, I. Issifu, B. Hunter, B. Belton, S. Bush, L. Cao, S. Gelcich, J. Gephart, C. Golden, M. Jonell, J. Koehn, D. Little, S. Thilsted,

M. Tigchelaar, B. Crona, Blue food demand across geographic and temporal scales, Nat. Commun. 12 (2021) 5413, https://doi.org/10.1038/s41467-021-25516-4.
[17] C. Free, T. Mangin, J. Molinos, E. Ojea, C. Costello, S. Gaines, Realistic fisheries management reforms could mitigate the impacts of climate change in most countries, PLoS One 15 (2020), e0224347, https://doi.org/10.1371/journal.pone.0224347.
[18] UN, Small Island Developing States, (n.d.).
[19] R. Watson, A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950-2014, Nat, Sci. Data. 4 (2017), 170039, https://doi.org/10.1038/sdata.2017.39.
[20] National Marine Fisheries Service, A User's Guide to the National and Coastal State I/O Model, 2011. ⟨http://www.st.nmfs.noaa.gov/documents/commercial_seafood_impacts_2007–2009.pdf⟩.
[21] UN DESA, World Population Prospects, World Popul. Prospect. (2015).
[22] C. Costello, L. Cao, S. Gelcich, M. Cisneros-Mata, C. Free, H. Froehlich, C. Golden, G. Ishimura, J. Maier, I. Macadam-Somer, T. Mangin, M. Melnychuk, M. Miyahara, C. DeMoor, R. Naylor, L. Nøstbakken, E. Ojea, E. O'Reilly, A. Parma, A. Plantinga, S. Thilsted, J. Lubchenco, The future of food from the sea, Nature 588 (2020) 95–99, https://doi.org/10.1038/s41586-020-2616-y.
[23] J. Garcia Molinos, B. Halpern, D. Schoeman, C. Brown, W. Kiessling, P. Moore, J. Pandolfi, E. Poloczanska, A. Richardson, M. Burrows, Climate velocity and the future global redistribution of marine biodiversity, Nat. Clim. Chang. 6 (2016) 83–88, https://doi.org/10.1038/nclimate2769.
[24] S.D. Gaines, C. White, M.H. Carr, S.R. Palumbi, Designing marine reserve networks for both conservation and fisheries management, Proc. Natl. Acad. Sci. U. S. A. 107 (2010) 18286–18293, https://doi.org/10.1073/pnas.0906473107.
[25] M. Webster, M. Colton, E. Darling, J. Armstrong, M. Pinsky, N. Knowlton, D. Schindler, Who should pick the winners of climate change, Trends Ecol. Evol. 32 (2017) 167–173, https://doi.org/10.1016/j.tree.2016.12.007.
[26] J.D. Bell, M. Kronen, A. Vunisea, W.J. Nash, G. Keeble, A. Demmke, S. Pontifex, S. Andréfouët, Planning the use of fish for food security in the Pacific, Mar. Policy 33 (2009) 64–76, https://doi.org/10.1016/j.marpol.2008.04.002.
[27] J.E. Cinner, T.R. McClanahan, N. a J. Graham, T.M. Daw, J. Maina, S.M. Stead, a Wamukota, K. Brown, Ö. Bodin, Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries, Glob. Environ. Chang. 22 (2012) 12–20, https://doi.org/10.1016/j.gloenvcha.2011.09.018.
[28] T. Garlock, F. Asche, J. Anderson, A. Ceballos-Concha, D. Love, T. Osmundsen, R. Pincinato, Aquaculture: the missing contributor in the food security agenda, Glob. Food Sec 32 (2022), https://doi.org/10.1016/j.gfs.2022.100620.
[29] A.M. Friedlander, J.M. Shackeroff, J.N. Kittinger, Customary marine resource knowledge and use in contemporary Hawai'i 1, Pacif. Sci 67 (2013) 441–460, https://doi.org/10.2984/67.3.10.
