LETTER

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# Harnessing global fisheries to tackle micronutrient deficiencies

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**Micronutrient deficiencies account for an estimated one million premature deaths annually, and for some nations can reduce gross domestic product[1,2] by up to 11%, highlighting the need for food policies that focus on improving nutrition rather than simply increasing the volume of food produced[3]. People gain nutrients from a varied diet, although fish—which are a rich source of bioavailable micronutrients that are essential to human health[4]—are often overlooked. A lack of understanding of the nutrient composition of most fish[5] and how nutrient yields vary among fisheries has hindered the policy shifts that are needed to effectively harness the potential of fisheries for food and nutrition security[6]. Here, using the concentration of 7 nutrients in more than 350 species of marine fish, we estimate how environmental and ecological traits predict nutrient content of marine finfish species. We use this predictive model to quantify the global spatial patterns of the concentrations of nutrients in marine fisheries and compare nutrient yields to the prevalence of micronutrient deficiencies in human populations. We find that species from tropical thermal regimes contain higher concentrations of calcium, iron and zinc; smaller species contain higher concentrations of calcium, iron and omega-3 fatty acids; and species from cold thermal regimes or those with a pelagic feeding pathway contain higher concentrations of omega-3 fatty acids. There is no relationship between nutrient concentrations and total fishery yield, highlighting that the nutrient quality of a fishery is determined by the species composition. For a number of countries in which nutrient intakes are inadequate, nutrients available in marine finfish catches exceed the dietary requirements for populations that live within 100 km of the coast, and a fraction of current landings could be particularly impactful for children under 5 years of age. Our analyses suggest that fish-based food strategies have the potential to substantially contribute to global food and nutrition security.**

Uneven progress in tackling malnutrition has kept food and nutrition security high on the development agenda globally[1,3]. Micronutrients, such as iron and zinc, are a particular focus; it is estimated that nearly 2 billion people lack key micronutrients[1], underlying nearly half of all deaths in children under 5 years of age[1] and reducing gross domestic product in Africa[2,3] by estimates of up to 11%. Consequently, efforts to tackle malnutrition have shifted from a focus on increasing energy and macronutrients (for example, protein) to ensuring sufficient consumption of micronutrients[3]. People gain nutrients from a mixture of locally produced and imported food products. Fish, which are harvested widely and traded both domestically and internationally, are a rich source of bioavailable micronutrients; these micronutrients are often deficient in diets that rely heavily on plant-based sources[6,7]. Fish could therefore help to address nutritional deficiencies if there are sufficient quantities of fishery-derived nutrients accessible in places in which deficiencies exist. However, addressing this major food policy frontier has been complicated, in part because the nutrient composition of fish varies considerably among species and data remain sparse for most species[5].

Here we determine the contribution that marine fisheries can make to addressing micronutrient deficiencies. First, using strict inclusion protocols, we developed a database of 2,267 measures of nutrient composition from 367 fish species for 43 countries for 7 nutrients that are essential to human health: calcium, iron, selenium, zinc, vitamin A, omega-3 fatty acids (n-3 fatty acids) and protein. We then gathered species-level environmental and ecological traits that capture elements of diet, thermal regime and energetic demand in fish[8,9] to develop a series of Bayesian hierarchical models that determine drivers of nutrient content (Methods).

Our models successfully predicted nutrient concentrations, with posterior predictive distributions consistently capturing both the observed overall mean and individual values of each nutrient[10] (Extended Data Figs. 1, 2 and Methods). We show that calcium, iron and zinc—nutrients that are critical for growth, health and human capital[11,12]—were found at higher concentrations in tropical fishes (Fig. 1). Tropical soils are often zinc- and calcium-deficient, because these nutrients are easily exported from land to sea during the strong pulse rainfall events that are common in the tropics; this process may increase the levels of these nutrients in marine foodwebs[13]. Higher concentrations of calcium, zinc and omega-3 fatty acids were found in small fish species. Consumption of small fishes is promoted, particularly in Asia and Africa[14,15], as a rich source of micronutrients and, although these high concentrations are often linked to the practice of consuming whole fish[15], we also detected elevated levels of these nutrients in muscle tissue of smaller fish.

