Recreational inland fish as food: Nutrition, economic value, and climate vulnerability

Abigail J. Lynch[1]*, Holly S. Embke[2], Elizabeth A. Nyboer[3, 4], Louisa E. Wood[5], Andy Thorpe[5], Sui C. Phang[6], Daniel F. Viana[7], Christopher D. Golden[7], Marco Milardi[8], Robert Arlinghaus[9,10], Claudio Baigun[11], T. Douglas Beard, Jr.[1], Steven J. Cooke[3], Ian G. Cowx[12], John D. Koehn[13, 14], Roman Lyach[15], Warren Potts[16, 17], Ashley M. Robertson[18], Josef Schmidhuber[19], Olaf L.F. Weyl[17+]

[1]United States Geological Survey, National Climate Adaptation Science Center, 12201 Sunrise Valley Drive MS 516, Reston, VA, 20192, USA; ajlynch@usgs.gov, http://orcid.org/0000-0001-8449-8392; dbeard@usgs.gov, https://orcid.org/0000-0003-2632-2350

[2]United States Geological Survey, Midwest Climate Adaptation Science Center, 1954 Buford Ave, St. Paul, MN, 55108, USA, hembke@usgs.gov; https://orcid.org/0000-0002-9897-7068

[3]Canadian Centre for Evidence-Based Conservation, Department of Biology and Institute of Environmental and Interdisciplinary Science, Carleton University, Ottawa, ON, Canada, b.a.nyboer@gmail.com, https://orcid.org/0000-0003-3004-009X; StevenCooke@cunet.carleton.ca; https://orcid.org/0000-0002-5407-0659

[4]Virginia Polytechnic Institute and State University, Department of Fish and Wildlife Conservation, Blacksburg, VA, USA

[5]Centre for Blue Governance, University of Portsmouth, Portsmouth, PO1 2UP, UK; louisa.wood@port.ac.uk, 0000-0002-8649-5010 andy.thorpe@port.ac.uk, 0000-0002-5025-1209

[6]The Nature Conservancy, London, United Kingdom; sui.phang@tnc.org, https://orcid.org/0000-0002-2735-0241

[7]Department of Nutrition, Department of Environmental Health, Department of Global Health and Population, Harvard T. H. Chan School of Public Health, Boston, MA, USA; golden@hsph.harvard.edu, dviana@hsph.harvard.edu; https://orcid.org/0000-0002-2258-7493; https://orcid.org/0000-0002-6000-2011

[8] Southern Indian Ocean Fisheries Agreement (SIOFA/APSOI), 97489 Saint-Denis Cedex, La Réunion marco.milardi@siofa.org, https://orcid.org/0000-0001-6104-294X

[9]Leibniz Institute of Freshwater Ecology and Inland Fisheries, Department of Fish Biology, Fisheries and Aquaculture, Müggelseedamm 310, 12587 Berlin, Germany

[10]Humboldt-Universität zu Berlin, Faculty of Life Sciences, Division of Integrative Fisheries Management, Philippstrasse 13, Haus 7, 10115 Berlin, arlinghaus@igb-berlin.de, https://orcid.org/0000-0003-2861-527X

[11]Institute of Environmental Research and Engineering, National University of San Martin-CONICET, Buenos Aires, Argentina, cbaigun@gmail.com, https://orcid.org/0000-0001-8412-8586

[12]University of Hull, International Fisheries Institute, Hull HU6 7RX, United Kingdom; i.g.cowx@hull.ac.uk, https://orcid.org/ 0000-0003-3538-924X

[13]Applied Aquatic Ecology, Arthur Rylah Institute for Environmental Research, Department of Energy, Environment and Climate Action, 123 Brown St., Heidelberg, Victoria, 3084 Australia, john.koehn@delwp.vic.gov.au, https://orcid.org/0000-0002-0913-1133

[14]Gulbali Institute for Agriculture, Water and Environment, Charles Sturt University, P.O. Box 789, Albury, NSW, 2640, Australia

[15]Institute for Evaluations and Social Analyses (INESAN), Sokolovská 351/25, 186 00 Prague, Czech Republic, lyachr@seznam.cz, https://orcid.org/0000-0001-7783-8256

[16]Department of Ichthyology and Fisheries Science, Rhodes University, Makhanda, 6140, South Africa, w.potts@ru.ac.za, https://orcid.org/0000-0002-6707-0383

[17]South African Institute for Aquatic Biodiversity, Makhanda, South Africa

[18]Department of Environmental Science and Policy, George Mason University, 4400 University Drive, Fairfax, VA, 22030, USA, arober28@gmu.edu

[19] Via Odoardo Beccari 40/13, 00154 Roma, Italia, schmidhuber.roma@gmail.com, https://orcid.org/0000-0002-6055-4596

**Contact author; [+]Deceased*

Abstract

Inland recreational fishing is often conceived as primarily a leisure-driven activity in freshwaters, yet it can contribute substantially to food systems. We estimate harvest from inland recreational fishing equates to 11.3% of all reported inland fisheries catch, globally. However, lack of consumption data means this aspect of inland recreational fisheries is typically not considered in policy-making and management - an oversight that could have consequences as climate change threatens the stability of food systems. We identify nutrition, economic value, and climate vulnerability of inland recreational consumption by country. Austria, Canada, Germany, and Slovakia are above the third quantile for all three metrics. These results may have profound implications for sensitive groups dependent on inland recreational fishing for food, particularly when not managed as food fisheries. Our findings can inform climate adaptation planning for inland recreational fisheries and highlight the underappreciated role they play for human nutrition in some countries.

Introduction

More than 90% of the Food and Agricultural Organization of the United Nations (FAO)'s reported 11.5 million tonnes of inland catch is consumed by humans[1,2]. Inland fisheries are, by a wide margin, food fisheries. Several recent analyses have highlighted that aquatic food-based strategies (also known as 'blue foods') can contribute to global food security and play an important and, in some countries, expanding role for human nutrition in the future[3,4]. However, climate change and other anthropogenic impacts (e.g., pollution, damming) are altering global fisheries, leading to reduced access to healthy aquatic foods[5–8]. Furthermore, these challenges are compounded for inland fisheries because harvest and consumption from inland waters are vastly underestimated[8,9].

An important knowledge gap in consumption of inland fish sourced from recreational fisheries, that is primarily leisure-driven fisheries but often with "fuzzy boundaries" compared to subsistence fisheries[10,11]. This is particularly an issue for low and middle income countries. We focus explicitly on inland recreational fisheries (i.e., in lakes, rivers, and other landlocked waters) because consumption data for them are globally sparse[12] and they hardly register in global aquatic foods accounting[4]. Because food is not considered an important motivation for inland recreational fisheries in many countries, management agencies tend to overlook consumption of fish when conducting surveys and collecting data to inform management decisions for them[10,11]. However, recent studies show that the consumption of recreationally caught inland fish contributes substantially to nutrition and food security for some demographics and countries[10,11]. In countries where recreational fishing emerged from the working class, eating fish continues to be a relevant motivation for fishing and, in some countries, catching fish for food is the only socially accepted reason to engage in fishing (e.g., Germany[13]). Embke et al.'s global dataset[14] on consumption of harvested inland recreational fish provides a critical data-driven baseline and an opportunity to quantify the nutritional and economic value and climate vulnerability of consumptive inland recreational fisheries.

Here, we estimate the dietary and related market economic importance of consumption from inland recreational fisheries to refute the common assumption that food from recreational fishing is of negligible consequence (see **Online Methods** for detailed approach). Using Embke et al.'s global dataset[14] of national inland recreational consumption estimates by species (**Figure 1**), we quantify the country-specific nutritional and economic (measured as total consumptive use value [TCUV]) contributions to inland recreational fishers and identify the vulnerability of this consumption to climate change (**Figure 2**). By integrating the nutritional and economic dimensions of food consumption, we discuss the implications of inland recreational fishing as a source of food in future climate scenarios (**Figure 3**). Our analysis demonstrates that inland recreational fisheries are important for food security and sensitive to climate change in some countries. It also highlights the need to integrate recreational fisheries into local, regional, and global food governance, and into resource management planning for inland fisheries. Rethinking how we value and manage inland recreational fisheries with strong food motives can help ensure food systems are sustainable across multiple sectors, and climate-resilient for those engaged in the inland recreational fisheries now and into the future.

Results

Total consumption

We estimate 280 million people are actively engaged in recreationally harvesting over 1.3 million tonnes of inland fish to consume annually (**Table 1**). Our 1.3 million tonnes estimate of inland recreational harvest for consumption each year, equates to 11.3% of FAO's current estimate for inland fisheries catch (11.5 million tonnes[2]). We estimated an inland recreational fisher consumption rate (kg/fisher) for each country (**Supplementary Figure 1A**). This approach can be enhanced with additional data for future comparison but, for this baseline assessment, the uncertainty tiers indicate our level of confidence in these data (see **Online Methods** for calculations including uncertainty classifications). Ten countries with middle and high income (Canada, Poland, Argentina, Finland, Sweden, Germany, China, Japan, Mexico, United States) accounted for >90% of overall consumable harvest, with Canada and Poland having the highest fisher consumption rates (**Table 1**, **Figure 1**). Species contributions to consumed harvest varied across countries, with Salmonidae spp., Percidae spp., and Cyprinidae spp. having the largest harvest and consumption (**Figure 1**).

Canada, Poland, and Argentina fisher consumption rates were much higher than FAO's national estimates of freshwater fish consumption (kg/capita/yr), which do not consider recreationally harvested fishes (**Figure 1**). Yet, fishing is likely unreported in many cases so the consumption data, although the best available, is probably underestimated. Our consumption estimates were also based on individual fishers so this may overestimate the individual contribution of catch that feeds other household dependents, family members, and friends, and therefore may underestimate the number of individuals consuming inland recreationally caught fish. Additionally, we acknowledge that these country-level summaries cannot showcase important in-country regional variation as demonstrated by the example of state-level variability in the United States (**Figure 1 inset**). We also recognize that the nutritional and economic value of recreational fisheries may be critically important locally and obscured by national-scale averaging.

Nutrition

We estimated the calcium, omega-3 long-chain polyunsaturated fatty acids docosahexaenoic acid and eicosapentaenoic acid (hereafter referred as DHA+EPA), iron, protein, vitamin B_{12}, and zinc supply from inland recreational fisheries summed across all consumed species within each country relative to the national-level supply of each nutrient from aquatic foods (**Figure 2**). Note that these nutritional estimates were highly dependent on the species composition for consumption in each country (i.e., nutritional content is driven by species consumed). We found that inland recreational fisheries represent 0-403% of the per-fisher nutrient supply compared to national-level nutrient consumption estimates, with a median of 0.9% and a mean of 4.7% across all assessed nutrients (see **full data table**).