[30] A.L. Ayers, J.N. Kittinger, Emergence of co-management governance for Hawai'i coral reef fisheries, Glob. Environ. Chang. 28 (2014) 251–262, https://doi.org/10.1016/j.gloenvcha.2014.07.006.
[31] B. Quimby, A. Levine, Adaptive capacity of marine comanagement: a comparative analysis of the influence of colonial legacies and integrated traditional governance on outcomes in the Pacific, Reg. Environ. Chang. 21 (2021), https://doi.org/10.1007/s10113-020-01730-6.
[32] M. Tigchelaar, J. Leape, F. Micheli, E. Allison, X. Basurto, A. Bennett, S. Bush, L. Cao, W. Cheung, B. Crona, C. Golden, B. Halpern, C. Hicks, M. Jonell, A. Kishore, J. Koehn, D. Little, R. Naylor, M. Phillips, E. Selig, R. Short, U. Sumaila, S. Thilsted, M. Troell, C. Wabnitz, The vital roles of blue foods in the global food system, Glob. Food Sec. 33 (2022), 100637, https://doi.org/10.1016/j.gfs.2022.100637.
[33] J.D. Bell, N.L. Andrew, M.J. Batty, L.B. Chapman, J.M. Dambacher, B. Dawson, A.S. Ganachaud, P.C. Gehrke, J. Hampton, A.J. Hobday, O. Hoegh-guldberg, J.E. Johnson, J.P. Kinch, R. Le Borgne, P. Lehodey, J.M. Lough, T.D. Pickering, M.S. Pratchett, A. Vunisea, M. Waycott, Adapting tropical Pacific fisheries and aquaculture to climate change: Management measures, policies and investments, in: J. Bell, J. Johnson, A. Hobday (Eds.), Vulnerability Trop. Pacific Fish. Aquac. to Clim. Chang., Secretariat of the Pacific Community, Noumea, New Caledonia, 2011: pp. 17–28.
[34] T.M. Daw, J.E. Cinner, T.R. McClanahan, K. Brown, S.M. Stead, N. a J. Graham, J. Maina, To fish or not to fish: factors at multiple scales affecting artisanal fishers' readiness to exit a declining fishery, PLoS One 7 (2012), e31460, https://doi.org/10.1371/journal.pone.0031460.
[35] J.E. Cinner, C. Huchery, E.S. Darling, A.T. Humphries, N. a J. Graham, C.C. Hicks, N. Marshall, T.R. McClanahan, Evaluating social and ecological vulnerability of coral reef fisheries to climate change, PLoS One 8 (2013), e74321, https://doi.org/10.1371/journal.pone.0074321.
[36] T. McClanahan, E. Allison, J. Cinner, Managing fisheries for human and food security, Fish Fish 16 (2015) 78–103, https://doi.org/10.1111/faf.12045.
[37] G. Soffiantini, Food insecurity and political instability during the Arab Spring, Glob. Food Sec 26 (2020), 100400, https://doi.org/10.1016/j.gfs.2020.100400.
[38] C. Golden, J. Koehn, A. Shepon, S. Passarelli, C. Free, D. Viana, H. Matthey, J. Eurich, J. Gephart, P. Fluet-Chouinard, M. Barange, S. Vannuccini, L. Cao, K. Kleisner, E. Rimm, G. Danaei, C. DeSisto, H. Kelahan, K. Fiorella, D. Little, E. Alisson, J. Fanzo, S. Thilsted, Aquatic foods to nourish nations, Nature 598 (2021) 315–320, https://doi.org/10.1038/s41586-021-03917-1.
[39] B. Pentz, N. Klenk, S. Ogle, J. Fisher, Can regional fisheries management organizations (RFMOs) manage resources effectiely during climate change? Mar. Policy 92 (2018) 13–20, https://doi.org/10.1016/j.marpol.2018.01.011.