Higher concentrations of omega-3 fatty acids—which support neurological function and cardiovascular health[16]—were found in species that are pelagic feeders, from cold regions and approach their maximum size more slowly (Fig. 1). Pelagic feeders consume plankton, the main source of omega-3 fatty acids in aquatic systems[17], whereas species adapted to a colder thermal regime have a greater need for energy storage compounds and fat, including fatty acids[18]. Selenium concentrations were higher in species found at greater depths and lower for species found in tropical waters, whereas lower concentrations of vitamin A were found in species from cold regions, with high trophic levels and short, deep body shapes. Concentrations of protein were greater in species with higher trophic levels and those with a pelagic feeding pathway, and lower in species found in cold regions and with a flat or elongated body shape (Fig. 1).

Given the alignment between our posterior predictions and observed data (Extended Data Fig. 2), we used our trait-based models of nutrient concentration, and traits for species within the landed catch of the world's marine fisheries[19], to produce global estimates for nutrient concentrations (Fig. 2) and nutrient yields (Extended Data Fig. 3) of

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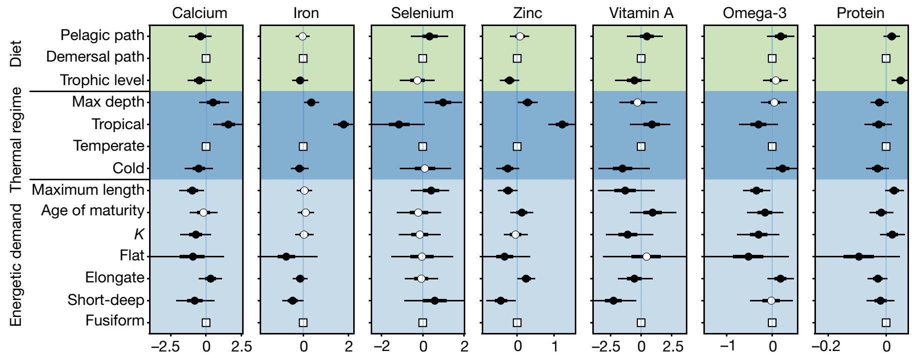

**Fig. 1 | Bayesian hierarchical predictive model of nutrient concentrations in fish.** Standardized effect sizes for environmental and ecological drivers of nutrient concentrations for diet, thermal regime and energetic demand. Parameter estimates are Bayesian posterior median values, 95% highest posterior density uncertainty intervals (thin lines) and 50% uncertainty intervals (thick lines). Black dots indicate that the 50% uncertainty intervals do not overlap zero, indicating that more than 75% of the posterior density was either positive or negative, whereas open circles indicate that the 50% uncertainty intervals overlap zero. Open squares indicate the baseline category in the statistical model. *K* denotes parameter *K* of the von Bertalanffy growth equation. Underlying sample sizes are as follows: calcium, $n = 170$ biologically independent samples; iron, $n = 173$; selenium, $n = 134$; zinc $n = 196$; vitamin A, $n = 69$; omega-3 fatty acids, $n = 176$; protein, $n = 627$. Effect sizes are not on a common *x*-axis scale for clarity of presentation.

marine fisheries (Methods). These data reflect catches from within the economic exclusive zone (EEZ) of each country that are landed and consumed domestically, landed outside the country by foreign fleets or traded internationally[19]. We include both officially recorded and reconstructed unrecorded catches (see Methods for comparisons), but do not include discards. There was no correlation between the concentration of nutrients per unit catch and either total nutrient yield or total fishery yield (Extended Data Fig. 4), suggesting that the nutrient quality of fishery landings is influenced by species composition rather than simply by quantity landed. Therefore, fish-based food policy guidelines[20] should specify the types of fish that should be consumed.