We focused our integrative analysis on vitamin B_{12}, an essential micronutrient that is abundant in aquatic species and important for human health including bone density, red blood cell formation, and nerve function. However, we do note that there are other important nutritional benefits from eating fish (see **Supplementary Figure 2** for individual analysis of calcium, DHA+EPA, iron, protein, vitamin B_{12}, and zinc). For vitamin B_{12}, the highest contribution of recreationally caught fish to the nutrient supply of recreational fishers was in Austria (247%), followed by Belarus (97%), Argentina (94%), Belgium (35%), and Poland (22%). This means that, for example, recreational-sourced inland fish consumption per fisher in Austria provides 2.4 times or 247% of the estimated national-level average per capita consumption of vitamin B_{12} from aquatic foods. National-level nutrient consumption estimates were derived from the Global Nutrient Database, which estimated national availability of nutrients based on FAO's food balance sheets[15]. Nutritional value of species caught by inland recreational fishers was derived from mapping the Aquatic Foods Composition Database[4] to Embke et al.'s species-specific consumption estimates[14]. Nutrients from inland recreational fisheries are particularly important in communities that are not achieving recommended vitamin B_{12} intake, such Bangladesh and Canada (see **Supplementary Figure 3**). However, even for countries with small inadequate intake levels at a national scale, recreationally caught fish can be an important source of nutrients for subpopulations that rely on inland fisheries for food.

Economic value

As recreational consumption is not market-based, we estimated total consumptive use value (TCUV) of inland recreational fish using 'shadow prices' of the closest comparable offering in local market prices. Using this approach, we estimated TCUV of inland recreational fish destined for human consumption to be US$9.95 billion annually (see **full data table**). The highest TCUV derived from recreational inland fisheries was Canada (US$2.74 billion), China (US$2.57 billion), and the United States (US$2.38 billion). Seven additional countries (Germany, Finland, Japan, Argentina, Poland, Mexico, South Korea) recorded values exceeding US$100 million (see **Supplementary Table 1**, **Supplementary Figures 1** and **4**). The countries where the economic contribution of consumption from inland recreational fish was high also had high nutritional benefits (except for Argentina; **Figure 3A**). While ideally markup in the value chain could be considered in these calculations, the variation between species and countries was too high to derive a consistent estimation of markup to adjust prices and TCUV may be somewhat inflated as a result.

TCUV was not proportional to the number of fishers (**Figure 1**). China had the largest community of fishers (126 million fishers) but the United States (50.2 million fishers) and Canada (2.8 million) had higher annual TCUVs per fisher with fewer fishers (US $20.39 in China compared with US$47.4 in the United States and US$969.1 in Canada respectively). The highest TCUV per fisher, after Canada, was in Austria (US$201.7), Finland (US$132.9), Germany (US$132.2) and Argentina (US$110.3). To compare economic contribution across countries, we standardized TCUV per recreational fisher as a share of 2021 gross domestic product (GDP) per capita corrected for purchasing power parity (PPP; **Figure 2**). Canada remained out in front (1.861%), followed by Argentina (0.466%), Morocco (0.446%), Bosnia (0.408%), and Serbia (0.402%; **Table 1**). Note that these percentages reflect this income source which has *supplemental* value to local livelihoods. As the importance of our estimates may be masked at a national level, the significance of this food source may be more pronounced at local or regional scales or within certain socio-economic or ethnic groups. Additionally, as TCUV is an estimate of the economic value of the fish consumed at the household level by inland recreational fishers and not the total economic benefits associated with inland recreational fisheries, the total economic value of recreational inland fisheries is much larger than estimated here based on the market value of consumed fish alone[16–18].

Climate vulnerability

We estimated country-level climate vulnerability of consumed fish using species-specific vulnerability index scores developed by Nyboer et al.[19] using species traits (e.g., thermal tolerance ranges, dependence on seasonal cues) to estimate sensitivity and adaptive capacity as well as climate change projections across a species's range (e.g., projected changes in temperature and precipitation) to estimate exposure to the impacts of climate change. We summed index scores for each of the species consumed within a country weighted by the proportion that each species contributed to the country's total recreational consumption (**Figure 2**). Following Nyboer et al. [19], we compared four climate change exposure scenarios, but highlighted an end-of-century (average year 1975) mid-range representative concentration pathway (RCP4.5) as a plausible future scenario based on current emissions patterns (see **Supplementary Figure 5** for analysis of the other scenarios).

Vulnerability index scores for individual fish species ranged from <0.001 (low) to 0.50 (high) with a mean of 0.05 ± 0.07 SD (see **full data table**). Most species had very low vulnerability and few species had very high vulnerability. Country-level vulnerability scores based on summed species vulnerability weighted by proportion contribution were normally distributed and ranged from 0.26 (low) to 0.52 (high) with a mean of 0.43 ± 0.06 SD (see **full data table**). Countries with the highest scores for climate vulnerability of consumed recreational fish included Iceland, New Zealand, Denmark, Kenya, Norway, Ireland, Greenland, Uganda, Canada, and Switzerland (in that order). Note that country vulnerability reflects the species composition in each country (i.e., country vulnerability is driven by species consumed); even though warming may be expected to be greatest in higher latitudes, fish at low latitudes may have higher vulnerability (e.g., narrower thermal tolerance ranges, or reliance on predictable rainy and dry seasons).

Interactions

We examined interactions among nutritional contribution (Vitamin B_{12}), economic contribution (TCUV), and climate vulnerability at the country level through bivariate maps overlaying all combinations of variables (**Figure 3**) and by examining relationships among variables visually using correlation (**Figure 4**). Both economic and nutritional values were standardized considering the income and fish-source nutrients available to recreational fishers in each country; these normalizations had the greatest effects in countries with outlier aquatic food profiles (e.g., Spain falls in the lower left for nutritional and economic contribution because they consume high proportions of *marine*-sourced foods making their total contribution from freshwater recreationally harvested fish lower; see **Figure 4**). Countries were climate-vulnerable if nutritionally or economically important species consumed were also climate vulnerable (e.g., salmonids in Canada; **Figure 3B**, **3C**).

The nutritional (Vitamin B_{12}) benefits of recreational fisheries were highest in Eastern Europe, Canada, Argentina, and Bangladesh (**Table 1**). These locations also had high TCUV (apart from Bangladesh; **Figure 3A**), and some countries were deemed particularly climate-vulnerable (e.g., Slovakia, Germany, Sweden, Belgium, Austria, and Canada; **Figure 3B**). Although many of these countries may be perceived to be nutritionally secure, in-country variability in species consumed is common for diverse populations (see **Figure 1 inset**) and there are communities within each country who are nutritionally vulnerable who may be particularly reliant on recreational fish for food. For example, recreational inland fisheries may be critically important to low-income populations or people without land tenure (see Nyboer et al.[11] and case studies therein).

Discussion

Current global food systems are challenged to provide both healthy diets and support environmental sustainability[20]. The under-recognized and under-valued food source from inland recreational fisheries provides an affordable and sustainable contribution to human nutrition[21] and can have an increasingly prominent role in future foodscapes. However, limited data availability, data gaps, and uncertainty in extrapolating local and regional estimates to broader scales has hindered inclusion of inland recreational fisheries in global analyses (e.g., Golden et al.[4]). Because recreational fisheries vary among regions, cultural heritage, socio-economic status, fishing method, and target species[22], how they contribute to food systems is heterogeneous (e.g., Hutt and Neal[23], Embke et al.[24], Nyboer et al.[11]). Here, we highlighted Vitamin B_{12} to represent a nutrition portfolio from fish but other fish-derived nutrients can also fill important gaps in certain food systems[4] (**Supplementary Figure 2**). Highlighting the potential implications for food security and human nutrition in inland recreational fisheries management and policy discussions is an important step towards integrating them into food systems planning[10].

This study is the first to quantitatively value the nutritional and consumptive economic contributions of inland recreational fisheries on a global scale, which have long been recognized to be important to local and regional food systems[10,17,24–26]. It is also the first to link the potential global impact of climate change on the social and economic value of recreational fishing consumption. With approximately 280 million consumptive inland recreational fishers, harvesting over 1.3 million tonnes annually (**Table 1**), this study illustrates that recreational inland fish make a substantial contribution to inland yields globally (equivalent to 11.3% of the reported 11.5 million tonnes of inland catch[2]). Our analysis illustrates that inland recreational fisheries have an important, yet undervalued, role to play in current and future diets of recreational fishers and their dependents and therefore may warrant inclusion in inland fishery resource management policies. However, further exploration and expanded data are needed to better understand uncertainties in these estimates and examine more specific implications. For example, what role these fisheries play for vulnerable subpopulations (e.g., pregnant women and infants) has yet to be determined. Likewise, there may be some important health trade-offs to recognize in terms of toxins consumed in the diet through certain fish from certain locations and bioaccumulation of contaminants by fish.

Climate, land use, water use, basin fragmentation, and other large-scale forces are already shifting global food landscapes, including inland recreational fisheries. For example, climate change is affecting fish populations and fish assemblages, fishers' behaviors, and policies, and there are connections and feedbacks among all three pathways[27]. This synergy also exceeds local frameworks when it comes to transboundary basins. The global pattern we observed was the result of the complex interplay between region-specific species preferences, their interaction with projected climate change scenarios, and the country-specific reliance on recreational fisheries. The pattern we derived cannot be easily identified or interpreted in terms of geography alone, as reliance on recreational fisheries is highly variable even within a limited geographical range (e.g., Europe, **Figure 3B**, **3C**). While countries from North and South America, as well as Asia, were among the most reliant on recreational fisheries, this often was not coupled with a target species' high vulnerability to climate change. Conversely, Asian and African countries were most vulnerable despite their relatively limited recreational harvest, due to their region-specific species catch compositions. In other words, countries that recreationally harvest climate-vulnerable species are likely to be most at risk, regardless of their overall harvest of those species[11].

The projected impact of climate change on recreational fisheries hinges on the specific vulnerabilities of exploited fish species in different geographical areas. Fishers target fish species based on region-specific species preference patterns, cultural, economic, nutritional, and logistical considerations, among others. As climate change continues to impact food security[28], reliance on consumption of recreationally harvested fish for food could grow as commercial food systems (e.g., agricultural production) are disrupted. At the same time, climate change will also place additional pressure on water resources, which, in turn, can impact recreational fisheries[19]. This also poses the challenge of understanding the intricate relationship between recreational, subsistence, and small-scale commercial fishing in the face of climate change's effect on different species and freshwater bodies. Consequently, understanding which countries have highly important inland recreational fisheries and the people dependent on them, and which are most vulnerable to climate impacts can help inform adaptive planning. We found Germany, Austria, Slovakia, and Canada are among the countries that have the highest nutritional and economic contributions with the highest climate vulnerability (i.e., above the third quantile across all three dimensions; **Table 1**; **Figure 4**). Groups from these countries that are dependent on recreationally harvested inland fish to supplement their nutrient intake may be vulnerable to nutritional and economic challenges if recreational fisheries value as food is not incorporated into future planning. How species substitutions for shifting species ranges and recreational fishing preferences will impact vulnerability and adaptation has yet to be explored.

