ECONOMICS

Sustainability and Global Seafood

Tight coupling to ecosystems and dependence on common-pool resources threaten fisheries and aquaculture.

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Although seafood is the most highly traded food internationally, it is an often overlooked component of global food security. It provides essential local food, livelihoods, and export earnings. Although global capture fisheries production is unlikely to increase, aquaculture is growing considerably. Sustaining seafood's contributions to food security hinges on the ability of institutions, particularly in developing countries, to protect and improve ecosystem health in the face of increasing pressures from international trade.

Seafood (fish and shellfish harvested from capture fisheries and aquaculture production in marine and freshwater environments) contributes at least 15% of average animal protein consumption to 2.9 billion people and as much as 50% for some small island and West African states (*1*). Seafood is the main source of omega-3 fatty acids that are essential for brain development (*2*) and provides important micronutrients for the poor (*3*). As a source of livelihood, capture fisheries and aquaculture employed 43.5 million people in 2006, and 520 million people relied on income from seafood production (*1*). Seafood is also the most highly traded food commodity internationally (*1*). Fish and shellfish exports from developing countries exceed the value of coffee, rubber, cocoa, tea, tobacco, meat, and rice combined (*1*). Developing countries benefit from this trade by exporting high-valued seafood to developed countries, importing low-valued seafood, and using the surplus value to purchase other goods and services (fig. S1). However, they often lack the institutions necessary to prevent deleterious ecosystem impacts of seafood production and to sustain trade benefits. Developed countries have a history of these problems, as well, but with less-obvious consequences.

Although terrestrial food systems provide protein, support livelihoods, and generate export earnings, two characteristics of fisheries and aquaculture production uniquely threaten food security: tight coupling to ecosystems and dependence on common-pool resources. Fisheries and aquaculture are vulnerable to exogenous shocks to ecosystems such as climate change, but endogenous changes are particularly important. Common-pool fish stocks are often open-access, and fishing effort can push stock levels beyond maximum sustainable yield. In those cases, price increases lead to reduced seafood production (*4*, *5*). This scenario does not generally occur in terrestrial food production.

Fishing not only reduces target species populations but also can alter marine food webs (*6*) and has cumulative impacts on marine ecosystems (*7*), undermining the productive capacity of fisheries. Ultimately, the total productivity of a capture fishery is limited by the target species' ability to reproduce, and poor governance often leads to fish populations being pushed beyond this limit.

Aquaculture attempts to decouple fish production from environmental fluctuations by controlling growing conditions, feed input, and disease (*8*, *9*). However, poor management can lead to reduced production even when prices rise, partly due to poorly defined property rights in locations where aquaculture is conducted. In estuarine and marine environments, nutrient pollution, farmed fish escapes, disease spread, and the use of capture fish in feed also threaten aquaculture's sustainability (*10*).

Consumption is not shared equally among countries (see the figure on page 785). Levels are high in developed and island countries but low in some developing countries (China and Southeast Asia are notable exceptions). Overlaying net exports, governance, and undernourishment suggests that seafood's contribution as a source of protein and livelihood is precarious. To compare institutional effectiveness across countries, we used an average of four governance indicators developed for the World Bank (*11*) as a proxy. Countries with undernourishment and weak governance often serve as net exporters of seafood to well-nourished countries with strong governance (see the table on page 786). However, the largest seafood net exporters (China, Norway, and Chile) have neither the weakest governance nor the greatest undernourishment, suggesting that they have some institutional capacity to promote sustainability (see the figure).

At the global scale (see the table), regions with low undernourishment are net importers of seafood from regions with high undernourishment. In principle, developing countries could consume more seafood simply by exporting less of it. But prevailing conditions in the global seafood market make it advantageous for many countries to be seafood exporters and generate surplus value (fig. S1). A population-weighted average governance score follows the same trend as per capita seafood consumption; regions with more undernourishment tend to have weaker governance (see the figure and the table). Poor governance ultimately squanders seafood availability, for example, by failing to control overfishing and bycatch, as well as failing to regulate the environmental impacts of aquaculture. Corruption (included in governance) can also prevent export earnings from benefiting the poor.

