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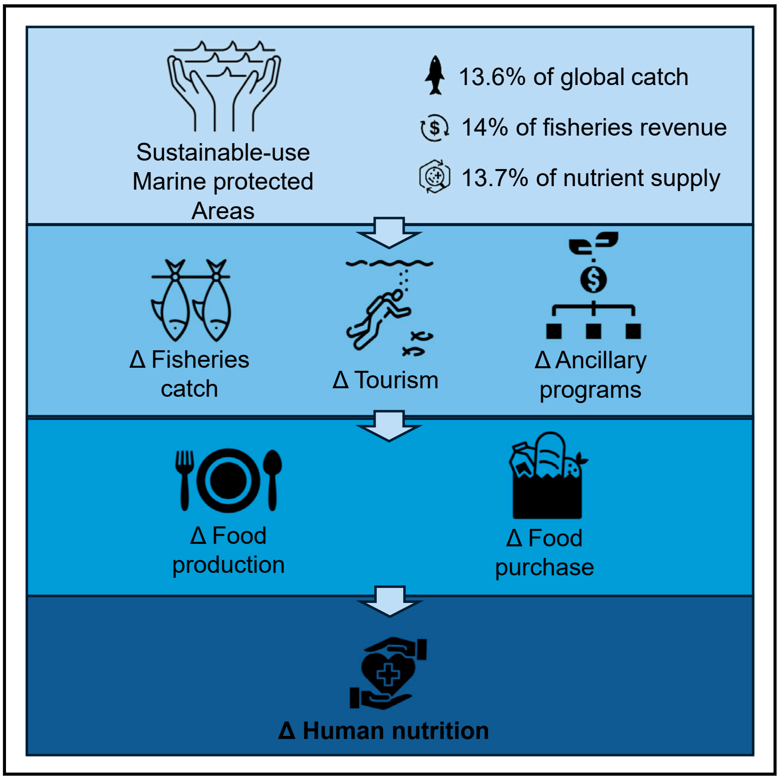
Sustainable-use marine protected areas provide co-benefits to human nutrition

Graphical abstract



Highlights

- Sustainable-use MPAs contribute up to 14% of global fisheries nutrient supply
- MPAs can enhance nutrition via increased fisheries, tourism, and ancillary programs
- Nutritional benefits depend on MPA management, design, governance, and context
- Few studies directly link MPAs to human health, highlighting a key research gap

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In brief

Sustainable-use marine protected areas (MPAs) have indirect impacts on human nutrition. Our study highlights the role of MPAs in improving fisheries productivity and income generation via tourism, which can lead to improved access to seafood. These changes in access to seafood lead to improved nutrient supply in diets, which is particularly important for coastal communities dependent on aquatic foods. By examining the pathways linking MPAs to nutrition, this research underscores the potential of well-managed MPAs to improve ecological outcomes and human well-being.

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Article

Sustainable-use marine protected areas provide co-benefits to human nutrition

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SCIENCE FOR SOCIETY Overfishing, climate change, and marine habitat destruction pose severe threats to marine biodiversity and the communities that depend on marine foods for essential nutrients like protein, minerals, vitamins, and omega-3 fatty acids. In response, countries have set a global target to protect 30% of the oceans by 2030 through marine protected areas (MPAs) and other conservation measures. Yet, how MPAs affect human nutrition and well-being is poorly understood. This study fills that gap by exploring how MPAs that allow regulated fishing affect nutrition through impacts on fisheries productivity, tourism, and local livelihoods. We find that well-designed and managed MPAs can both conserve biodiversity and improve nutritional security, benefitting the health and livelihoods of vulnerable communities dependent on marine resources.

SUMMARY

Aquatic foods are a vital source of nutrients for coastal communities around the world. The global commitment to expand marine protected areas (MPAs) means it is critical to understand how MPAs affect human nutrition and health. Here, we perform a literature review to identify the major pathways through which sustainable-use MPAs, those that allow for fishing activities within their borders, affect human nutrition and health. We found that sustainable-use MPAs often affect nutrition through three main pathways: (1) changes in fisheries catch, (2) changes in tourism activity, and (3) changes in ancillary programs. We also quantitatively analyze the contribution of sustainable-use MPAs to global catch, revenue, and nutrient supply. We estimate that sustainable-use MPAs contribute an average of 13.6% of global catch, 14% of fisheries revenue, and 13.7% of nutrient supply. Given dire global nutritional vulnerabilities, the potential impacts of MPAs on diets should be a key consideration in MPA expansion discussions.

