Supplementary information to: Fall in fish catch threatens human health (Comment in *Nature* 534, 317–320; 2016)

Christopher D. Golden, Edward H. Allison, William W. L. Cheung, Madan M. Dey, Benjamin S. Halpern, Douglas J. McCauley, Matthew Smith, Bapu Vaitla, Dirk Zeller & Samuel S. Myers

In order to estimate the number of people worldwide nutritionally vulnerable to declines in fish catch, the GENuS model was used to estimate nutrient intake for 34 age-sex groups across all countries for which there were data[1]. Using the newly published catch reconstructions from the Sea Around Us database[2], we more accurately reconstructed fisheries catch in each country in the world, including within the small-scale subsistence and artisanal sectors which are greatly underestimated in previous data. In addition to information on marine food resources from the Sea Around Us database, the model used intra-household allocation data from recent food consumption datasets to predict the distribution of food across age-sex groups. We then used GENuS nutrient composition data for the fish species, as well as for all other foods, to predict nutrient intake for each age-sex group.

These intakes were then used in conjunction with estimated average requirements (EARs) of nutrients to estimate the fraction of the population newly vulnerable to nutritional deficiencies following a shock to wild-capture fisheries. Because there is no standard for a threshold value to define a food as being important to the nutrient supply, following internal discussion we chose 10% for zinc and vitamin A as a reasonable value to demonstrate a high reliance on fish. On average, countries derive <1% of their caloric supply and ~5% of their total protein from fish; 10% was chosen to reflect the greater importance of fish to micronutrient supplies, while being congruent with their contributions to macronutrient supplies as well. Regarding iron, because the type of iron supplied by fish and other animal source foods is a heme-type iron and much more easily absorbed, we used a lower value (5%) to reflect the disproportionately large importance of fish-based iron to achieving dietary sufficiency. DHA omega-3 fatty acids were deemed to be nearly exclusively obtained from animal source foods because de novo conversion rates of ALA (obtained from many vegetarian sources) to DHA omega-3 fatty acids (obtained directly only from animal products) has been estimated to occur at a rate of roughly 0.1%[3].

To model vulnerability, we used Monte Carlo simulations— for each of a 1,000 iterations, we estimated how many people are vulnerable and deficient for each country, as well as summed for the whole world. Therefore, we have 1,000 individual country estimates for those vulnerable and deficient, as well as 1,000 estimates for the global total, and for all of these, we then calculate median and 95% uncertainty intervals. This means our “Global” estimate represents the median of the sums, not the sum of the medians, which are not equal (See Supplementary Table).

We are currently improving our global estimate of nutritionally vulnerable populations by integrating the above procedure with more detailed ecological and economic modeling. The Sea Around Us catch reconstructions will be inputted into a dynamic bioclimatic envelope model[4] (DBEM) to predict future distributions and catch of fish species to the year 2050 that are driven by changes in ocean conditions under climate change scenarios, as well as by changes in catch effort.

We will then use these projections as supply inputs into a partial equilibrium model to evaluate the interaction of producers, consumers, and foreign traders in generating annual predictions of market clearing quantities of a wide variety of fish species[5]. Non-fish commodities are determined outside of the system but assumptions about trends in such exogenous factors—including increases in income per capita, policy changes, technological improvements, and so on—can be incorporated into the model. Given available data to parameterize the supply and demand functions, especially elasticities characterizing producer and consumer responses to price changes, the model can be used at any geographic scale. Our work aims at global coverage of all fisheries-dependent populations at high risk of undernutrition and other health problems, largely through the aggregation of high-resolution models at the country and sub-country levels. To characterize fisheries dependence, we will need to have a better understanding of how populations substitute other foods for seafood in the context of fish declines, and to what degree populations can compensate for lost fish through dietary alternatives, fortification, and supplementation. Without accounting for these factors, we may be overestimating fisheries dependence in the current estimation. Yet, GENuS only covers 152 countries, and there are several without data (Cambodia, Gabon, Vietnam, Myanmar, Kiribati, etc.) which we would expect to be vulnerable to fish declines. This, then, represents an underestimation of global vulnerability.