Our study highlights the often-ignored value of inland recreational fish as food and therefore could be useful to reformulate the perspective on the purpose and drive behind recreational fishing. As most recreational fisheries are not predominantly managed as food fisheries, our results highlight potential management misalignments. For example, rather than managing systems to just conserve fish or produce high catch rates, there may also be opportunities to manage fisheries in ways that maximize potential nutritional benefits (e.g., by combating pollution and allowing high harvests that increase yields[29]). We do not suggest that recreational fisheries should be necessarily managed like subsistence fisheries, but rather that recreational management may benefit from broader perspectives. Unlike the classical view that evaluates the impact of recreational fishing based on the catch of the main target species, the perspective of the nutritional value could also evaluate the incidence on species not frequently included in catch statistics which may have high value to consumptive users. Also, arguments for climate response may be more powerful in policy negotiations if diminishing fish populations are presented as a threat to food systems as well as conservation. We suggest that recreational fishing oriented to consumption values may promote a more balanced harvesting of resources by including a wider range of species and sizes and, at the same time, motivate measures to address climate concerns. As global food systems change, accounting for the contributions of inland recreational fisheries may help avoid unanticipated repercussions to food availability with the most vulnerable human communities at highest risk for destabilization. Elevating the importance of inland recreational fisheries for consumption from local management up to global food policy can help ensure future food systems are sustainable and climate resilient.

References

1. Welcomme, R. L. *et al.* Inland capture fisheries. *Philos. Trans. R. Soc. B-Biol. Sci.* **365**, 2881–96 (2010).
2. FAO. *State of the World Fisheries and Aquaculture - 2022 (SOFIA)*. 236 (2022).
3. Hicks, C. C. *et al.* Harnessing global fisheries to tackle micronutrient deficiencies. *Nature* **574**, 95–98 (2019).
4. Golden, C. D. *et al.* Aquatic foods to nourish nations. *Nature* **598**, 315–320 (2021).
5. Golden, C. D. *et al.* Fall in fish catch threatens human health. *Nat. News* **534**, 317–320 (2016).
6. Nyboer, E. A., Liang, C. & Chapman, L. J. Assessing the vulnerability of Africa's freshwater fishes to climate change: A continent-wide trait-based analysis. *Biol. Conserv.* **236**, 505–520 (2019).
7. Tigchelaar, M. *et al.* Compound climate risks threaten aquatic food system benefits. *Nat. Food* **2**, (2021).
8. Fluet-Chouinard, E., Funge-Smith, S. & Mcintyre, P. B. Global hidden harvest of freshwater fish revealed by household surveys. *Proc. Natl. Acad. Sci.* (2018) doi:10.1073/pnas.1721097115.
9. Ainsworth, R. F., Cowx, I. G. & Funge-Smith, S. J. Putting the fish into inland fisheries – A global allocation of historic inland fish catch. *Fish Fish.* **24**, 263–278 (2023).
10. Cooke, S. J. *et al.* The nexus of fun and nutrition: Recreational fishing is also about food. *Fish Fish.* **19**, 201–224 (2018).
11. Nyboer, E. A. *et al.* Overturning stereotypes: The fuzzy boundary between recreational and subsistence inland fishereis. *Fish Fish.* **23**, 1282–1298 (2022).

12. Thorpe, A., Zepeda, C. & Funge-Smith, S. The economic value of inland fisheries. in *Review of the state of the world fishery resources: inland fisheries* 214–253 (Food and Agriculture Organization of the United Nations (FAO), 2018).
13. Arlinghaus, R. Voluntary catch-and-release can generate conflict within the recreational angling community: A qualitative case study of specialised carp, Cyprinus carpio, angling in Germany. *Fish. Manag. Ecol.* **14**, 161–171 (2007).
14. Embke, H. S. *et al.* Global dataset of species-specific inland recreational fisheries harvest for consumption. *Sci. Data* **9**, 488 (2022).
15. Schmidhuber, J. *et al.* The Global Nutrient Database: availability of macronutrients and micronutrients in 195 countries from 1980 to 2013. *Lancet Planet. Health* **2**, e353–e368 (2018).
16. Weithman, S. Socioeconomic benefits of fisheries. in *Inland Fisheries Management in North America* (eds. Kohler, C. C. & Hubert, W. A.) 193–213 (American Fisheries Society Press, 1999).
17. Arlinghaus, R., Mehner, T. & Cowx, I. G. Reconciling traditional inland fisheries management and sustainability in industrialized countries, with emphasis on Europe. *Fish Fish.* **3**, 261–316 (2002).
18. Parkkila, K. *et al. European Inland Fisheries Advisory Commission Methodologies for Assessing Socio-Economic Benefits Methodologies Socio-Economic of European for Inland Recreational Fisheries Benefits of European Inland Recreational Fisheries Methodologies for Assessing Soc*. *EIFAC Occasional Paper 46* vol. 46 (2004).
19. Nyboer, E. A. *et al.* Global assessment of marine and freshwater recreational fish reveals mismatch in climate change vulnerability and conservation effort. *Glob. Change Biol.* **27**, 4799–4824 (2021).
20. Willett, W. *et al.* Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet* **393**, 447–492 (2019).
21. Simmance, F. A. *et al.* Nudging fisheries and aquaculture research towards food systems. *Fish Fish.* **23**, 34–53 (2022).

22. Aas, Ø. & Ditton, R. B. Human dimensions perspective on recreational fisheries management: implications for Europe. 153–164 (1998).

23. Hutt, C. P. & Neal, J. W. Arkansas urban resident fishing site preferences, catch related attitudes, and satisfaction. *Hum. Dimens. Wildl.* **15**, 90–105 (2010).

24. Embke, H. S., Beard, T. D., Lynch, A. J. & Vander Zanden, M. J. Fishing for food: quantifying recreational fisheries harvest in Wisconsin lakes. *Fisheries* **45**, 647–655 (2020).

25. Arlinghaus, R. *et al.* Governing the recreational dimension of global fisheries. *Proc. Natl. Acad. Sci. U. S. A.* **116**, 5209–5213 (2019).

26. Joosse, S., Hensle, L., Boonstra, W. J., Ponzelar, C. & Olsson, J. Fishing in the city for food—a paradigmatic case of sustainability in urban blue space. *Urban Sustain.* **1**, 1–8 (2021).

27. Hunt, L. M. *et al.* Identifying alternate pathways for climate change to impact inland recreational fishers. *Fisheries* **41**, 362–372 (2016).

28. Gregory, P. J., Ingram, J. S. I. & Brklacich, M. Climate change and food security. *Philos. Trans. R. Soc. B Biol. Sci.* **360**, 2139–2148 (2005).

29. Ahrens, R. N. M., Allen, M. S., Walters, C. & Arlinghaus, R. Saving large fish through harvest slots outperforms the classical minimum-length limit when the aim is to achieve multiple harvest and catch-related fisheries objectives. *Fish Fish.* **21**, 483–510 (2020).

30. Arlinghaus, R., Tillner, R. & Bork, M. Explaining participation rates in recreational fishing across industrialised countries. *Fish. Manag. Ecol.* **22**, 45–55 (2015).

31. Arlinghaus, R. *et al.* Global Participation in and Public Attitudes Toward Recreational Fishing: International Perspectives and Developments. *Rev. Fish. Sci. Aquac.* **29**, 58–95 (2021).

32. Bower, S. D. *et al.* Knowledge Gaps and Management Priorities for Recreational Fisheries in the Developing World. *Rev. Fish. Sci. Aquac.* **28**, 518–535 (2020).

33. Grove, E. W. & Koffsky, N. M. Measuring the Incomes of Farm People. *Am. J. Agric. Econ.* **31**, 1102–1111 (1949).

34. Arslan, A. & Taylor, J. E. Farmers' Subjective Valuation of Subsistence Crops: The Case of Traditional Maize in Mexico. *Am. J. Agric. Econ.* **91**, 956–972 (2009).

35. Kerrison, G. *Impact Summary: Importation of Trout Meat for Sale*. 17 https://www.doc.govt.nz/globalassets/documents/about-doc/role/legislation/importation-trout-meat-products-ris.pdf (2018).

36. FAO. *Conversion Factors: Landed weight to live weight. FAO Fisheries Circular No. 847, Rev. 1*. 176 (2000).

37. Funge-Smith, S. *Review of the state of the world fishery resources: inland fisheries*. vol. FIAF / C94 376 (2018).

38. Funge-Smith, S., Bennett, A., Funge-Smith, S. & Bennett, A. A fresh look at inland fisheries and their role in food security and livelihoods. *Fish Fish.* **20**, 1176–1195 (2019).

Online methods

Inland recreational consumption

The data used in this study arose from a comprehensive literature search and expert knowledge review where we quantified multiple aspects of recreational fisheries for 81 countries, including ~192 species[14]. Though the boundaries between recreational and subsistence fisheries can be "fuzzy"[11], and the misclassification of small-scale fishers as recreational fishers or vice versa may have resulting in over- or underestimation of consumption, this data collection exercise specifically targeted inland recreational fisheries harvest for consumption and we used national experts to reduce this potential bias.

For each country, we collated information on recreational fisher participation rate (%) and estimated species-specific inland recreational harvest (kg), species composition of harvest (%), species-specific per capita consumption rate (kg/person), and species-specific per fisher consumption rate (kg/fisher). Following a hierarchical methodological approach, we began by selecting countries for inclusion in the dataset by consulting three recent studies to confirm participation in inland recreational fisheries[30–32] as well as the Organization for Economic Cooperation and Development high income countries list to identify countries with relevant recreational fishing not included in the studies. Finally, we consulted a panel of global recreational experts to review our final country list to confirm that we included all nations where inland recreational harvest could be estimated. From our overall dataset (countries n = 81), we limited our analysis for this work to those countries where harvest occurred, and we were able to collate relevant economic information (n = 58).