INTRODUCTION

In 2022, the Kunming-Montreal Global Biodiversity Framework under the Convention on Biological Diversity set an ambitious target to protect 30% of the planet's oceans and lands by 2030 through protected areas (PAs) and other effective area-based conservation measures (OECMs).[1] Marine PAs (MPAs) are "a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values."[2] While MPAs have a primary objective of nature conservation, they can be highly tailored to a local context,[3] and many have multiple objectives, including improving the social well-being of coastal communities.[4,5] MPAs are rapidly being implemented all over the world as a solution to the degradation of marine ecosystems and fisheries declines and are increasingly being applied to enhance climate resilience and food security.[6] Today, there are about 18,000 MPAs worldwide, covering about 8% or 29 million km^2 of our oceans.[7] Expanding MPAs and OECMs to 30% of global oceans that meet their desired social and ecological objectives requires a robust, evidence-based foundation of their effects on biodiversity and coastal communities.

MPAs can be designed and implemented to not only protect biodiversity and promote sustainable fisheries but also to contribute to food and nutrition security. While there is substantial variation in MPA configurations and zonation, MPA zones often provide varying levels of protection. These range from fully protected areas (i.e., no take), where fishing is prohibited, to lightly or minimally protected areas (i.e., sustainable-use areas), where some forms of fishing are allowed—normally with the intention of sustainable management.[8] Sustainable-use MPAs employ a range of fisheries management tools to promote the sustainability of fisheries and are often zoned for multiple purposes, including tourism, aquaculture, and conservation.[5] All MPA zones, regardless of their protection level, can have significant positive effects on the biomass of aquatic species when compared to open-access areas.[9–12] Such an increase in biomass can improve fisheries production[13] and boost local tourism,[14] potentially increasing income and food consumption in coastal communities.[15] MPAs can improve fisheries production through improved fisheries management within sustainable-use zones or spillover from no-take areas to fished areas within or outside MPAs.[11] On the other hand, changes in access rights and harvest restrictions can reduce fisheries catch[16] and consequently limit access to aquatic foods, thereby decreasing nutrient intakes. These complexities, trade-offs, and timelines of realized costs and benefits are critically important to understand. Yet, overall, the effects of MPAs on food and nutrition security at global and local scales are understudied.[17]

Many coastal communities around the world rely heavily on seafood as their primary source of animal-sourced food consumption,[18–20] as they provide essential micronutrients (vitamins and minerals), protein, and fatty acids.[21,22] Consumption of aquatic foods can improve the nutritional status of vulnerable communities and avert the consumption of more harmful animal-sourced foods that can lead to obesity, diabetes, and other diet-related diseases.[21] Nutrients from aquatic foods are particularly important for communities that do not have access to diverse diets and terrestrial animal-source foods.[19,21–23] For many coastal communities around the world, a typical diet relies heavily on staple foods (e.g., corn, rice, wheat, cassava), and aquatic foods serve as the main or only source of essential nutrients and protein, which is vital for human health and growth.[22] Consumption of nutrients such as omega-3 fatty acids is critical for brain health,[24] and aquatic food consumption can reduce the risk of anemia, pre-eclampsia, and maternal and perinatal mortality, among other health issues.[25] In addition, nutrients in aquatic foods are highly bioavailable, meaning they are quickly absorbed by the body. Furthermore, consumption of aquatic foods can enhance the absorption of nutrients such as iron from plant-based foods.[22] With over 3.1 billion people unable to consistently access safe, nutritious, and sufficient food and over 700 million people undernourished globally,[26] it is critical to understand how MPAs will alter access to nutrients from aquatic foods.

Here, we examine the social outcomes of MPA establishment, focusing particularly on health and nutrition. We employed both qualitative and quantitative methods. Through a scoping literature review using a vote count study method,[27] we synthesized current empirical research on the potential mechanisms by which sustainable-use MPAs can affect human nutritional outcomes. Based on findings from the literature, we developed a conceptual framework to better understand the pathways by which sustainable-use MPAs can influence human health and nutrition. Our analysis focused on sustainable-use MPAs because these areas allow fishing within their borders and can have a greater direct impact on livelihoods and aquatic food production.[5] Finally, we estimated the proportion of catch, value, and nutrient supply originating from sustainable-use MPAs on national and global scales. We found that sustainable-use MPAs can indirectly impact nutrition through three key pathways: changes in fisheries catch, tourism activity, and ancillary programs. Our analysis shows that these MPAs contribute 13.6% to global catch, 14% to global fisheries revenue, and 13.7% to the global nutrient supply across assessed nutrients. Our research provides a crucial foundation for assessing indirect effects of MPAs on human nutrition, but further studies are needed to measure their direct impact on nutritional outcomes.