On each continent, the governance index is lower in less-nourished regions. Per capita seafood consumption follows the same pattern, except in Oceania, which has a preponderance of small island nations with abundant seafood sources (see the table).

Asia generates most of the world's net seafood exports from countries with moderate to

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severe undernourishment. China, Indonesia, Vietnam, Thailand, Taiwan, India, and Myanmar are large net exporters (>300,000 metric tons) and, with the exception of Taiwan (for which data are unavailable), have moderate to high undernourishment. China illustrates the potential for aquaculture to contribute to food security by expanding export-oriented and domestically consumed aquaculture. This growth contributed to China's recent substantial reduction in undernourishment (*12*). Ninety-two percent of global animal aquaculture production occurs in developing countries, of which 31% is carp that is mostly grown in small Chinese facilities for domestic consumption (*13*). In contrast, Japan is the world's largest net importer (3.82 million metric tons) and has low undernourishment.

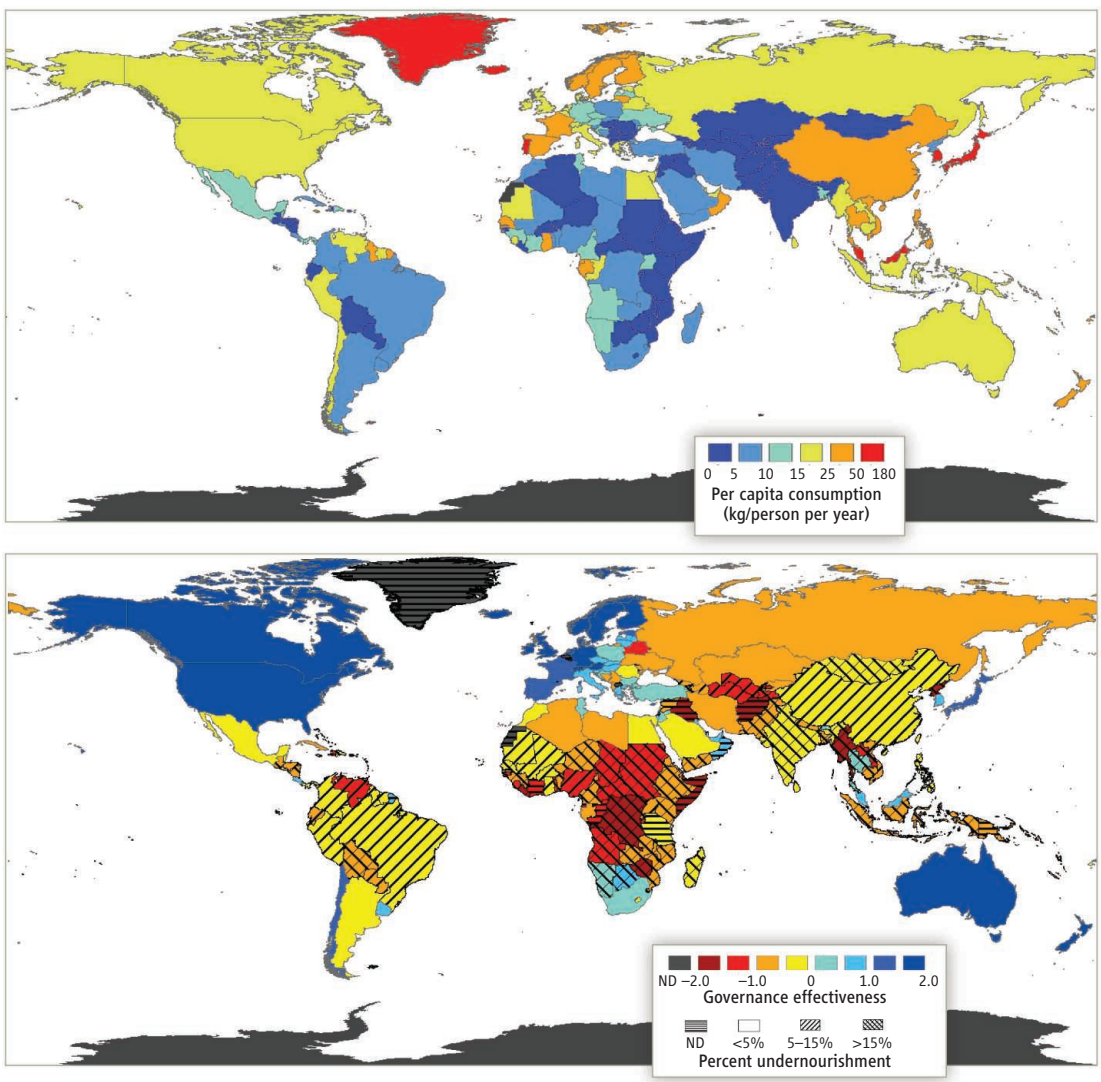
In Africa, severely undernourished regions, e.g., Namibia and Senegal, are net exporters, but moderately undernourished regions are net importers, e.g., Nigeria (see the table). Small amounts of exports from Africa also reflect access agreements between countries in West Africa and other regions (mostly Europe and Asia) to exploit their offshore fish stocks. These landings are counted neither as African production nor as African exports, although they come from African waters.