To collect data on fisher participation rate, species-specific harvest, and species-specific consumption rate from inland recreational fisheries, we used literature searches (primary and grey literature), online governmental and Food and Agriculture Organization of the United Nations (FAO) databases, and by consulting individuals with expert knowledge in their respective country. Depending on harvest data availability, we used a hierarchical approach to estimate total inland recreational harvest (kg) for each country. For most countries (n = 45), some form of inland recreational harvest information was available. If species-specific harvest estimates (kg) were available (n = 16), we summed these data to estimate total inland recreational harvest. In some cases (n = 7), species-specific harvest (abundance) was known. We used corresponding literature-based mean total length (cm) and length-weight relationships to convert the number of fish harvested to biomass of fish harvested. In some cases (n = 22), fisher harvest estimates were available for limited portions of a given country, which we used to 'scale-up' to the entire country. When no recreational harvest information was available for a country, but species harvest contributions were available (n = 15), we used a 'nearest neighbor' approach, wherein we applied the harvest rate (kg/fisher or kg/ha) from the country geographically nearest to the country of interest. If no information was available, we relied on expert knowledge to estimate a fisher harvest rate (n = 6).

We identified the predominant species harvested from literature sources and/or expert knowledge as quantified as the percent contribution of each species to the overall harvest estimate. When species-specific contributions were unknown, we assumed an equal contribution of each species to overall harvest (n = 4). Using total recreational harvest (kg) and species composition (%), we calculated species-specific harvested biomass for each country. We used species-specific estimates of literature-based filet yield (i.e., edible portion (%) of a given fish) to calculate the consumable portion of harvest (kg). We divided the consumable harvest (kg) by the number of fishers of the country to estimate per fisher consumption. For extensive dataset information including species-specific source citations, please see Embke et al.[14].

It is important to note that participation rate, species-specific harvest, and species-specific consumption rate forms the foundation of all of the subsequent calculations in this analysis. For example, while there are many similarities between the United States (US) and Canada, a fundamental difference lies in the recreational fishing populations, where Canada's participation rate is 7.5% (2.8 million anglers) and the US's is 15.1% (50 million anglers), therefore all corresponding harvest and consumption estimates have been scaled to these numbers.

For a given country, we recognize total recreational harvest (kg) and consumption (kg/fisher) does not account for within-country variability, where some areas in a country may experience much higher harvest and/or consumption than other areas. However, finer-scale analyses of inland recreational harvest and consumption beyond aggregated country estimates are challenging given limited data availability despite the nuance this variability may contribute to understanding inland recreational harvest and consumption patterns. Therefore, we sought to understand how within-country differences in inland recreational harvest and consumption varied relative to aggregated estimates using available data for one country, the US. For the US, comprehensive species-specific angler harvest, effort, and participation data are available for many states including Florida, Utah, and Wisconsin[24]. For each state, we took slightly different approaches to estimate species-specific harvest (kg) and consumption (kg/fisher). For Florida and Wisconsin, we used the most recent ten years of data for the top harvested species (>90% all harvest) and calculated mean areal harvest (n/ha). We then scaled-up mean areal harvest (n/ha) by total inland water surface area to estimate species-specific harvest (n). For Utah, species-specific total harvest (n) was available, therefore additional extrapolations were not necessary.

For all states, mean length (cm) of harvested species was available; therefore, once we estimated species-specific harvest (kg), we used literature-based species-specific length-weight relationships[14] to estimate species-specific total harvest (kg).

Additionally in the US, individual states require the purchase of a fishing license to participate in fishing, therefore the approximate number of fishing licenses (i.e., number of fishers) is known for each state each year. Thus, we calculated state-specific fisher participation as the number of fishing licenses sold divided by the total population in a year. We calculated species-specific consumption (kg/fisher) for each state using species-specific harvest (kg) divided by the total number of fishers.

Nutrition

To estimate the contribution of recreational fisheries for nutrient supply, we first multiplied the production of each species and sector by the estimated edible portion, according to the Aquatic Food Composition Database (AFCD[4]). This step is important since several parts of aquatic food can be discarded and not consumed (e.g., bones, head, tail). Next, we assigned the nutritional content of each species using AFCD. We focused our analysis on raw muscle tissue only due to data limitations. Focusing on raw muscle tissue is recommended for global analysis to be consistent across countries. However, when looking at the importance of recreational fisheries on a local scale, it would be important to consider food preparation. We focused our analysis on calcium, omega-3 long-chain polyunsaturated fatty acids docosahexaenoic acid and eicosapentaenoic acid (hereafter referred to as DHA+EPA), iron, protein, vitamin B_{12}, and zinc. We focused our main analyses on Vitamin B_{12} (see **Figure 2**), an essential micronutrient that is abundant in aquatic species and important for human health[4]. To assign a nutritional value for all nutrients and species, we used a hierarchical rule-based approach, giving sequential priority to: 1) average of scientific name, 2) average of species' genus, 3) average of species' family, 4) average of species' order, 5) average of species' class, 6) average of FAO fish commodities categories. Through this approach, we were able to assign nutritional values for all species in the database (see **full data table**). We then summed the nutrient supply across all species and divided by the total estimated number of fishers in each country to calculate the nutrient supply per fisher:

$$NS_{k,j} = \frac{\sum_{i=1}^{i} B_{k,i} * E_i * C_{i,j}}{N_k}$$

Where: $NS_{k,j}$ is the per fisher nutrient supply of nutrient *j* in country *k*, *B* is the harvested biomass of species *i* in country *k*, *E* is the edible proportion of species *i*, *C* is the nutrient composition of species *i* and nutrient j, and N is the total number of fishers in country *k*.

Next, we calculated relative contribution of recreational fisheries to nutrient supply by dividing the total estimated per fisher nutrient supply by the national-level population-averaged per capita nutrient supply from all aquatic food sources from the Global Nutrient Database (GND[15]). The GND estimates the national availability of macronutrients and micronutrients for nearly every country on earth. It matches over 400 food and agricultural commodities from the FAO's Supply and Utilization Accounts to food items in the United States Department of Agriculture (USDA) Food Composition Database and obtained data on nutrient composition of the Supply and Utilization Accounts food items[15]. We then multiplied by 100 to obtain the percent contribution of recreational fisheries to aquatic foods nutrient supply:

$$R_{k,j} = 100 * \frac{NS_{k,j}}{AF_{k,j}}$$

Where: $R_{k,j}$ is the relative per fisher nutrient supply of nutrient j in country k, $AF_{k,j}$ is per capita nutrient supply from all aquatic foods for nutrient j in country k (from GND[15]). Because we used a global database (GND) that has already been developed and published, we cannot test how this affects our global outcomes. This database estimates the nutrient supply of all foods (not just aquatic foods) and it used the USDA Food Composition Database to have consistent values across all foods.

Total Consumptive Use Value (TCUV)

We computed TCUV in line with the methodology applied by Thorpe, Zepeda, and Funge-Smith[12] across the countries and species in Embke et al.[14]. As self- (or home) consumption is not marketed, we assigned 'shadow prices' to this catch by making recourse to the local market prices for that species, a technique commonly used by agricultural economists when valuing peasant self-consumption of basic grains[33,34]. This required price data relating to 559 species distributed across 64 countries. While we were able to locate price data for 511 species spanning 58 countries, we were unable to gather information for six countries (Albania, Kosovo, Luxembourg, Moldova, Panama, and Slovenia) and the 47 species caught and consumed therein (accounting for 0.02% of the total recorded recreational harvest).

We sought price data from for the 511 species in 58 countries from: (i) co-authors to this paper [e.g., Canada and Germany], (ii) long-standing collaborators of the authors [e.g., Lithuania and Uzbekistan], (iii) through contacting academics publishing on fisheries topics [e.g., Macedonia and Serbia], and by online price searches [e.g., Spain and Ireland]. A full list of these contributors is provided in the acknowledgements.

We obtained prices for 368 of the 511 (72%) species for which we sought price data. In the other 143 cases, the species in question was not available in the marketplace – 'missing' markets - at the time of the survey. Reasons cited by our contributors for this included, for example, that the species was only available in certain seasons [e.g., vendace *Coregonus vandesius* in Estonia], that catches were low and/or highly localized [e.g., European grayling *Thymallus thymallus* in Switzerland], that demand was absent [e.g., brown trout *Salmo trutta* in Spain] or for other factors, so the price of the nearest available substitute species was used instead. In New Zealand, for example, wild trout can be recreationally fished and consumed. However, the sale of wild and farmed (national or and imported) trout is effectively illegal in the country due to legislation oriented to preserving the wild trout fishery[35]. Hence, prices of Chinook Salmon (Quinnat Salmon *Oncorhynchus tshawytscha*) were used instead. Whenever possible, substitute species were identified, and the prices were supplied by data contributors (51 instances). When this option was unavailable, the author team themselves identified alternate substitute species based on expert knowledge (67 instances). In 25 cases, we were unable to identify any locally available substitute species (e.g., European eel *Anguilla anguilla* in both the Netherlands and Switzerland), and so these species were excluded from our analysis (these 25 species accounted for 0.5% of the total recorded recreational harvest). Ultimately, we identified market prices (either directly, with substitute species or with alternates) for a total of 487 species.

Price data were collected over the period November 2021 to end February 2022 (excluding the two-week Christmas period, as the price of some species [e.g., common carp *Cyprinus carpio* in Poland] rises sharply at this time). Where possible, we collected market price data for whole unprocessed fish (320 cases, 66%). This was not always possible and in 148 cases (30%) and 18 cases (4%) our price data related to gutted whole fish and processed fillets, respectively. To account for biomass loss associated with processing, we converted gutted whole and fillet fish products into whole unprocessed fish equivalents using conversion factors taken from FAO Fisheries Circular No.847[36] (*'Conversion factors landed weight to live weight'*) where possible. Where conversion factors were not available from FAO[36], the species-specific estimates of edible portion (%) were taken from Embke et al.[14].

While, ideally, we would also have collected prices at the point of first sale for all cases (indeed, we did for 98 cases – 20% of total), this proved impractical in most cases due to the 'thinness' of inland fish markets[1,37,38]. Instead, we used either fish/wet market (201 cases, 41%), supermarket (171 cases, 35%), or other commercial (16 cases, 3% - e.g., fish auction) prices in our estimations. The high variation in markup between species and countries inhibited our ability to derive a consistent estimation of markup to adjust the prices. While this induces an upward bias in the TCUV estimates, it does have the merit of [partially] capturing the non-use values associated with recreational fishing for domestic consumption. Given that prices vary by market outlet (spatially), we asked our data contributors to provide a range of prices for each species across several outlets (339 cases, 70%). In the absence of data indicating the volumes sold in each of these markets, we computed a simple average to generate a national market price for whole unprocessed fish by species.