RESULTS

Evidence from published studies

Through a scoping review of the literature, we found a total of 234 reported MPA outcomes that can indirectly affect human nutrition (see Note S1). We focused on the indirect effects because of the low number of studies that directly investigated the effects of MPAs on human nutrition (n = 3). We found three dominant pathways for MPAs to influence nutritional outcomes: (1) changes in fisheries catch, (2) changes in tourism activity, and (3) changes in ancillary programs. Most reported outcomes (n = 167, 65%) indicated improvements in all reported outcomes following MPA establishment. Results were reported for both sustainable-use MPAs, where fishing is allowed, and no-take areas, where no extractive activities are permitted. In sustainable-use areas, changes in fisheries catch were directly related to fishing activities conducted within the MPA, while in no-take zones, the emphasis is on assessing spillover benefits affecting fish populations and catch rates outside the no-take boundaries.

For the fisheries productivity pathway, we found that the majority of reported outcomes indicated an increase in fisheries catch (n = 64 of 96, 66%), catch per unit effort (CPUE; n = 62 of 87, 71%), and income (n = 22 of 35, 62%) (Figure 1). Such increases in fisheries productivity and income can occur because of improved governance and fisheries management within MPAs, leading to increased fish biomass or decreased competition over fisheries resources.[11] However, of the reported outcomes, 18% (n = 14) indicated a decline in catch and 13% (n = 12) in CPUE following MPA implementation, showing evidence of potential negative effects on nutrition. Such declines in catch are expected, particularly in the short term immediately after restrictive policies are implemented or when no-take MPAs are implemented in previously fished areas.[28] The remaining 15% indicated no change in fisheries performance.

Most studies that analyzed the effects of tourism (n = 10) also found an increase in income from tourism. About 75% of the reported outcomes (n = 8) indicated that stakeholders experienced an increase in their income from tourism following MPA implementation. Such increases can occur due to the increased

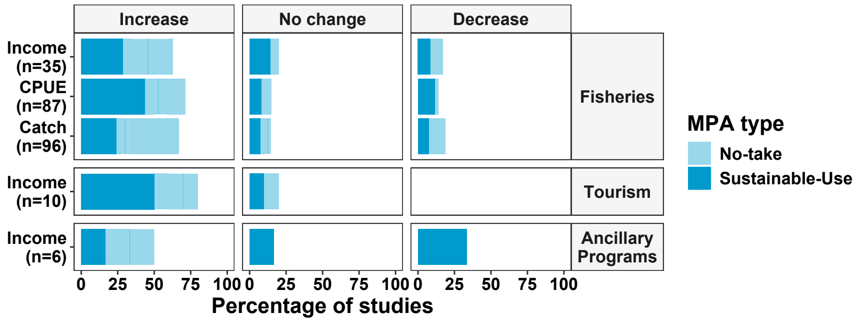

Figure 1. Summary of MPA outcomes with indirect effects on human nutrition

Directionality of 234 reported marine protected area (MPA) outcomes that can be associated with human health and nutrition. Percentages refer to the total number reported for each specific outcome. Darker colors represent outcomes from sustainable-use MPAs. Fisheries benefits from no-take areas represent "spillover" to areas with fishing, while fisheries benefit for sustainable-use zones represent both direct catch and catch per unit effort (CPUE) within the MPA as well as spillover to other fished areas.

number of visitors within MPAs and the consequent multiplier effects that additional tourists have on the local economy.[14] A low number of reported outcomes (*n* = 2, 20%) found no change in income from tourism following MPA implementation. This could suggest that the presence of a tourism economy might not be a viable option in all MPAs and that minimal infrastructure likely needs to be in place for tourism to provide an increase in income.[14]

We found few studies quantifying the impacts of ancillary programs associated with MPAs on the employment and income of coastal communities (*n* = 6). Ancillary programs include alternative livelihood programs, MPA employment opportunities, and/or payment for ecosystem service programs such as carbon credits.[29] From studies that reported these activities, most communities around MPAs observed an increase in income following MPA establishment (*n* = 3, 50%). However, a few studies (*n* = 2, 33%) also reported a decrease in income following MPA establishment, which can be associated with changes in property rights and employment inequity.[30]

Very few studies (*n* = 3) have directly investigated the effects of MPAs on human health and nutrition. One study in the Solomon Islands compared nutritional outcomes of several villages with and without MPAs to assess their impacts on human health and nutrition.[31] By using data from 24-h dietary recall surveys, they showed that residents of villages with effective MPAs had higher seafood intake compared to villages with ineffective or no MPAs. Another study in the Philippines found a positive association between MPAs and children's dietary diversity.[32] Finally, a study in the Mesoamerican reef region of Central America found that communities near MPAs had 40%–47% lower probability of child stunting compared to communities located farther from MPAs.[15] These types of studies are crucial to assess the impacts of MPAs on human health and nutrition and need to be expanded to other locations to provide more general insights.