High concentrations of iron and zinc (>2.5 mg per 100 g and >1.8 mg per 100 g, respectively, of the raw, edible portion of the fish) are found in species caught in a number of African and Asian countries (Fig. 2 and Extended Data Table 1)—the same regions that are at greatest risk of deficiencies in these nutrients[11,12]. This suggests that, in areas with critical public health concerns, a single portion (100 g) of an average fish could provide approximately half of the recommended dietary allowance (RDA) of iron and zinc for a child under 5 years of age. Calcium concentrations are high (>200 mg per 100 g of the raw, edible portion of the fish) in species caught in the Caribbean region, an area in which there is a high prevalence of deficiency[11], again highlighting

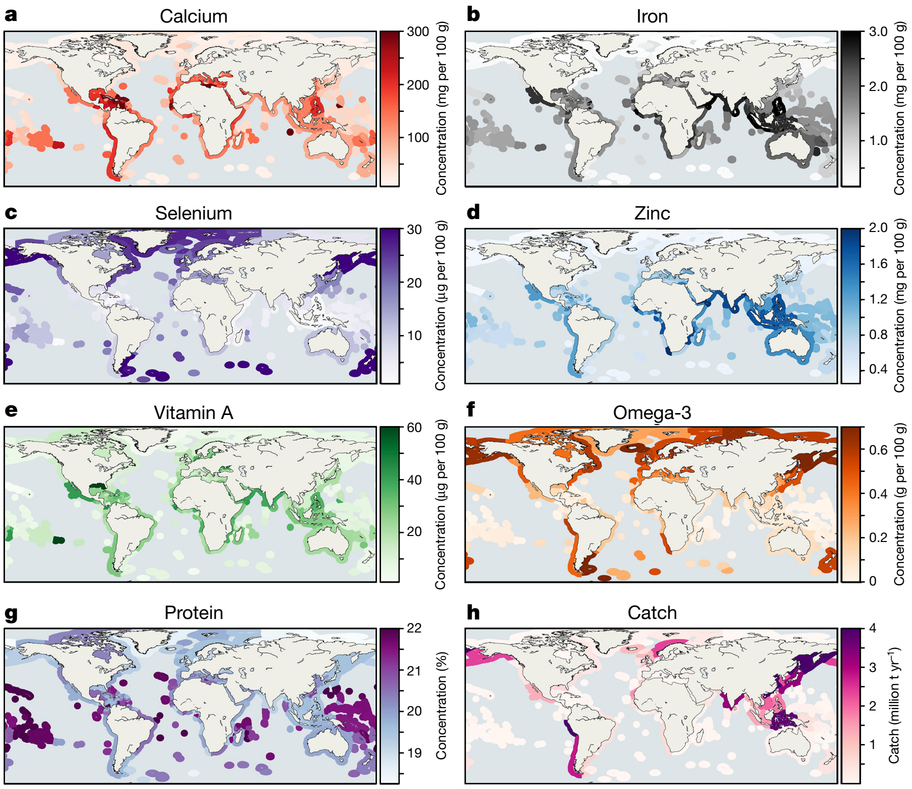

**Fig. 2 | Nutrient concentration of fisheries and total catch by EEZ.** Data are based on annual catch composition[19] between 2010 and 2014. **a**–**g**, Plots show the concentrations of calcium (in mg per 100 g), iron (in mg per 100 g), selenium (in µg per 100 g), zinc (in mg per 100 g), vitamin A (µg per 100 g), omega-3 fatty acids (g per 100 g) and protein (%) in each EEZ. **h**, Total catch (in million tonnes (t) per year (yr)). Data are plotted at the scale of EEZ areas as previously defined[19]. Base maps were generated using the matplotlib library[31] (https://matplotlib.org) in Python.

