

A GLOBAL ANALYSIS OF MARICULTURE PRODUCTION AND ITS SUSTAINABILITY, 1950–2030¹

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The biodiversity of the ecosystems in which our economy and culture are embedded provides us with food. However, we often act as though these environmental food services are somehow free and infinite. In reality, the scope and scale of our current human activities, and our tendency to rely on a short-term mindset, are damaging our environment and threatening this provisioning role of natural systems (Sumaila and Walters 2005).

This threat is evident in the evolution of global capture fisheries to their present state (Pauly and Zeller 2016). Indeed, capture fisheries alone are no longer expected to be capable of supplying the projected increases in the demand for food fish, a term used to collectively refer to finfish, molluscs, crustaceans, and other aquatic animals that are caught or farmed (FAO 2012b). Aquaculture is expected to both fill the supply gap and meet the growing worldwide consumption demand for fish (Ye 1999; FAO 2009a; FAO 2014).

Aquaculture is “the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants, with some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc.” (FAO 2008a), and its ability to provide fish for human con-

sumption has changed dramatically since the first documented production of herbivorous pond fish in China more than 3,000 years ago (Ling 1977). Historically, aquaculture began as a low-intensity farming practice that applied basic rearing techniques to naturalized or native fish, primarily in freshwater pond environments. Today global-scale commercial aquaculture production across freshwater, brackish, and marine environments provides a large fraction of the fish consumed worldwide. Aquaculture therefore can also be expected to play a pivotal role in our attempt to meet the projected increases in global seafood demand.

Although the freshwater sector continues to be a very important contributor to global supplies of food fish, since 1970 there has been a reported threefold increase in the production and economic value of industrial-scale and intensively reared marine and brackish, or “mariculture,” species (FAO 2009a), a trend that appears to be holding (FAO 2014). These species fetch a high price in international markets, but the effects of their rearing practices can be detrimental to the health of coastal ecosystems and their people (Trujillo 2007), and to fisheries as well (Goldburg 2008; Naylor et al. 1998, 2000; Pullin et al. 1992; Primavera 2006).

As part of its goal of improving understanding of the impact of fisheries on the world’s marine ecosystems (Pauly 2007), the *Sea Around Us* supported research intended to improve understanding of global mariculture sector

trends, linkages and processes, and their relationship to global fisheries, to people, and to the environment through time. This work led to a spatially and taxonomically disaggregated database of mariculture production from 1950 to 2010, an index of mariculture sustainability, and scenario-based simulations exploring how sustainable mariculture development policies might affect the long-term health and well-being of people and their environment vis-à-vis meeting the future demand for food fish in 2030. The following highlights parts of this work (see also Campbell and Pauly 2013).

GLOBAL ANALYSIS OF MARICULTURE PRODUCTION TRENDS SINCE 1950

In 1950, the Food and Agriculture Organization of the United Nations (FAO) began to disseminate annual worldwide statistics that, until 1985, combined fisheries landings with aquaculture production. Although many countries now publish their aquaculture production statistics online, the FAO remains the primary source of global aquaculture statistics and analyses. However, the growing interest in and need for reliable and increasingly de-

tailed aquaculture statistics has highlighted the fact that global information systems for aquaculture lag behind systems for agriculture (FAO 2008b) and hinder understanding of aquaculture's role and status throughout the regions of the world.

To address some of these issues, a global database of marine and brackish aquaculture (or mariculture) production was constructed, using a bottom-up method and a detailed taxonomic and spatial resolution, as a mean of independently validating and further refining the existing FAO Global Aquaculture Production Database (FAO 2009a). This sub-national-level Global Mariculture Database (GMD) covers the years 1950 to 2010 and was used to reanalyze reported trends in mariculture production and highlight ongoing issues chronic to the collection and interpretation of global aquaculture datasets.

ASSESSING THE ACCURACY OF GLOBAL MARICULTURE PRODUCTION DATA

To assess the accuracy of currently reported global mariculture production trends, the provincial-scale GMD data compiled by the