[40] C. Goodman, R. Davis, K. Azmi, J. Bell, G. Galland, E. Gilman, B. Haas, Q. Hanich, P. Lehodey, L. Manarangi-Trott, S. Nicol, P. Obregon, G. Pilling, I. Senina, K. Seto, M. Tsamenyi, Enhancing cooperative responses by regional fisheries management organizations to climate-driven redistribution of tropical Pacific tuna stocks, Front. Mar. Sci. 9 (2022), https://doi.org/10.3389/fmars.2022.104618.
[41] E. Allison, A. Perry, M. Badjeck, W. Adger, K. Brown, D. Conway, A. Halls, G. Pilling, J. Reynolds, N. Andrew, N. Dulvy, Vulnerability of national economies to the impacts of climate change on fisheries, Fish Fish 10 (2009) 173–196, https://doi.org/10.1111/j.1467-2979.2008.00310.x.
[42] T. Daw, N. Adger, K. Brown, M. Badjeck, Climate change implications for fisheries and aquaculture. Overview of current scientific knowledge., Rome, 2009.
[43] I. Martins, M. Gasalla, Adaptive capacity level shapes social vulnerability to climate change of fishing communities in the South Brazil Bight, Front. Mar. Sci. 7 (2020) 481, https://doi.org/10.3389/fmars.2020.00481.
[44] J. Cinner, C. Huchery, M. MacNeil, N. Graham, T. McClanahan, J. Maina, E. Maire, J. Kittinger, C. Hicks, C. Mora, E. Allison, S. D'Agata, A. Hoey, D. Feary, L. Crowder, I. Williams, M. Kulbicki, L. Vigliola, L. Wantiez, G. Edgar, R. Stuart-Smith, S. Sandin, A. Green, M. Hardt, M. Beger, A. Friedlander, S. Campbell, K. Holmes, S. Wilson, E. Brokovich, A. Brooks, J. Cruz-Motta, D. Booth, P. Chabanet, C. Gough, M. Tupper, S. Ferse, U. Sumaila, D. Mouillot, Bright spots among the world's coral reefs, Nature 535 (2016) 416–423, https://doi.org/10.1038/nature18607.
[45] Q. Hanich, C. Wabnitz, Y. Ota, M. Amos, C. Donato-Hunt, A. Hunt, Small-scale fisheries under climate change in the Pacific Islands region, Mar. Policy 88 (2018) 279–284, https://doi.org/10.1016/j.marpol.2017.11.011.
[46] R. Watson, G. Nowara, K. Hartmann, B. Green, S. Tracey, C. Carter, Marine foods sourced from farther as their use of flobal ocean primary productiion increases, Nat. Commun. 6 (2015), https://doi.org/10.1038/ncomms8365.
[47] F. Berkes, Devolution of environment and resource governance: trends and future, Environ. Conserv. 37 (2010) 489–500.
[48] B. Worm, R. Hilborn, J.K. Baum, T.A. Branch, J.S. Collie, C. Costello, M.J. Fogarty, E.A. Fulton, J.A. Hutchings, S. Jennings, O.P. Jensen, H.K. Lotze, P.M. Mace, T. R. Mcclanahan, Rebuilding Global Fisheries 578 (2010), https://doi.org/10.1126/science.1173146.
[49] C. Klein, C. Kuempel, R. Watson, L. Teneva, M. Coll, C. Mora, Global fishing between jurisdictions with unequal fisheries management, Environ. Res. Lett. 17 (2022), 114004, https://doi.org/10.1088/1748-9326/ac97ab.
[50] D. Belhabib, U. Sumaila, V. Lam, D. Zeller, P. Le Billon, E. Kane, D. Pauly, Euros vs. Yuan: comparing European and Chinese fishing access in West Africa, PLoS One 10 (2015), e0118351, https://doi.org/10.1371/journal.pone.0118351.
[51] D. Kroodsma, J. Mayorga, T. Hochberg, N. Miller, K. Boerder, F. Ferretti, A. Wilson, B. Bergman, T. White, B. Block, P. Woods, B. Sullivan, C. Costello, B. Worm, Tracking the global footprint of fisheries, Science (80-.) 359 (2018) 904–908, https://doi.org/10.1126/science.aao5646.