The United States and European Union countries are well nourished and among the largest net importers. In contrast, large-scale aquaculture production creates opportunities for countries with all levels of nourishment (low, moderate, and high) to be net exporters, e.g., Vietnam, Chile, and Norway.

These data highlight the benefits of the seafood trade but also seafood's precarious role in contributing to food security. Weak governance threatens countries' abilities to consume seafood domestically or export it and use the trade system to purchase other foods. Because much of the world's seafood production comes from regions with weak governance, improved governance is essential to sustain or increase seafood's contribution to food security.

Two very different histories of fish production in Chile and Mexico illustrate the importance of effective governance. Chile's rugged coastline is well suited to salmon farming. Salmon production has been primarily an indirect source of food through earnings and employment. Global trade and lax environmental regulations in Chile facilitated rapid expansion of salmon farming, but currently the industry is experiencing its worst disease crisis ever, an outbreak of infectious salmon anemia. Although 670,000 metric tons were produced in 2008, the prediction is that Chile will produce less than 100,000 metric tons in 2010. The outbreak has been attributed to institutional failure to react to known risks from lake-based smolt production and unvaccinated fish (*14*). Chile's crisis tells a cautionary tale about expanding aquaculture production without effective institutions to protect the environment.

The spiny lobster fishery (*Panulirus interruptus*) along the central west coast of the Baja California peninsula is the largest lobster fishery in Mexico, with ~1600 metric tons captured every year. Ninety percent of the catch is exported live, and the export is critical for local livelihoods and quality of life. There are 500 fishermen organized into nine fishing cooperatives har-



Seafood consumption, governance, and undernourishment. (**Top**) Apparent per capita edible seafood consumption (2003 to 2005 average kg per year in live weight equivalent) from FAO FishStat Plus (*13*). Edible seafood is from fisheries and aquaculture used for human consumption. Apparent consumption is calculated for each nation by adding total seafood production to total imports and subtracting total exports. Per capita consumption divides apparent consumption by population. (**Bottom**) Governance by nation is the average of four World Bank indicators (each with a score of −2.5 to 2.5 and averaged for 2003 to 2005): rule of law, control of corruption, governmental effectiveness, and regulatory quality (*11*). Undernourishment categories by nation are FAO's average percentage of the population that is undernourished for 2003 to 2005 (*12*).

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vesting the resource. Strong comanagement by cooperatives and the federal government has kept the Mexican Baja California lobster fishery from overexpanding to increase short-term export earnings at the expense of future resource availability (*15*).