Conceptual framework

Based on the results of the literature review, we developed a conceptual framework that details the major pathways reported in the literature by which sustainable-use MPAs can affect human nutrition (Figure 2). The relative strength of each pathway and the magnitude, directionality (i.e., positive or negative), and distribution of outcomes within this framework are shaped by the distinct local social, economic, and ecological characteristics, as well as the specificities of MPA design, management, and governance.

Changes in fisheries catch

The establishment of sustainable-use MPAs can have positive or negative impacts on fisheries catch based on the local social-ecological context or the time since establishment. Many studies show how MPAs can increase target species biomass within their borders compared to areas outside,[5] and no-take areas within sustainable-use MPAs can increase fisheries productivity through the spillover of adults and larvae to fished areas.[33] Areas that have experienced overfishing can benefit the most from MPA establishment because they can help recover overfished stocks and increase catch through the implementation of management measures.[34,35] MPAs established in pristine or well-managed areas can have little or no net effect on fisheries catch but can be important to prevent catch decline and maintain a supply of nutrients into the future.[10,36] However, depending on pre-fishing activity and MPA design and management, management measures (e.g., size limits, season closure) following MPA establishment can also decrease catch in the short term, and no-take areas can exclude fishers from highly productive fishing areas, with potentially detrimental effects on food consumption.[37,38] In addition, the displacement of effort following MPA creation can change the location and distance of fishing grounds, increasing costs and potentially decreasing catch.[39] Management measures can, therefore, increase or decrease the availability of seafood in coastal communities depending on the local context, and the impacts can be felt quite differently by various groups, such as women or socio-economically marginalized populations, due to varied access restrictions, dependency, and adaptive capacity.[30,40,41]

Seafood consumed by fishers and their families is a vital source of nutrients that is directly affected by catch fluctuations, processing, and quality of the seafood consumed.[19] Fluctuations in catch from MPAs can affect human nutrition through two main pathways: changing the availability of fish for local consumption and/or changing the net income of fishers from the sale of aquatic food products (Figure 2). Fish that is sold in local markets or given as gifts can be an accessible source of nutrients for households that are not directly engaged in fisheries.[42] In addition, fish that are sold in local or external markets generate income for fishers, as well as for local processors and resellers, and can also be directly affected by MPA catch fluctuations.[43,44] Changes in the income of households that depend on resources from MPAs (Figure 2) can affect the quantity and quality of food bought.[45] In poor coastal communities, small changes in income can significantly affect the amount and type of food consumed and, consequently, their nutritional status.[46] However, localized

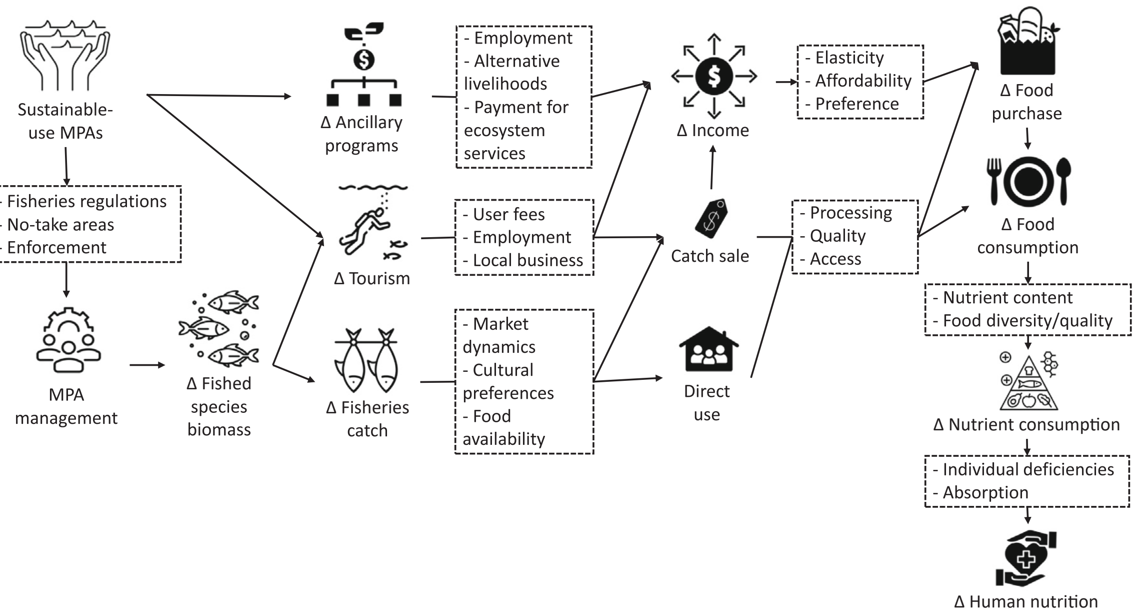

Figure 2. Conceptual framework connecting MPAs and human nutrition

Outlines the main pathways through which MPAs can affect the nutrition of coastal communities reported in the literature. Arrows show the direction of impact. Dotted text boxes highlight examples of factors that influence each impact pathway.