The economic outputs—projected quantities of various fish species available for consumption at the population level for every year to 2050—are the inputs for our refined dietary modeling approach. We assume that all artisanal and industrial catches are potentially available to the global trade market6 (realizing such global access may vary by country and over time) and thus captured within the import-export model. Subsistence catch enters directly into local dietary input. In the future, we hope to model dietary intake at subnational levels, applying additional strata (socioeconomic class, rural/urban location, etc.) as needed. This could include the analysis of vulnerable populations such as indigenous people who may have greater subsistence reliance on fisheries. Without these subnational analyses, many vulnerable populations around the world were unaccounted for in the current analysis. In the next iteration of the analysis, we will examine the sensitivity of these results to changes in aquaculture productivity, population growth, and GDP growth. We will assess the nutritional vulnerability of the future global population under expected dietary intakes of seafood from our projections of what fish catch will be in the future.

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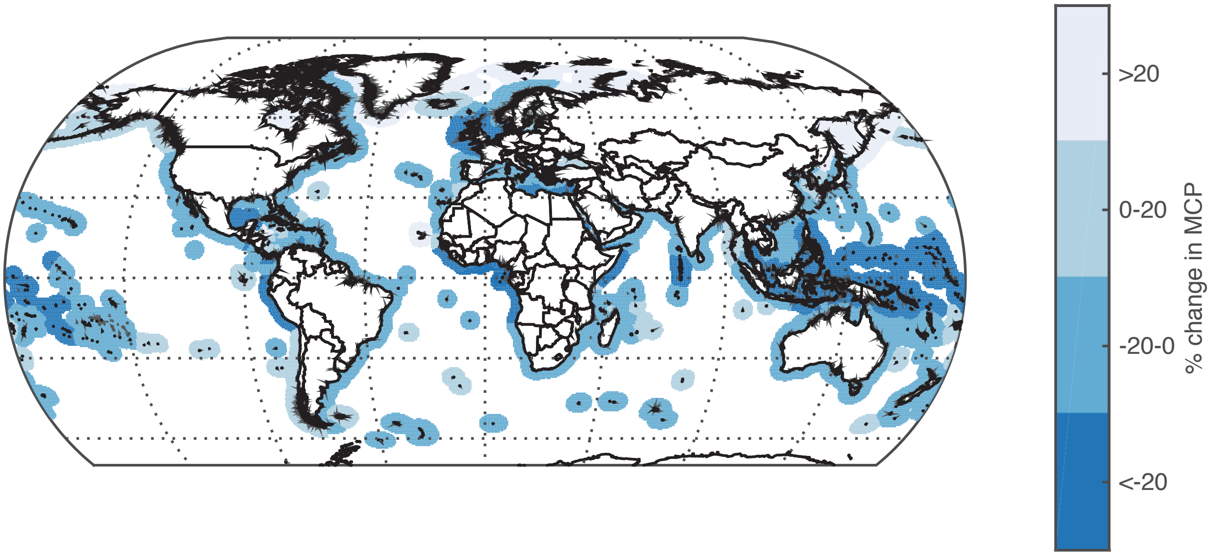
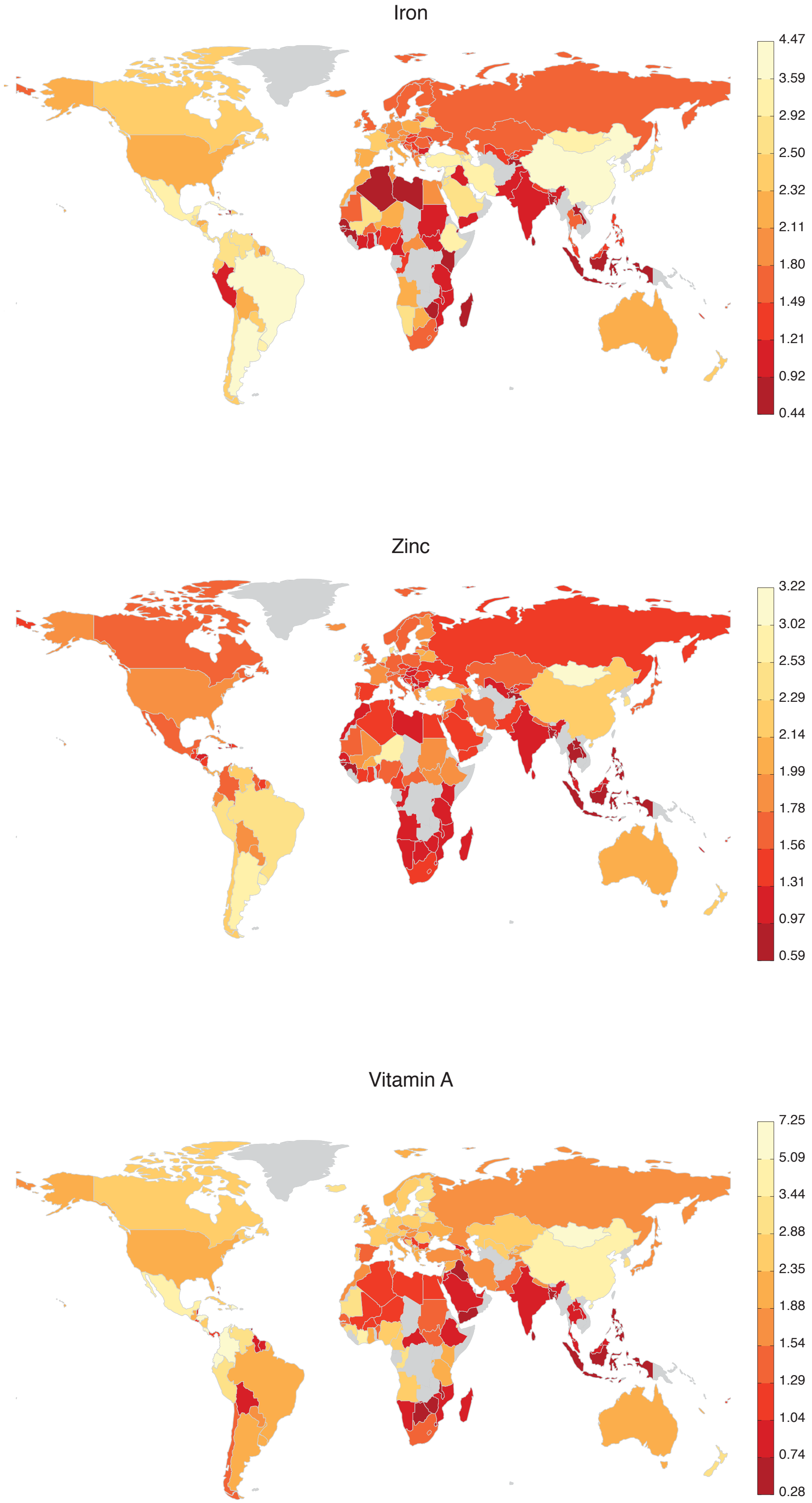
Supplementary Figures