What policy initiatives can create incentives for better governance and enhance seafood's role in food security? Developing countries rely heavily on common property resource management, in which communities organize themselves to solve the commons problem (*16*, *17*). These institutions may fail during rapid change (e.g., new technology) or if they are not buffered from external forces (e.g., international trade) (*18*–*20*). Thus, developing countries are in a quandary with respect to seafood exports; existing common property institutions are threatened by export-oriented seafood production, and robust rights-based institutions generally require effective governance. Given the high tradability of seafood, trade policy is a natural consideration, and import tariffs theoretically can promote renewable resource sustainability (*21*). But seafood tariffs are likely to violate World Trade Organization (WTO) rules, reduce short-term trade, and fail to differentiate among well-managed and poorly managed fisheries and aquaculture operations. In contrast, private initiatives such as ecolabeling, third-party certification, and direct sourcing have the potential to differentiate among seafood suppliers. Success of these voluntary initiatives may require that consumers are willing to pay a premium for sustainability to cover the costs of investment in sustainable governance (e.g., management), equipment (e.g., fishing gear), and infrastructure (e.g., traceability systems). Whether consumers actually will pay this premium is an open question, which suggests that other funding sources such as direct foreign aid, may be necessary. Aid providers would need to coordinate with WTO to ensure that recipients are not accused of dumping seafood on the global market.

Natural resource prices fail to reflect the cost of sustainability in many countries (*22*). In the short run, as producers transition toward environmental stewardship, prices rise for products like shrimp, lobster, and salmon. But over the longer term, producers and consumers are better off because seafood supplies and livelihoods are sustainable. Price increases that reward sustainability may also raise prices of low-valued seafood, displacing fish protein from diets of the poorest of the poor in the short term. That is, when the price of the high-value product increases, demand for a substitute low-value product increases, raising its price. Research is needed to determine whether these price increases are large enough to warrant a policy intervention such as direct aid. Finally, bilateral trade between developed and developing countries highlights the importance of governance in developed countries as well. Developing countries import low-valued seafood for consumption, as well as high-valued seafood for processing, from developed countries. Sustaining these contributions to consumption and livelihood requires that developed countries also govern their resources effectively.

Trends by Continent

Continent level of undernourishment	Percent of world population	Seafood net exports (metric tons/year)	Seafood consumption (kg/person per year)	Pop. weighted avg. governance
World				
Low	29.3	−7,838,123	21.72	0.63
Moderate	31.1	3,387,403	20.05	−0.40
High	37.9	3,182,602	9.03	−0.51
Africa				
Low	3.1	73,540	11.09	−0.13
Moderate	3.7	−935,520	10.71	−0.87
High	7.1	289,134	5.57	−0.93
Asia				
Low	6.6	−5,462,261	31.89	0.32
Moderate	22.4	3,858,470	24.21	−0.36
High	30.0	2,912,576	9.95	−0.41
Europe				
Low	11.3	−2,376,047	20.09	0.68
Moderate	0.0	0		
High	0.0	0		
North America				
Low	7.0	−2,190,357	20.54	1.17
Moderate	0.3	−51,508	9.48	−0.28
High	0.6	−11,711	5.22	−0.73
Oceania				
Low	0.4	90,891	25.69	1.79
Moderate	0.0	91,751	34.14	−0.77
High	0.0	0		
South America				
Low	0.9	2,026,111	11.07	0.07
Moderate	4.7	424,210	8.16	−0.19
High	0.1	−7,397	1.61	−0.58

Relation of exports, undernourishment, seafood consumption, and governance. Data were obtained as described in the figure legend. Low, moderate, and high refer to population-weighted averages of country-level undernourishment status. They indicate, for each continent, the proportion of the population that lives in countries where <5%, 5 to 15%, and >15%, respectively, of that country's population is undernourished. Undernourishment data are unavailable for countries representing <3% of the population of each continent, with the exception of Oceania (for which 20% of the population lives in countries without data).

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