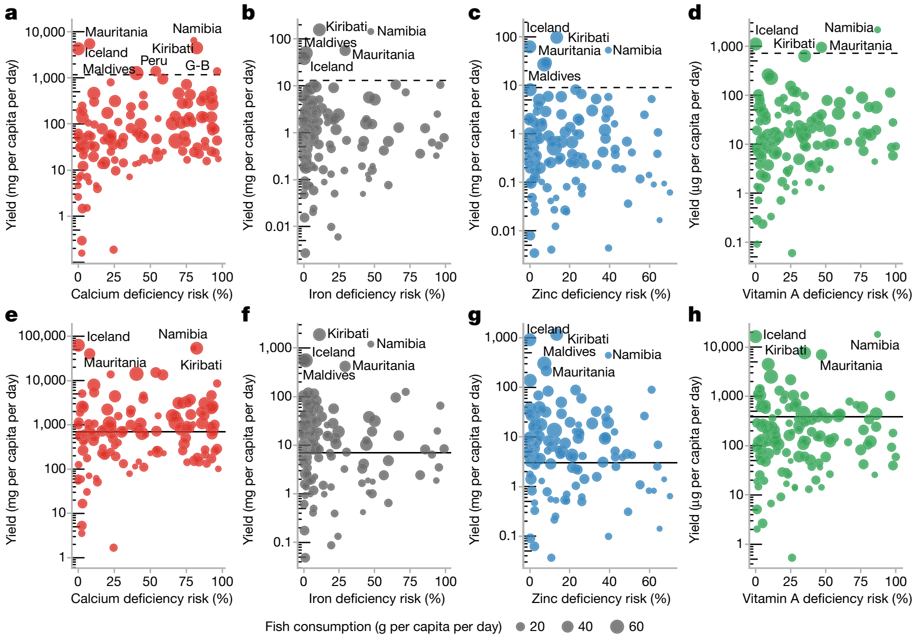

**Fig. 3 | The contribution that fisheries could make to closing dietary nutrient gaps. a–h**, Nutrient yield per capita for coastal residents (**a–d**) and per capita for coastal residents under 5 years old (**e–h**) by dietary deficiency risk[12] for all coastal countries on the basis of the concentrations of calcium (**a**, **e**), iron (**b**, **f**), zinc (**c**, **g**) and vitamin A (**d**, **h**). The size of the circle indicates the national consumption of seafood (g per capita per day)[25]. Solid horizontal lines denote the RDA for children under 5 years of age; dotted horizontal lines denote the RDA for the rest of the population[26]. G-B, Guinea-Bissau.

the potential contributions fish can make to targeted health interventions in these areas. Concentrations of selenium and omega-3 fatty acids are high (>25 μg per 100 g, >0.5 g per 100 g, respectively, of the raw, edible portion of the fish) in fish species caught from high-latitude regions, including parts of Russia, Canada, Northern Europe and Alaska (Fig. 2 and Extended Data Table 1). This is consistent with the observation that omega-3 fatty acids are abundant in marine foods consumed by Arctic indigenous populations such as the Inuit of Nunavik, Canada[21]. Furthermore, these high selenium concentrations are found in some of the areas in which selenium deficiencies are common[22], yet a single portion of an average fish (Methods) from these waters contains enough selenium to meet the daily RDA for a child under 5 years of age, and nearly half of the selenium required by adults.

Although we recognize the challenges of the sustainability of fisheries and potential climate-driven declines in yields[23], the availability of high concentrations of key nutrients in areas that are at risk of nutrient deficiencies suggests that marine fisheries could be critical in helping to close nutrient gaps. To assess this, we calculated nutrient yields per capita using the estimated national nutrient yield in our models and the human population living within 100 km of the coast (which represents 39% of the global population[24]; Methods). We focus on calcium, iron, zinc and vitamin A, which constitute a major burden of malnutrition, particularly within low-income countries[1,11,12]. For each nutrient and country, we compare this to published dietary deficiency risks[12], seafood consumption rates[25] and RDA[26] (Methods). We specify RDA averaged for the population aged 5 years and older, and for children between 6 months and 4 years of age (Fig. 3). Children under 5 years of age represent a vulnerable proportion of the population, in which interventions have the greatest potential long-term effects on growth, development and health.