studies on consumer choice behavior and income elasticities are required to precisely quantify how changes in income affect food purchasing.[47,48] Depending on the context, any additional income can be spent on non-food items or foods with little nutritional value.[47,49]

Changes in tourism activity

Increased fish biomass within MPA boundaries can attract tourists and provide important economic benefits to local communities.[14,50–52] These changes in income and markets can affect food consumption patterns and, consequently, human nutrition.[53] Several studies show that tourists, particularly divers and recreational fishers, are attracted to MPAs, with factors such as local tourism infrastructure and species biomass playing a crucial role in determining potential tourism benefits.[14,54] Tourism benefits can be obtained through recreational activities within the MPA and the resulting multiplier effects on local business related to tourism, such as hotels, restaurants, and souvenir shops.[55] In many MPAs around the world, tourism can be the main source of revenue for local coastal communities, increasing seafood prices and generating jobs and income for community members.[50] However, tourism-related jobs can be highly specialized or directed toward non-locals, thus preventing local community members from benefiting from growing tourism.[56] In addition, increased tourism activity can lead to less people being involved in aquatic food production and increases in the price due to high demand.[57] This can also lead to a shift from traditional, more nutritious diets to less healthy processed foods.[49]

Changes in ancillary programs

Designation of MPAs and the buildup of fish biomass can attract or come in conjunction with private and public investments to communities surrounding the MPA.[58] For example, research and social projects (e.g., alternative livelihood initiatives, payment for ecosystem service schemes) within the MPA can generate employment for local communities and, consequently, lead to increased local income.[59] Several funding agencies and non-governmental organizations seek to work with communities in or around MPAs.[60] In addition, management activities within the MPA (e.g., monitoring, enforcement, administration) require resources and labor, which can also involve local communities.[61] However, many of these MPA management and other employment opportunities can be highly specialized and not accessible to all community members.[62] The distribution of income is key in determining the real impacts of ancillary programs on the income of local communities and, subsequently, nutrient intake.

Global catch, revenue, and nutrients

To better understand the magnitude of the effects of sustainable-use MPAs on human nutrition, we estimated the share of global catch that overlaps with sustainable-use MPAs. We estimate that catches from sustainable-use MPAs represent an average of 7% of total global catches within exclusive economic zones (EEZs). The relative contribution of sustainable-use MPAs to national catches is variable, with a median of 2.5% and an average of 13.6% (Figure 3). For island countries such as Bonaire, Palau, and Cook Island, catch from sustainable-use MPAs can represent more than 95% of national catches (Figure 3).

By multiplying species-specific catch with their respective price and nutritional values, we estimated the percentages of total revenue and nutrient supply that are provided by sustainable-use MPAs globally. We focused our analyses on zinc, iron, calcium, omega-3 long-chain polyunsaturated fatty acids docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) (hereafter referred as DHA+EPA), and vitamins A and B_{12}. These nutrients are abundant in aquatic species and are often deficient

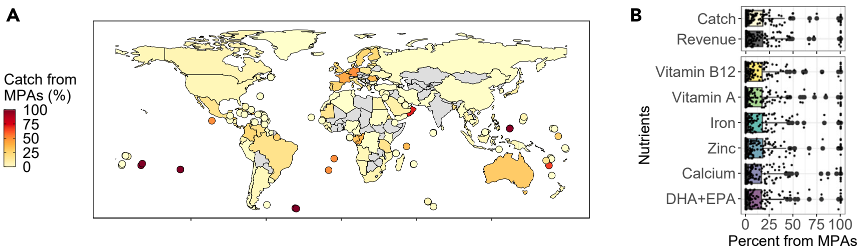

Figure 3. Contribution of sustainable-use MPAs to catch, revenue, and nutrient supply

Estimates are at a national scale relative to all fish landings from the countries' exclusive economic zone (EEZ). (A) shows the percentage of catch from sustainable-use MPAs. Countries smaller than 25,000 km^2 are illustrated as points. (B) shows the distribution (in percentage) of sustainable-use MPA contributions across countries to total revenue and nutrient supply (iron, EPA+DHA, calcium, zinc, and vitamins A and B_{12}).

in the diets of people in low- and middle-income countries (LMICs).[21] We found that, on aggregate, sustainable-use MPAs contribute to 7.5% of global fisheries revenue (average of 14% across all analyzed countries) and an average of 13.7% of fisheries nutrient supply across all assessed nutrients (ranging from 13% to 14% across assessed nutrients) (Figure 3).