To compute TCUVs for each country, we multiplied these national market prices (P) by the annual estimated volume (V) of each species caught and consumed by recreational fishermen in that country (see **Figure 2**). In 14 countries, these prices were expressed in US$. In the case of the other 44 countries, we either converted to US$ equivalent prices by using currency conversion rates drawn from Bloomberg (36 countries), or the country's Central Bank website (8 cases). Prices were converted to US$ equivalents based on the exchange rate prevailing on the date when our informants collected and forwarded the local price data. The TCUV figure referred to in the paper is the sum of TCUV for the 58 countries in our sample. Higher income countries still generally dominate the rankings due to the Penn effect. The Penn effect suggests fish (price) levels are generally higher in high-income countries than they are in low-income countries. The failure to account these relative price differences when converting prices into a common currency (i.e., the US dollar) using the prevailing exchange-rate undervalues the TCUV of recreational fish in low-income countries with relation to high income countries, and so we corrected for this by deflating TCUV data using 2021 GDP per capita data in purchasing power parity (PPP) terms taken from the World Bank.

Climate vulnerability

A climate change vulnerability value was assigned to most species in our dataset based on a vulnerability index calculated in Nyboer et al.[19]. This index provides a numerical indicator of the climate change vulnerability of recreationally targeted fish based on three contributing components that make a species vulnerable to climate change, including sensitivity and adaptive capacity, both of which are based on species' traits (e.g., having high habitat specificity and low population sizes, respectively) and exposure (based on climate projections across a species' range; i.e., physical changes they are projected to face in their environment as climate change progresses). Climate change projections used in exposure estimates are based on two emission scenarios (representative concentration pathway [RCP] 4.5 and RCP8.5) for mid-century (average 2030) and late century (average 2075). See Nyboer et al.[19] for further details on how sensitivity, adaptive capacity, and exposure were determined, and how the multiple criteria decision analysis (MCDA) indices for vulnerability were developed. A comparison of outcomes under the four different scenarios is presented in supplemental (see **Supplemental Figure 5**).

Species' vulnerability index values were matched to species in the current dataset using a phylogenetic approach (**Supplementary Table 1**). When there was an exact species match, we assigned the appropriate vulnerability index value. When there was not an exact match, we assigned an index value based on the nearest relative or on a genus approach. We used the phylotree package in R (version 1.3.1093) to create a rooted phylogenetic tree (including branch lengths). If a species without an exact match had a close relative (i.e., sister taxa) with a vulnerability score, that score was substituted. If there were no sister taxa, but there were several species in the same clade denoted by the same genus, we used the average index values of species in that genus. When there was no match, rows were left blank. Maps reflect both the average of the MCDA index scores in each country.

Data availability statement

The raw and formatted datasets and accompanying metadata for the species-specific inland recreational fisheries harvest estimates for consumption as well as the **full data table** of nutrition, economic value, and climate vulnerability data are freely available to the public supported by the U.S. Geological Survey (USGS) National Climate Adaptation Science Center (https://doi.org/10.5066/P9904C3R and https://doi.org/10.5066/P9WO91SZ, respectively). The Aquatic foods Composition Database is freely available (https://do.org/10.7910/DVN/KI0NYM) and the Global Nutrient Database is available upon request. The data to support the currency conversions used in this study are available from Bloomberg. Restrictions apply to the availability of these data, which were used under license for this study. Data are available with the permission of Bloomberg (https://bba.bloomberg.net/). Climate change data from Nyboer et al.[19] are available through the Open Science Framework (https://osf.io/keajr/).

Acknowledgements

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Table 1: Nutritional contribution, economic contribution, and climate vulnerability of recreationally consumed inland fish by country. **Nutritional contribution** = species-specific vitamin B_{12} supply (ug/100g) from recreationally harvested fish per inland recreational fisher as a proportion of all aquatic foods weighted by proportion consumed and summed. **Economic contribution** = total consumptive use value (TCUV in USD) per recreational fisher as a share of 2021 gross domestic product (GDP) per capita corrected for purchasing power parity (PPP). **Climate vulnerability** = sum of species-specific climate vulnerabilities (derived from Nyboer et al. 2021) weighted by proportions of species consumption (using scenario Representative Concentration Pathway [RCP]4.5, 2075 projection). Inland recreational **fishers** (n), total inland recreational **harvest** (kg), and **consumption / fisher** (kg) are also displayed. Country name is shaded by uncertainty classification (from Embke et al. 2022), from light gray (=1, less uncertainty) to dark gray (=4, more uncertainty). Nutritional contribution, economic contribution, and climate vulnerability are color-coded (pink, blue, and yellow, respectively) with shading for outliers (above two standard deviations from the mean = dark color) and above the third quantile (= light color).

Country	Fishers	Harvest (kg)	Consumption / fisher (kg)	Nutritional contribution (%)	Economic contribution (%)	Climate vulnerability
Argentina	1751750	29000000	7.754	94.73	0.466	0.361
Australia	4284000	6721656	0.635	4.831	0.041	0.413
Austria	448800	6300000	6.892	247.86	0.345	0.481
Bangladesh	976200	2440500	1.24	6.678	0.121	0.393
Belarus	953000	8400000	3.884	97.279	0.015	0.368
Belgium	386100	772200	0.982	35.314	0.031	0.481
Bosnia	17100	320000	7.424	12.331	0.408	0.427
Brazil	1879200	7920000	1.613	1.191	0.054	0.316
Bulgaria	70000	1470000	8.547	10.124	0.339	0.444
Canada	2827500	133436083	21.12	8.332	1.861	0.491
Chile	327600	57633	0.09	0.052	0.008	0.465
China	126000000	835900000	2.572	0.237	0.105	0.449
Colombia	433800	3356738	3.069	2.406	0.167	0.285
Croatia	42000	575500	5.322	9.004	0.23	0.417
Czech Republic	342400	431420	0.832	0.673	0.024	0.461
Denmark	501500	173000	0.227	0.288	0.004	0.519
Estonia	48360	119659	1.258	3.239	0.024	0.418
Finland	1674400	18122000	5.177	10.317	0.242	0.45

France	5559600	45000	0.004	0.004	0.0002	0.473
Germany	5796000	40000000	3.389	5.776	0.228	0.481
Greece	132360	264720	0.94	1.723	0.116	0.267
Hungary	552221	5724935	4.027	3.717	0.174	0.406
Iceland	69796	188866	1.396	0.275	0.052	0.52
India	13000	65000	2.562	2.319	0.276	0.387
Ireland	402900	30000	0.038	0.068	0.001	0.5
Italy	1060800	10608	0.004	0.006	0.0002	0.486
Japan	4141500	17337000	2.415	0.435	0.111	0.435
Kenya	4840	9680	0.95	0.893	0.204	0.513
Latvia	100341	788188	3.748	8.699	0.123	0.385
Lithuania	758700	1425000	1.033	2.91	0.019	0.281
Mexico	4243800	21219000	2.042	0.751	0.151	0.341
Montenegro	1830	9150	2.801	1.86	0.115	0.407
Morocco	33830	300000	4.053	2.211	0.446	0.433
Myanmar	67920	135850	0.984	0.242	0.144	0.371
Netherlands	1118000	881693	0.542	0.757	0.002	0.439
New Zealand	869364	2533156	1.477	0.402	0.092	0.52
Nigeria	203500	387097	0.818	0.663	0.196	0.356
Norway	1738800	843000	0.235	0.091	0.008	0.501
Poland	1996800	46026240	10.296	22.647	0.175	0.419
Portugal	123600	309200	1.037	1.055	0.04	0.438
Romania	106500	852000	3.682	4.12	0.097	0.455
Russia	39813300	4300000	0.052	0.03	0.001	0.422
Serbia	78430	1664000	8.197	7.422	0.402	0.261
Slovakia	119680	1800000	5.551	4.358	0.29	0.466
South Africa	734500	987000	0.493	0.419	0.059	0.456

South Korea	5140000	10280000	0.752	0.043	0.051	0.459
Spain	4550000	38000	0.004	0.004	0.00002	0.467
Sweden	1387200	10490000	3.764	5.905	0.081	0.466
Switzerland	277200	253704	0.426	0.229	0.03	0.488
Turkey	574000	1331186	1.147	3.463	0.01	0.412
Uganda	4090	3420	0.384	0.161	0.158	0.494
Ukraine	4752000	8518608	0.79	1.181	0.021	0.367
United States	50222600	89968900	0.709	0.19	0.068	0.367
Uzbekistan	213885	112245	0.228	1.183	0.014	0.412
Zambia	232180	255130	0.549	0.36	0.055	0.36
Zimbabwe	209216	600729	1.316	2.476	0.261	0.387
Total	280367993	1325504694				

Figure 1: **Recreational fisher consumption rate** (kg/fisher) for the top 10 countries contributing to inland recreational fisheries harvest globally. Consumption rate is divided up into fish families. For each country, black dots correspond to the Food and Agricultural Organization of the United Nations' **annual estimates of freshwater fish consumption** (kg/capita). The **number of recreational fishers** (n) for each country is also presented. The inset figure for the United States shows select **state-specific consumption rate** (kg/fisher), highlighting within-country variability in consumption estimates.