Fish-derived contributions of calcium, iron, zinc and vitamin A, for a large number of countries, could provide a considerable proportion of the RDA for their coastal populations. For eight countries, these yields exceed requirements for at least one of these nutrients (Fig. 3a–d). Of those countries, only Iceland has mild dietary deficiency risks (<20%)[12,27] (Fig. 3a–d). Very high nutrient yields and prevalence of dietary deficiency risk coincide for at least two nutrients in Namibia, Mauritania and Kiribati (Fig. 3a–d). In these countries, a small fraction of the available production from fisheries has the potential to close nutrient gaps. For example, the dietary risk of iron deficiency in Namibia is severe (47%)[12]; however, only 9% of the fish caught in the EEZ of Namibia is equivalent to the dietary iron requirements for the entire coastal population.

Fisheries clearly have an important place in food and nutrition policies. This contribution could be particularly important if targeted to the most vulnerable groups within society, such as children under 5 years of age, capturing the period when most of the faltering growth occurs. More than 50% of coastal countries have moderate-to-severe deficiency risks (>20%)[12,27] and nutrient yields that exceed the necessary RDA for all children under 5 years of age in the coastal population (Fig. 3e–h). Notably, in Kiribati the dietary risk of calcium deficiency is severe (82%)[12]; however, only 1% of fish caught in the EEZ of Kiribati is equivalent to the calcium requirements for all children under 5 years of age. For a further 22 countries, predominantly in Asia and west Africa, the dietary requirements for all children under 5 years of age is equivalent to 20% or less of current catches. The fact that targeted approaches could require only a fraction of current landings to alleviate nutrient deficiencies suggests that a nutrition-sensitive fishery approach could align with environmental efforts to reduce current harvest levels.

Nutrient surpluses of some coastal countries in which nutritional needs are not being met highlight that large yields do not necessarily lead to food and nutrition security. International fishing fleets and trade deals[19], physical, economic or institutional access to the right food[28], food preferences and cultures, waste and reduction to fish oil for animal feed[29] can all act as barriers or avenues to these resources meeting local nutritional needs. For example, international trade and foreign fishing are dominant in countries with large nutrient yields, in which high rates of dietary deficiency risks exist (Extended Data Table 2 and Methods). Understanding why, when there is an adequate supply of nutrients, populations are still at risk of dietary deficiency will require a multiscale socio-economic research agenda that situates fish in the broader food system and accounts for patterns of production, distribution, preparation and consumption.

Our results identify the current world distribution of nutrients from the catches of fisheries. In doing so, we demonstrate that, for a number of nutrients that are essential to human health, current production has the potential to considerably and positively influence the nutritional status of some of the most nutrient-deficient countries globally, even at reduced catch levels. Given that fish are in many instances a more affordable animal-based food source[4] with a lower environmental impact[20], and the fact that nutrient supplies from fisheries are comparable to those from other animal-based food sources[30], fisheries should be a core component of food and nutrition policies. However, current fishery policies remain orientated towards maximizing profit or yield. Reorientating fisheries policies towards a more efficient and equitable distribution of consumption, aimed at meeting local nutritional needs, could close nutrient gaps in geographies of critical food and nutrition concern such as west and sub-Saharan Africa. Achieving this will require concerted efforts to scale approaches that protect local nutritional benefits, and to understand how policies can be redirected towards desired food and nutrition outcomes. Ultimately, multiple approaches and actors must work together to tackle malnutrition[20]. Fisheries should therefore form part of an integrated approach that is informed by health, production, development and environmental sectors.

## Online content

Any methods, additional references, Nature Research reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41586-019-1592-6.

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