[52] T. Aqorau, Recent developments in Pacific Tuna Fisheries: the Palau arrangement and the vessel day scheme, Int. J. Mar. Coast. Law. 24 (2009) 557–582, https://doi.org/10.1163/15718089X455647.
[53] T. Aqorau, J. Bell, J. Kittinger, Good governance for migratory species, Science (80-.). 361 (2018) 1208–1209, https://doi.org/10.1126/science.aav2051.
[54] T. Bahri, M. Vasconcellos, D. Welch, J. Johnson, R. Perry, X. Ma, R. Sharma, Adaptive management of fisheries in response to climate change, Rome (2021), https://doi.org/10.4060/cb3095en.
[55] M. Titley, S. Butchart, V. Jones, M. Whittingham, S. Willis, Global inequities and political borders challenge nature conservation under climate change, Proc. Natl. Acad. Sci. 118 (2021), e2011204118, https://doi.org/10.1073/pnas.2011204118.
[56] J. Cinner, T. McClanahan, Adapting to a Changing Environment: Confronting the Consequences of Climate Change, Oxford University Press, New York, 2012.
[57] UNGA, Transforming our world: the 2030 Agenda for Sustainable Development, New York, 2015.
[58] Food and Agriculture Organization of the United Nations, K.E.Y. Messages, The State of World Fisheries and Aquaculture 2016, 2016. ⟨http://www.fao.org/3/a-i3720e.pdf⟩.
[59] N. Bennett, E. Finkbeiner, N. Ban, D. Belhabib, S. Jupiter, J. Kittinger, S. Mangubhai, J. Scholtens, D. Gill, P. Christie, The COVID-19 pandemic, small-scale fisheries and coastal fishing communities, Coast. Manag. 48 (2020) 336–347, https://doi.org/10.1080/08920753.2020.1766937.
[60] E. White, H. Froehlich, J. Gephart, R. Cottrell, T. Branch, R. Bejarano, J. Baum, Early effects of COVID-19 on US fisheries and seafood consumption, Fish Fish 22 (2020) 232–239, https://doi.org/10.1111/faf.12525.
[61] W. Swartz, U. Sumaila, R. Watson, D. Pauly, Sourcing seafood for the three major markets: the EU, Japan and the USA, Mar. Policy 34 (2010) 1366–1373, https://doi.org/10.1016/j.marpol.2010.06.011.
[62] F. Asche, M. Bellemare, C. Roheim, M. Smith, S. Tveteras, Fair enough? Food security and the international trade of seafood, World Dev. 67 (2015) 151–160, https://doi.org/10.1016/j.worlddeve.2014.10.013.
[63] J.D. Bell, V. Allain, E.H. Allison, S. Andréfouët, N.L. Andrew, M.J. Batty, M. Blanc, J.M. Dambacher, J. Hampton, Q. Hanich, S. Harley, A. Lorrain, M. McCoy, N. McTurk, S. Nicol, G. Pilling, D. Point, M.K. Sharp, P. Vivili, P. Williams, Diversifying the use of tuna to improve food security and public health in Pacific Island countries and territories, Mar. Policy 51 (2015) 584–591, https://doi.org/10.1016/j.marpol.2014.10.005.
[64] J. Bell, I. Senina, T. Adams, O. Aumont, B. Calmettes, S. Clark, M. Dessert, M. Gehlen, T. Gorgues, J. Hampton, Q. Hanich, H. Harden-Davies, S. Hare, G. Holmes, P. Lehodey, M. Lengaigne, W. Mansfield, C. Menkes, S. Nicol, Y. Ota, C. Pasisi, G. Pilling, C. Reid, E. Ronneberg, A. Gupta, K. Seto, N. Smith, S. Taei, M. Tsamenyi, P. Williams, Pathways to sustaining tuna-dependent Pacific Island economies during climate change, Nat. Sustain. 4 (2021) 900–910, https://doi.org/10.1038/s41893-021-00745-z.