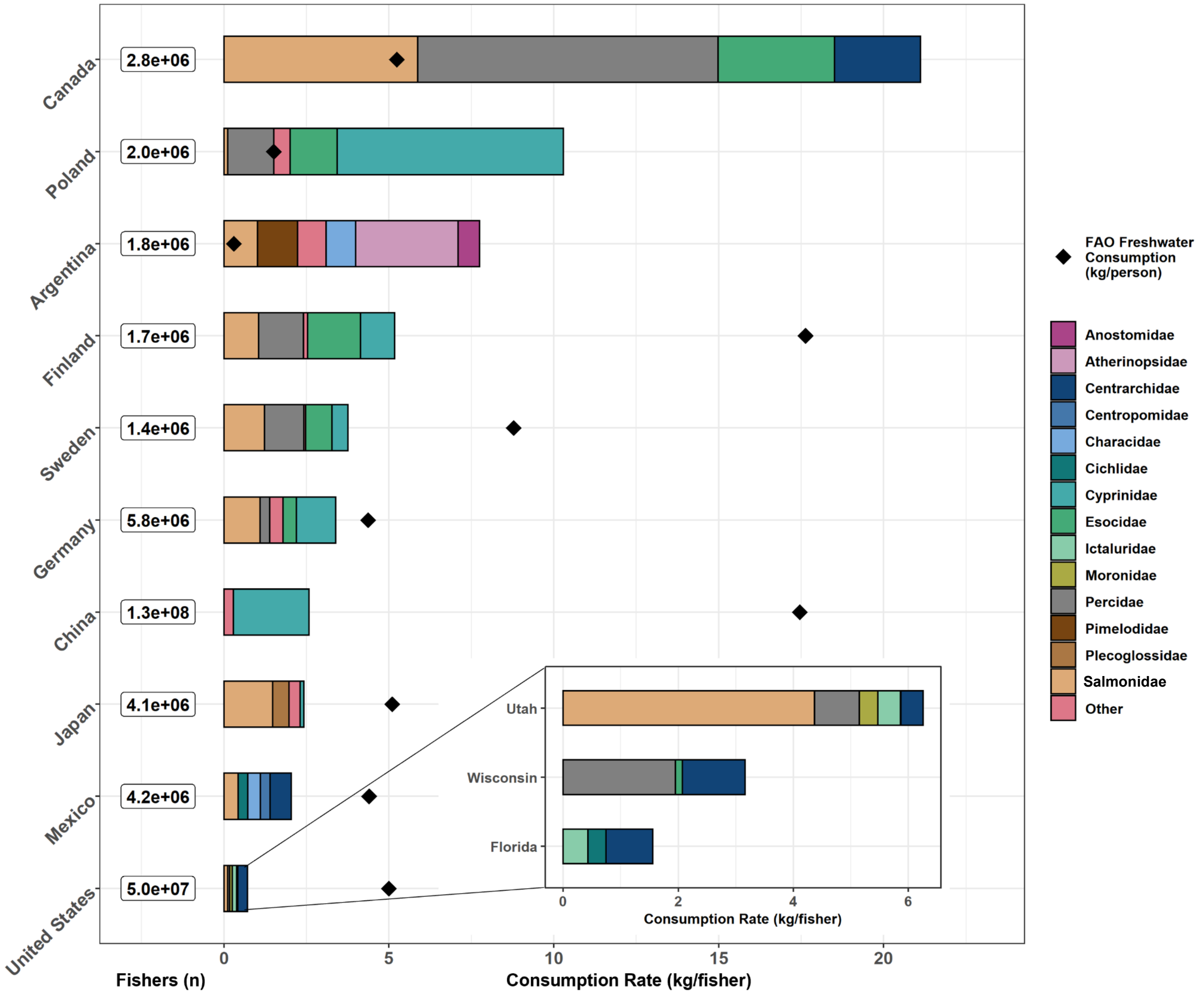
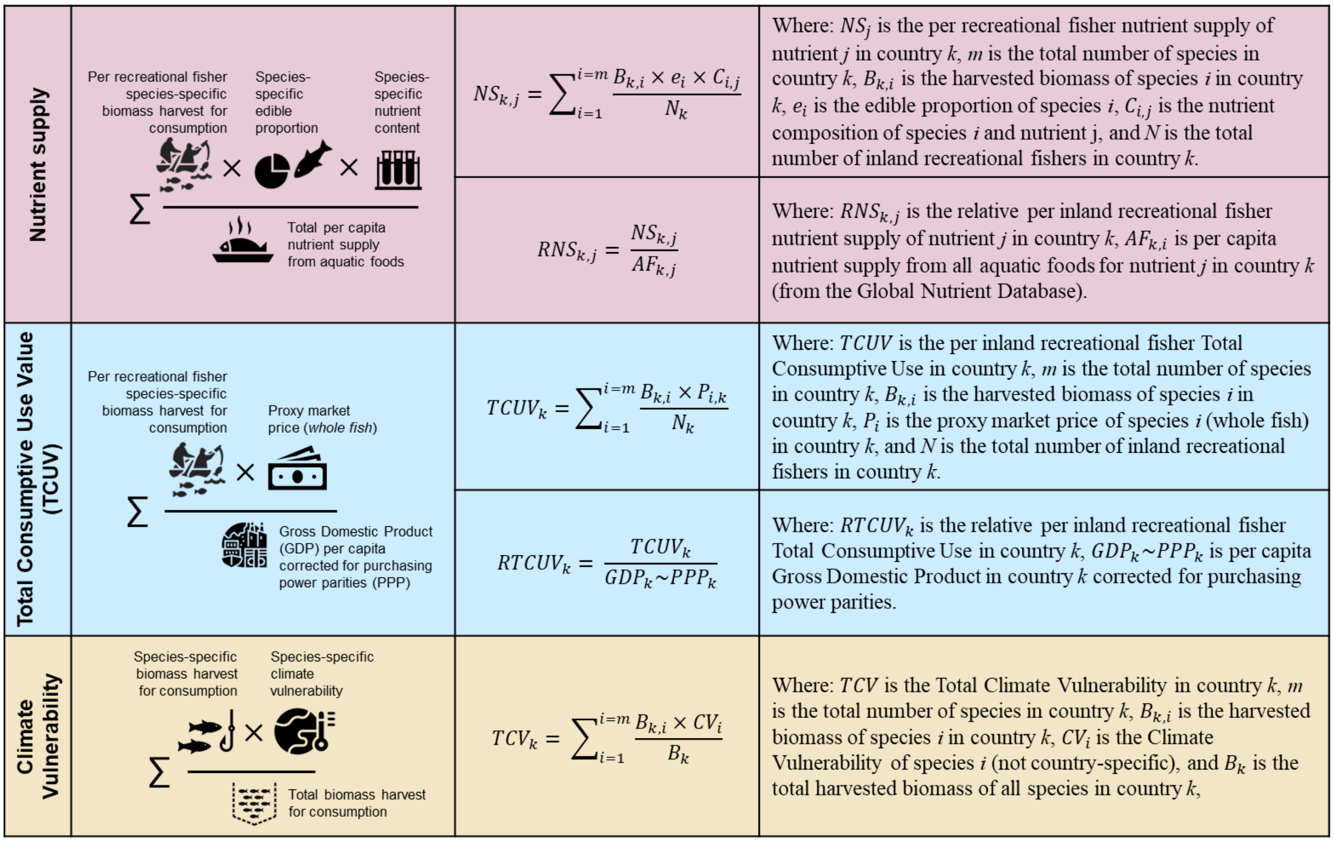


Figure 2: Computational methods for calculating **nutrient supply**, **total consumptive use value** (TCUV), and **climate vulnerability** for consumed inland recreational fish.



Nutrient supply	Per recreational fisher species-specific biomass harvest for consumption × Species-specific edible proportion × Species-specific nutrient content $\sum$ ――― Total per capita nutrient supply from aquatic foods	$NS_{k,j} = \sum_{i=1}^{i=m} \frac{B_{k,i} \times e_i \times C_{i,j}}{N_k}$	Where: NS_j is the per recreational fisher nutrient supply of nutrient j in country k, m is the total number of species in country k, $B_{k,i}$ is the harvested biomass of species i in country k, e_i is the edible proportion of species i, $C_{i,j}$ is the nutrient composition of species i and nutrient j, and N is the total number of inland recreational fishers in country k.
		$RNS_{k,j} = \frac{NS_{k,j}}{AF_{k,j}}$	Where: $RNS_{k,j}$ is the relative per inland recreational fisher nutrient supply of nutrient j in country k, $AF_{k,i}$ is per capita nutrient supply from all aquatic foods for nutrient j in country k (from the Global Nutrient Database).
Total Consumptive Use Value (TCUV)	Per recreational fisher species-specific biomass harvest for consumption × Proxy market price (*whole fish*) $\sum$ ――― Gross Domestic Product (GDP) per capita corrected for purchasing power parities (PPP)	$TCUV_k = \sum_{i=1}^{i=m} \frac{B_{k,i} \times P_{i,k}}{N_k}$	Where: $TCUV$ is the per inland recreational fisher Total Consumptive Use in country k, m is the total number of species in country k, $B_{k,i}$ is the harvested biomass of species i in country k, P_i is the proxy market price of species i (whole fish) in country k, and N is the total number of inland recreational fishers in country k.
		$RTCUV_k = \frac{TCUV_k}{GDP_k{\sim}PPP_k}$	Where: $RTCUV_k$ is the relative per inland recreational fisher Total Consumptive Use in country k, $GDP_k{\sim}PPP_k$ is per capita Gross Domestic Product in country k corrected for purchasing power parities.
Climate Vulnerability	Species-specific biomass harvest for consumption × Species-specific climate vulnerability $\sum$ ――― Total biomass harvest for consumption	$TCV_k = \sum_{i=1}^{i=m} \frac{B_{k,i} \times CV_i}{B_k}$	Where: TCV is the Total Climate Vulnerability in country k, m is the total number of species in country k, $B_{k,i}$ is the harvested biomass of species i in country k, CV_i is the Climate Vulnerability of species i (not country-specific), and B_k is the total harvested biomass of all species in country k,

Figure 3: (A) the association between **economic contribution** [**total consumptive use value** (TCUV in USD) per recreational fisher as a share of 2021 gross domestic product (GDP) per capita corrected for purchasing power parity (PPP)] and **nutritional contribution** [**species-specific vitamin B_{12} supply** (ug/100g) from recreationally harvested fish per inland recreational fisher as a proportion of all aquatic foods weighted by proportion consumed and summed]; **(B)** the association between **climate vulnerability** [sum of **species-specific climate vulnerabilities** (derived from Nyboer et al. 2021) weighted by proportions of species consumption (using scenario Representative Concentration Pathway [RCP]4.5, 2075 projection)] and **economic contribution** [TCUV]; and, **(C)** the association between **climate vulnerability** and **nutritional contribution** [B_{12} supply].