DISCUSSION

The conceptual framework (Figure 1) illustrates major pathways through which MPAs can affect human health and nutrition: changes in fisheries productivity, tourism activity, and ancillary programs. Although there are few studies directly linking MPAs with human nutrition, our review of the literature showed that most studies found positive effects of MPAs on income and catch, which can be linked to improved nutrition.[15] However, we also found evidence for negative effects of MPAs on income and catch, suggesting that additional policies might be required to ensure that MPAs do not have negative impacts on human nutrition. This is likely particularly the case for no-take areas, where there will be the need to offset the lag time for increases in biomass and spillover effects to materialize as fisheries benefits. In addition, we found that about 13% of global catch and nutrient supply are potentially sourced from sustainable-use MPAs globally, highlighting the importance of these areas for global nutrient supply. Although our sample includes sustainable-use MPAs that have no-take areas, the question of how the global network of no-take MPAs does or might impact health and nutrition is beyond the scope of the current paper but is one that deserves further attention.[17]

The nutritional benefits of MPAs are additional to their biodiversity conservation benefits. Promoting better resource management through sustainable-use MPAs can help to ensure long-term supply of critical nutrients by supporting the recovery of fisheries stocks. In addition, it has been suggested that MPAs can increase the resilience of natural systems, protecting fisheries stocks and nutrient supply against future climate-related shocks.[63] Given growing evidence of climate impacts on coastal fish stocks causing negative human well-being impacts,[64] this role for MPAs is likely to become more important in the future.

Unlike other interventions that may have ecological trade-offs or rely on external inputs (such as fertilizers/seeds for agriculture or feed for livestock), sustainably financed MPAs could function as self-sustaining systems that, when appropriately managed, can potentially provide long-term nutritional benefits without compromising the integrity of marine habitats. However, other policies such as promoting food cultivation (e.g., livestock, agriculture, aquaculture) or providing nutritional supplements can be faster at addressing nutritional needs.[26] Therefore, a balanced approach that integrates the long-term sustainability of MPAs with targeted short-term interventions can offer a comprehensive solution to improving the nutritional outcomes of vulnerable communities.

How MPAs are designed, managed, and governed can determine biological responses and, consequently, the effects of MPAs on human nutrition and health. Several studies show how factors such as staff capacity, enforcement, and level of local engagement influence MPA outcomes.[9,65–67] In addition, MPAs reallocate preexisting rights governing resource access and use,[68] which can potentially change who will benefit or lose from MPA establishment. For example, if a no-take MPA is established next to a nutritionally vulnerable community, then some members of this community might lose access to an important source of nutrients, while others might benefit from increased economic activity due to tourism.

It is crucial to emphasize the changing impacts of MPAs on human health and nutrition over time. First, because of potential changes in fisheries rules and restrictions following MPA implementation, there can be short-term loss in fisheries yield, followed by a potential long-term increase in fisheries productivity.[28] Such short-term yield losses can negatively impact the nutrition status of vulnerable coastal communities. Second, generation of income through tourism or ancillary program resources can also take time, especially when it is linked with increases in fish biomass.[14] Depending on the level of overfishing prior to MPA establishment, buildup of biomass can take several years.[28] Tourism activities that are linked with increases in fish biomass (such as diving) are also affected by these temporal dynamics.[14] Therefore, it is critical to acknowledge such temporal dynamics and nutritional dependence, implement policies to alleviate potential short-term costs (e.g., alternative livelihoods, tourism), and ensure that future benefits are directed to those that bear such costs and are highly dependent.

The location of MPAs can also influence human health and nutrition outcomes. MPAs located in fishing grounds of nutritionally vulnerable coastal communities can have the largest effects on human health and nutrition, both positive and negative. Many coastal communities around the world depend on seafood consumption for the supply of nutrients.[19] In such communities, establishing management measures that can recover overfished stocks and increase catch can have direct benefits to human health and nutrition over time, especially for communities closer to MPAs.[15] On the other hand, MPAs located in open ocean areas or areas far from human settlements have potentially limited effects on human health and nutrition. In most cases, these areas are fished by large vessels, and catch is often sold in international markets destined for wealthier countries.[69] Although wealthy countries can benefit from higher seafood consumption through increased omega-3 intake (which decreases the risk of developing heart diseases, for example[25]), the effect of MPAs is dissipated and likely lower than for MPAs located next to vulnerable coastal communities.