A.

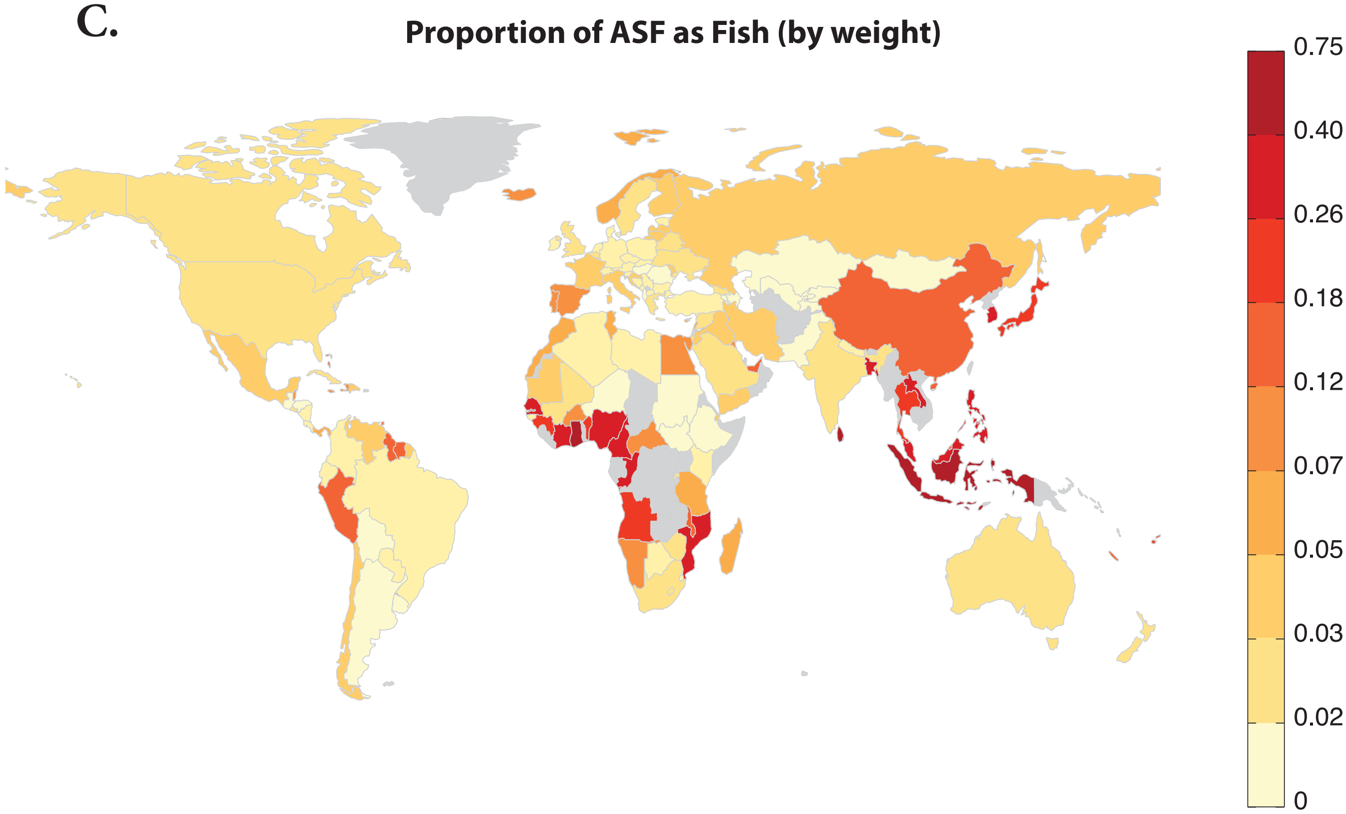


Nutrient Supply as Proportion of EAR

B.



C.



A) The figure shows projected change in maximum catch potential by 2050 (average between 2041–2060) relative to 2000 (average between 1991–2010) by Exclusive Economic Zones of the world's coastal countries under the RCP 8.5 scenario. The projections are obtained from the Dynamic Bioclimate Envelope Model driven by the mean ensemble outputs from NOAA's Geophysical Fluid Dynamics Laboratory Earth System Model (GFDL ESM 2G), the Institut Pierre-Simon Laplace Climate Model (IPSL-CM5A-MR) and the Max Planck Institute Earth System Model (MPI-ESM-MR) [1].

B) National average nutrient supplies as proportion of each country's population-weighted estimated average requirements (EAR). Nutrient supplies are from 2010 and are estimated from the GENuS nutrient supply model [2]. EARs were estimated based on FAO/WHO, IZiNCG, and US IOM recommendations by age and sex group [3-6], and population weighted using the UN World Population Prospects [7] to estimate national-average values. For age-sex categories that included pregnant and lactating women, the numbers for each were estimated using the crude birth rate from [7] and a 40-week gestational period; the average duration of breastfeeding in each country was based on WHO surveys [8], and estimates for countries without data were interpolated using regional averages. For zinc, we chose from between the two possible EARs for each age-sex group based on each country's phytate:zinc ratio (<=18 or >18), measured by [9]. For iron, there are four potential EARs based on the bioavailability of diets, which we sorted each country based on dietary criteria [10,11]: "5% bioavailability" — low meat intake (<50 g/day); "10% bioavailability" — moderate meat (50-150 g/day), low fruit & vegetable intake (<300 g/day); "12% bioavailability" — moderate meat (50-150 g/day), moderate-high fruit & vegetable intake (>300 g/day); "15% bioavailability" — high meat (>150 g/day) and fruit/vegetable intake (>300 g/day).

C) Fish and seafood consumption as a proportion of total animal-source food (ASF) intake. Fish/seafood and total ASF intake are measured as grams per day in 2010, estimated from [2]. Animal source foods include meat, offals, fish, seafood, dairy, eggs, and animal fats.

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