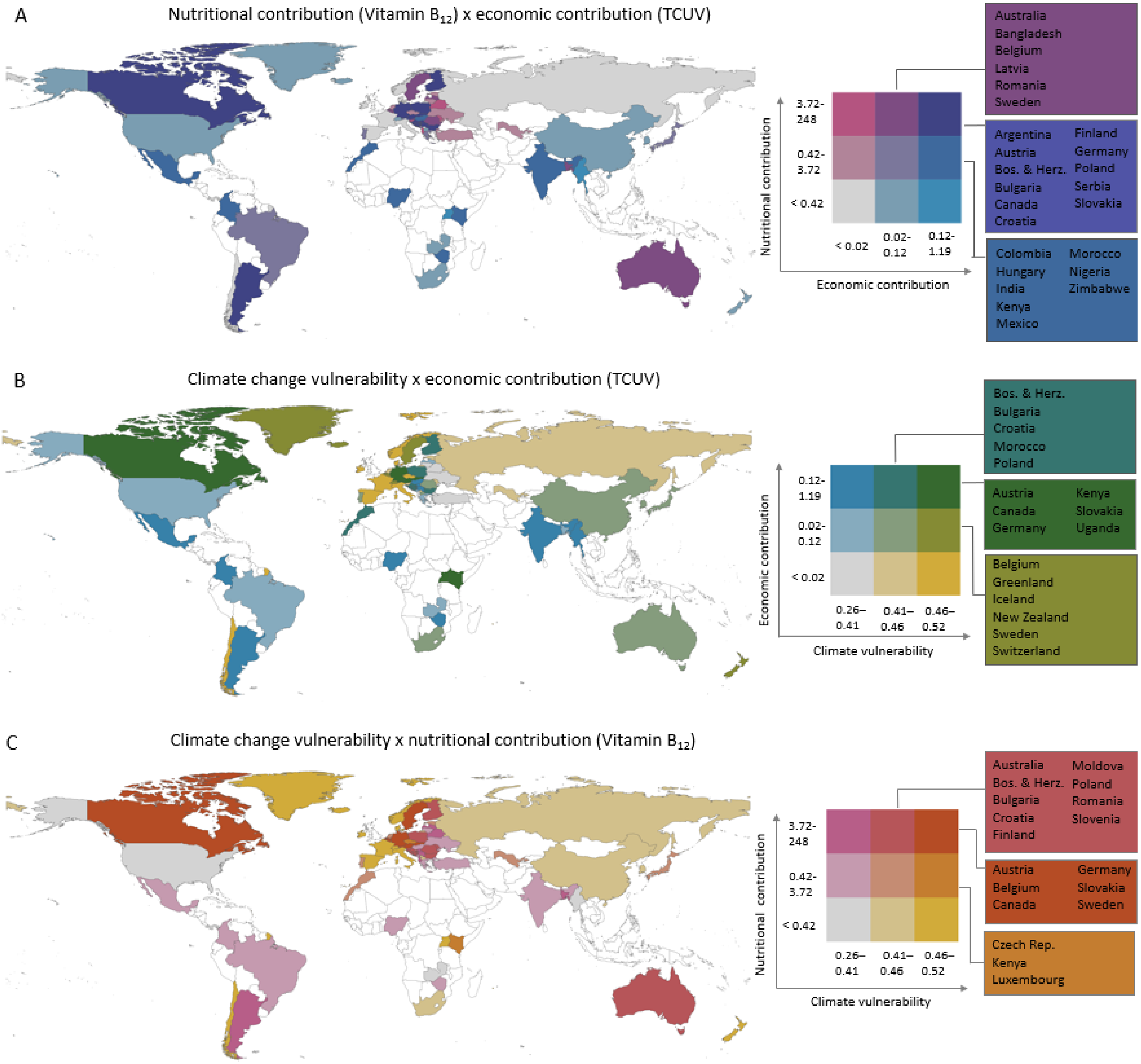
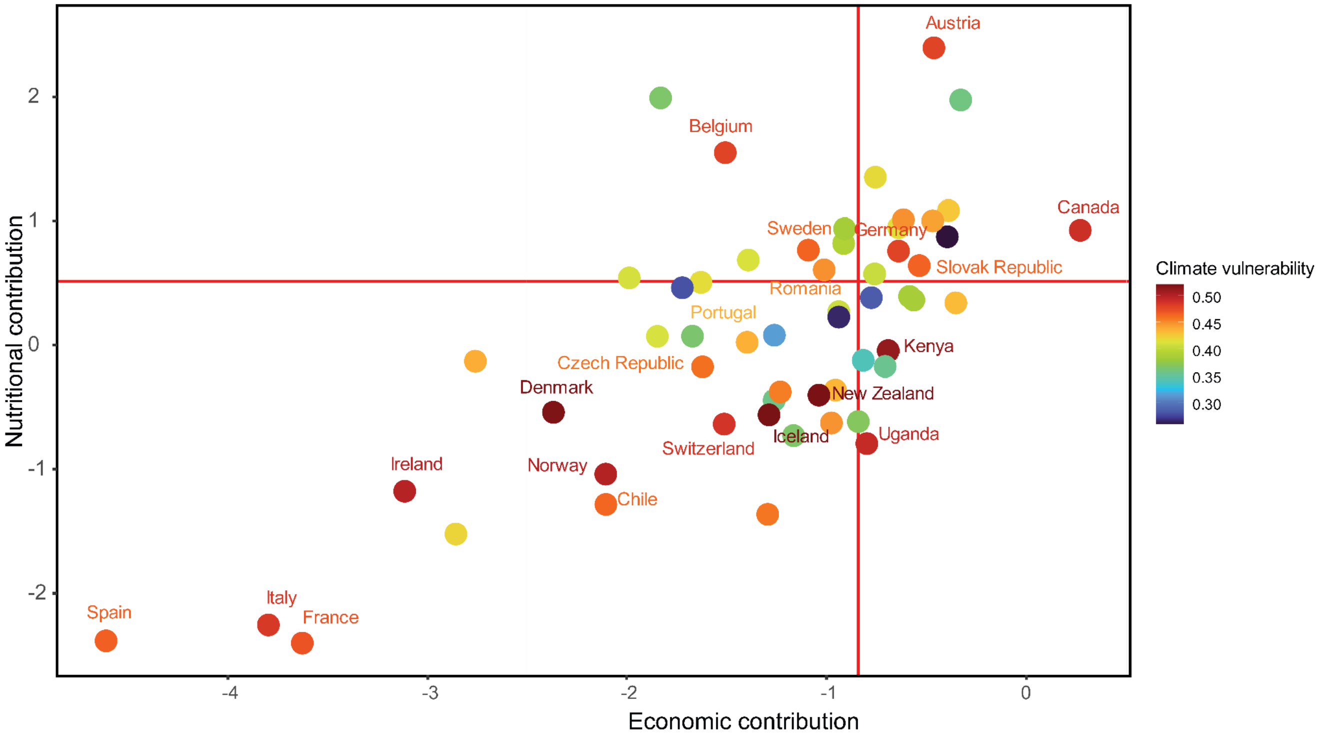


Figure 4. Nutritional contribution, economic contribution, and climate vulnerability of recreationally consumed inland fish by country. **Nutritional contribution** = log of species-specific vitamin B_{12} supply (ug/100g) from recreationally harvested fish per inland recreational fisher as a proportion of all aquatic foods weighted by proportion consumed and summed. **Economic contribution** = log of total consumptive use value (TCUV in USD) per recreational fisher as a share of 2021 gross domestic product (GDP) per capita corrected for purchasing power parity (PPP). **Climate vulnerability** = sum of species-specific climate vulnerabilities (derived from Nyboer et al. 2021) weighted by proportions of species consumption (using scenario Representative Concentration Pathway [RCP]4.5, 2075 projection). **Red lines** = third quantile nutritional and economic contribution across all countries. **Country names** displayed for countries in the upper third quantile of climate vulnerability.