The nutritional impacts of MPAs also depend on the specific nutritional needs of local communities and the nutritional content of the fished species within MPAs.[22] It is important to understand food and nutritional consumption patterns within targeted communities to evaluate the specific nutritional deficiencies of the population. Based on the need, management and accessibility actions can then focus on species that have high concentrations of the nutrients that are most needed by the local population.[70] The nutrients analyzed in this study, such as omega-3 fatty acids, protein, and essential minerals, serve as illustrative examples of the nutritional richness found in aquatic foods. These nutrients represent only a fraction of the diverse array of nutrients available in thousands of aquatic species being consumed globally.[22]

Nutritional benefits from MPAs also depend on the distribution, accessibility, condition, and preferences of the aquatic foods consumed by local communities.[19] The effectiveness of MPAs in enhancing human nutrition relies on the accessibility of aquatic foods to local populations. Aquatic foods are among the most traded and valued food commodities in the world, with much of the production moving from nutritionally vulnerable to nutritionally secure nations.[71] Therefore, it is critical to ensure that nutritious aquatic foods are consumed locally to improve the nutritional status of vulnerable populations. Communication campaigns can raise awareness of the importance of consuming nutrient-rich species by local communities. Market incentives can ensure that aquatic foods from sustainable-use MPAs are affordable, high quality, and readily available in local markets. Additionally, food processing techniques (e.g., drying, smoking, cold storage chain) that extend the shelf life while preserving important nutrients are key for aquatic species to provide safe and nutritious foods to local communities.

Study limitations

This study has several limitations that should be acknowledged. Firstly, in the literature review, we made assumptions about the links between catch, income, and nutritional outcomes even though these factors may be independent. Additionally, our use of vote counting does not assess the rigor of the studies reviewed or the causality of their findings. The literature review is also subject to sample size limitations and publication biases, as it may disproportionately focus on studies reporting positive impacts. Specifically, for benefit pathways related to the impacts of tourism and ancillary programs, the findings were based on a limited number of studies (n = 10 for tourism and n = 6 for ancillary programs); thus, more research is needed to draw definitive conclusions. Furthermore, both the Sea Around Us (SAU) database and Aquatic Foods Composition Database (AFCD) report catch and nutritional content (respectively) using average values from different taxonomic groups. As a result, in many cases, we derived our nutrient estimates using data from broader taxonomic levels. Regarding our catch estimates, the data from SAU have their limitations and assumptions necessary for their spatial allocations at a global scale.[72] The large raster cell size in the data requires assumptions of equal catch distribution within each cell, which may not accurately reflect reality. Moreover, we relied on the World Database on Protected Areas (WDPA) for information on MPAs, assuming that all MPAs are both designated and actively managed, which may not always be the case. We used the term "sustainable-use MPAs" for all MPAs where some forms of fishing are allowed; however, given data limitations, we could not assess whether these MPAs were sustainable. These limitations highlight the need for cautious interpretation of our findings and suggest areas for further research.

Knowledge gaps and future research directions

Future research should focus on elucidating the impacts of MPAs on nutrition through the development of comprehensive monitoring and evaluation frameworks that incorporate standardized indicators to quantify health and nutritional outcomes. Critical to such frameworks will be the disaggregation of impacts across demographic strata, including gender, ethnicity, and intersectional groups, to capture a nuanced understanding of these effects. Future research should adopt a systems approach, analyzing the entire seafood value chain to determine how social, political, economic, ecological, and governance aspects modulate the nutritional outcomes of marine conservation initiatives. A pivotal area of investigation should involve the optimization of MPA designs to bolster their contributions to aquatic food systems, with a thorough evaluation of both immediate and long-term nutritional impacts. This will encompass the analysis of various habitat types, species-specific responses, and the implications of species consumption on the health of local communities. Furthermore, future research can examine the distribution of aquatic foods from MPAs, differentiating between locally retained resources and those destined for export, while critically evaluating the frameworks governing rights and access. Addressing these areas will fill existing knowledge gaps and inform efforts to enhance the ability of MPAs to improve nutritional outcomes.

Conclusion

MPAs can affect the health and nutrition of coastal communities in various ways. With current global MPA expansion goals, it is critical to acknowledge the potential effects of MPA establishment on the health and nutrition of coastal communities. Factors such as MPA design, location, and management can increase or decrease the availability of seafood, consequently affecting the income and food consumption of coastal communities. This and other studies show that MPAs can contribute to fisheries catch, with potential positive downstream impacts on human health and nutrition. However, managers and policymakers need to ensure that economic incentives and public policies are in place to mitigate potential health risks related to short-term reductions in nutrient supply that can occur with MPA implementation.