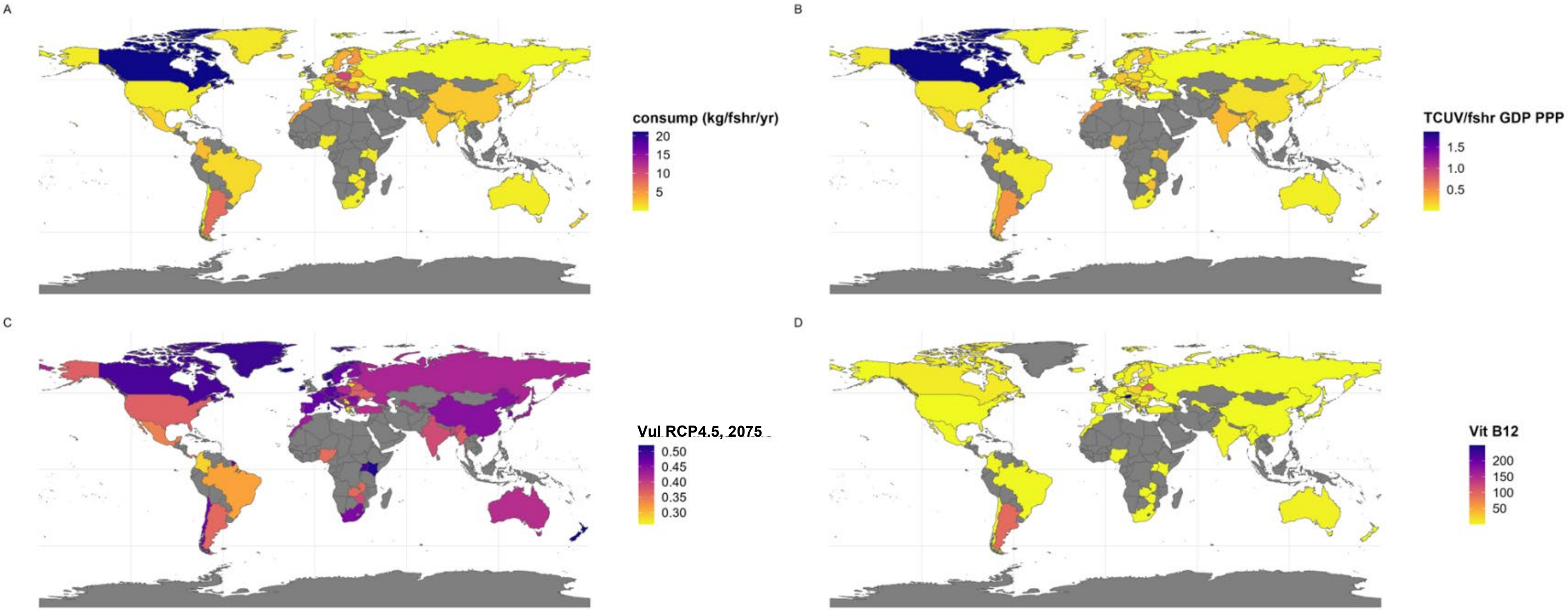


Supplementary tables and figures

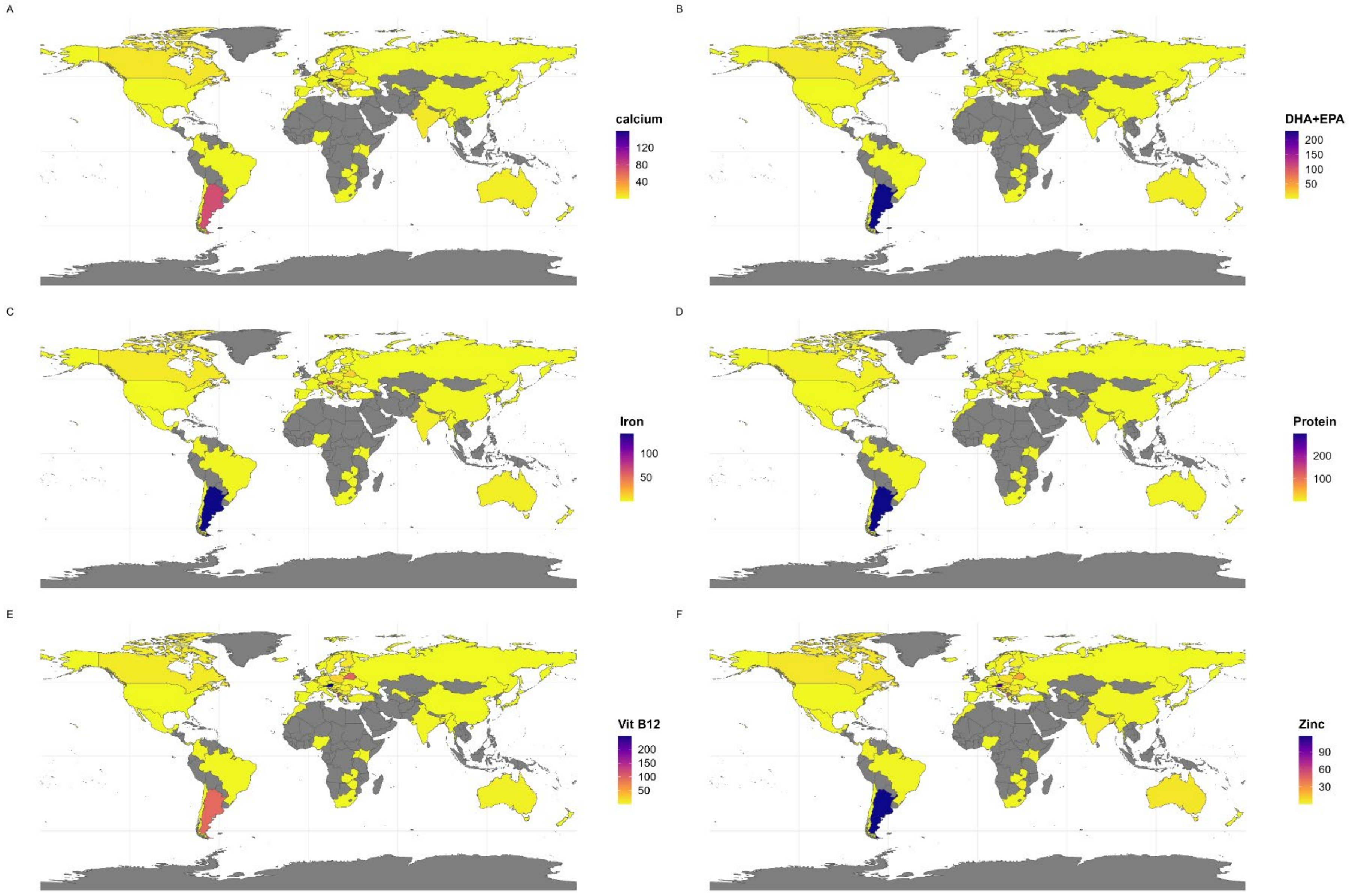
Supplementary Table 1. Number of species with matches for vulnerability scores that were exact, based on genus, based on nearest relative, or with no match. Species = each different species in the dataset.

Phylogenetic level used to match vulnerability score	Species	% Species
exact species match	58	29.1
matched based on genus	59	29.6
matched based on nearest relative	64	32.2
no match (none)	18	9.0
Grand Total	**199**	

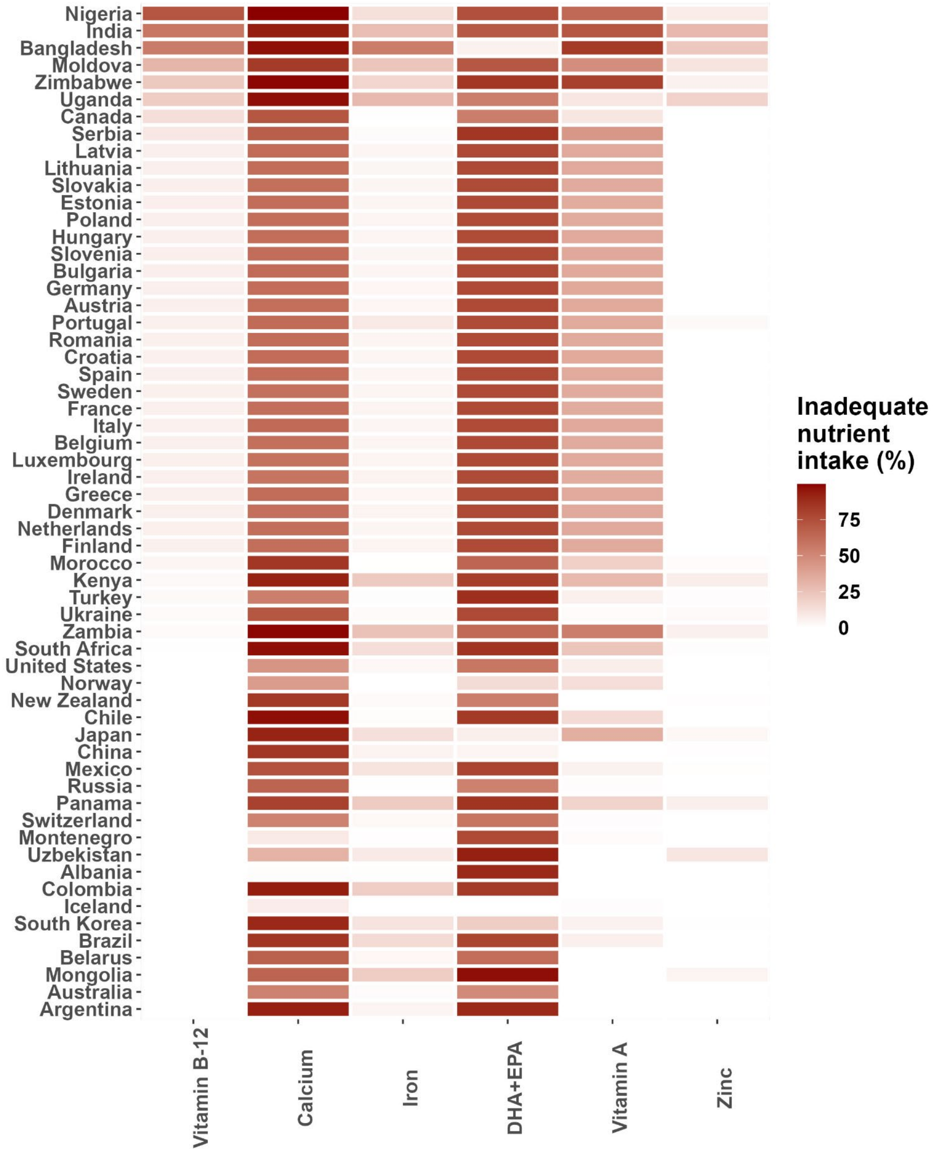
Supplementary Figure 1. Univariate maps showing (A) total consumption (kg per fisher); (B) total consumptive use value (TCUV in USD) per recreational fisher as a share of 2021 gross domestic product (GDP) per capita; C) climate vulnerability (summed, weighted by proportions of species consumption (using scenario Representative Concentration Pathway [RCP]4.5, 2075 projection) and (D) average nutritional contribution.



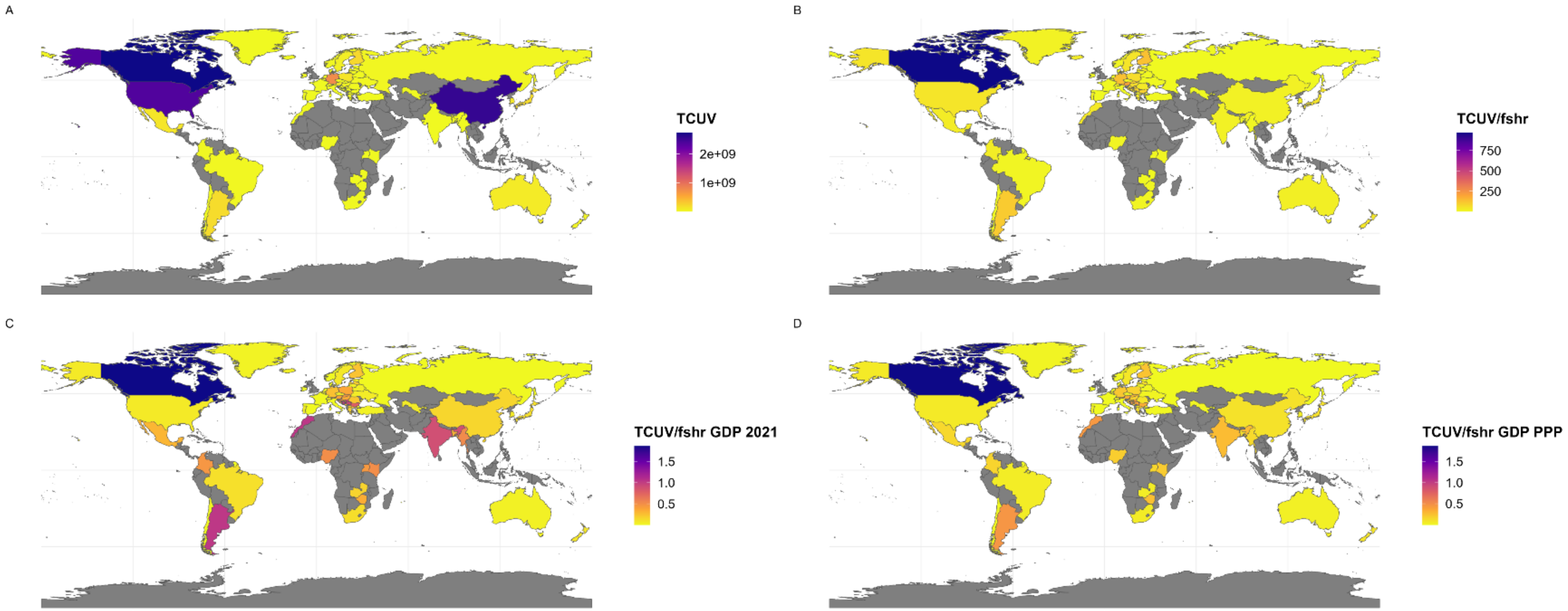
Supplementary Figure 2. Comparison of the contribution of recreational fish to micronutrients (calcium, omega-3 long-chain polyunsaturated fatty acids docosahexaenoic acid and eicosapentaenoic acid [DHA+EPA], iron, protein, vitamin B_{12} [Vit B12], and zinc) as a proportion (%) of estimated national-level average per capita consumption from aquatic foods.



Supplementary Figure 3. Prevalence of inadequate micronutrient intake across all assessed nutrients and countries based on previously published study (Golden et al.[4]). Prevalence of inadequate intake was calculated using the summary exposure values, which estimates the population-level risk related to diets by comparing intake distributions with average requirements. Estimated prevalence of inadequate intake ranges from 0% (no risk) to full population-level risk (100%).



Supplementary Figure 4. Comparison of total consumptive use value (TCUV in USD), TCUV per fisher, and TCUV per fisher corrected for gross domestic product (GDP) and TCUV per fisher corrected for GDP per capita corrected for purchasing power parity (PPP).



Supplementary Figure 5. Comparison of vulnerability of consumed recreational fish (weighted by proportion consumed) across four vulnerability scenarios (A - Representative Concentration Pathway [RCP]4.5, 2030; B - RCP8.5, 2030; C - RCP4.5 2075; D - RCP8.5, 2075).