Establishing MPAs in nutritionally vulnerable coastal communities can be an important measure to improve human health and nutrition. Current efforts to expand MPAs should consider the potential effects on human health and nutrition while being careful to also consider potential unintended impacts and the distribution of benefits and costs and ensure that the design fits the local context. Strategically placing sustainable-use MPAs in coastal communities that are nutritionally vulnerable, dependent on aquatic foods, and most threatened by overfishing can maximize their positive impact when appropriately designed and managed. Therefore, it is crucial that nutritional and health objectives are integrated into MPA expansion discussions to ensure that these areas effectively contribute to the well-being of vulnerable populations.

EXPERIMENTAL PROCEDURES

Literature review

We performed a scoping literature review of MPA outcomes to identify the main pathways by which they can affect human health and nutrition.[73] Because most studies did not report direct impacts on human nutrition, we inferred that changes in fisheries, tourism, and ancillary program resources resulting from MPA establishment would affect nutrition outcomes, as outlined in the conceptual framework (Figure 2). We conducted the review to extract the MPA outcome data used in the analysis (see Note S1). The review consisted of two main steps: (1) compiled information from reviewed papers on MPA social and economic outcomes and (2) complemented and updated search strings from other reviews. We compiled information on a total of 234 reported outcomes from around the world, published until 2021. The reported outcomes covered 32 countries, with 70% of them focusing on tropical ecosystems (Note S1; Figure S1). We included only peer-reviewed empirical studies written in English, excluding any theoretical modeling of MPA outcomes. In each paper, we collected information on whether there was a reported increase or decrease in fisheries, tourism, or ancillary program outcomes. In terms of fisheries, we compiled information on changes in income, CPUE, and catch. For tourism, we evaluated changes in income following MPA establishment. Finally, for ancillary programs, we evaluated outcomes in terms of reported changes in income that were not linked to tourism or fisheries.

Catch, revenue, and nutrient supply from MPAs

To assess the contribution of sustainable-use MPAs to global catch, revenue, and nutrient supply, we integrated spatial catch allocations from the SAU project[72] with the spatial distribution of MPAs from the WDPA.[7] First, we employed spatially explicit reconstructed SAU data for 2019, which allocate national catch within half-degree spatial cells from each country.[72] This analysis was confined to catches within countries' EEZs, excluding any catches from the high seas. Next, we overlaid these spatially explicit catch data with MPA polygons obtained from the WDPA,[7] considering only MPAs that permit fishing within their boundaries (i.e., sustainable-use MPAs) and excluding MPAs that are completely no-take zones. We estimated the total catch from sustainable-use MPAs for each coastal nation by comparing the catch within these MPAs to the estimated total catch for the entire EEZ. To calculate the contribution of sustainable-use MPAs to each country's revenue, we multiplied the catch by the species-specific ex-vessel prices provided in the SAU database.

To determine the nutritional contribution of sustainable-use MPAs, we utilized the Aquatic Foods Composition Database (AFCD),[21] which contains over 3,750 records of nutrient content from global databases and peer-reviewed literature. Nutritional content was assigned to each species using a hierarchical approach based on taxonomic information: starting with the scientific name, and if not available, using the average values for genus, family, order, and class, respectively. We focused on the median values of key nutrients: iron, zinc, DHA+EPA, vitamin A, vitamin B_{12}, and calcium, selected for their high concentrations in aquatic species and known inadequacies in many countries.[21] When catch from SAU was reported at higher taxonomic levels, we used the average value for the entire taxonomic group. For catch reported in broader categories, such as "miscellaneous marine fishes," we applied the average value for the corresponding functional group. To improve accuracy, we considered only raw nutrient values, excluding those affected by cooking methods, and used muscle tissue data, excluding bones, heads, and liver. We validated the nutrient values by checking for outliers and ensured consistency. In addition, we conducted a strict standardization and cleaning process for the AFCD data to ensure consistency of taxonomic information and nutrition data. The predicted catch was then multiplied by the edible portion of each species based on AFCD data, followed by multiplication with the nutritional values to obtain the total nutrient supply for each nutrient. Finally, we calculated the relative contribution of sustainable-use MPAs to the total nutrient supply of each EEZ.

RESOURCE AVAILABILITY

Lead contact

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Materials availability

This study did not generate new unique materials.

Data and code availability

All original data from literature review and code used in analysis have been deposited at a GitHub repository (https://github.com/danielfvi/MPA-Nutrition-OneEarth). Code for the AFCD package with standardized and cleaned data can be found in the following GitHub repository: https://github.com/Aquatic-Food-Composition-Database/AFCD.

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AUTHOR CONTRIBUTIONS

D.F.V., C.D.G., and D.A.G. conceptualized the research idea, with significant methodological and design input from A.V. and N.J.B. D.F.V. led the paper analysis and visualization. D.F.V. drafted the original manuscript, and all co-authors edited and revised the writing.

DECLARATION OF INTERESTS

The authors declare no competing interests.

SUPPLEMENTAL INFORMATION

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