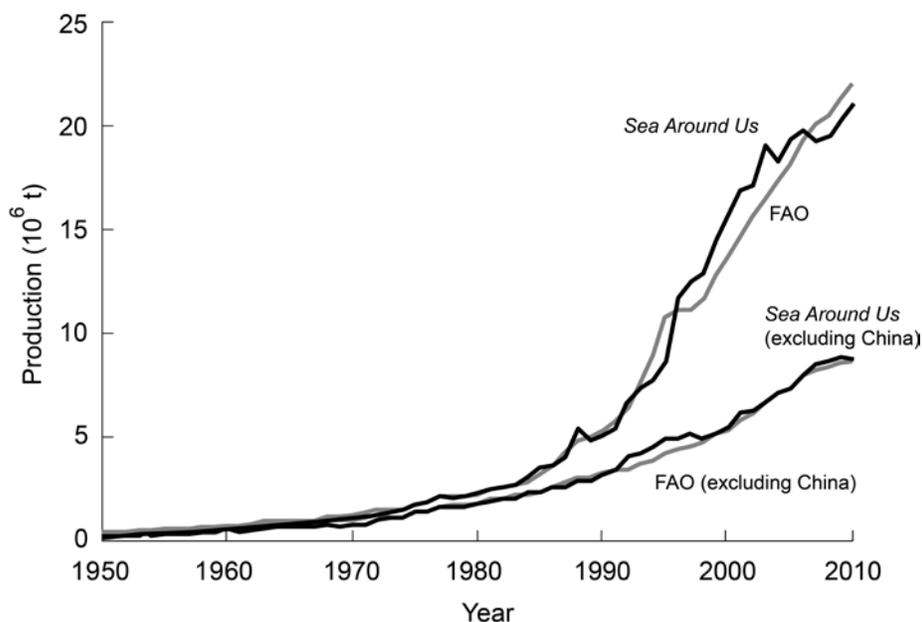


Figure 12.1. Comparison of global mariculture dataset trends between the FAO and the *Sea Around Us* GMD datasets, with and without China. Log-linear regressions of both datasets for the years 1970–2010 yielded R^2 values of 0.993 with China and 0.990 without China, indicating a strong match between datasets. The similarity in slopes during this same time period suggests a mean global rate of production increase of 7.7% per year with China and 5.5% per year without China. (Adapted from Campbell and Pauly 2013.)

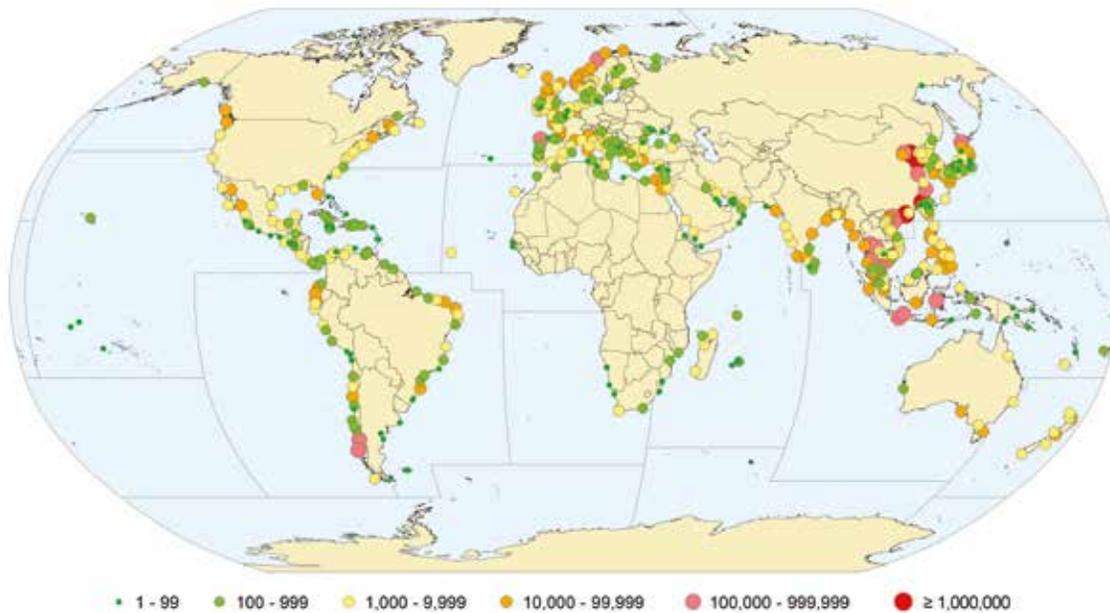


Figure 12.2. Average annual global mariculture production (t; all species combined) for 2000 to 2010, by coastal “province” (see text). (Adapted from Campbell and Pauly 2013.)

Sea Around Us were aggregated nationally and then globally. The resulting trend was then compared with the equivalent FAO FishStat Plus (v. 2.31) Global Aquaculture Production Database trend (FAO 2012a), whose content for 1950–1984 was derived by FAO through a post hoc disaggregation of their combined fisheries and aquaculture database, a necessary step, albeit fraught with uncertainties. Both datasets indicate a tripling in production between 1950 and 1970, as well as an overall similarity in total annual global production growth from 1970 to 2010 (i.e., just under three quarters of the compared annual production in these years is similar to within 10%). The similarity between the datasets increases to 80% when China is excluded from the analysis (figure 12.1).

The general resemblance between the datasets applies to all regions of the world except Africa, whose mariculture production continues to be negligible (see FAO 2014). The largest discrepancies between global datasets were found in the data-poor era before 1970, more than a decade before the establishment of FAO’s aquaculture data repository (FAO 2009a). In these years, the *Sea Around Us* GMD provides the more conservative production estimate.

Note that we cannot rule out that the similarity between the FAO-reported mariculture statistic and the database presented here is due (at least in part) to the same bias (e.g., due to overreporting of provincial mariculture production from China). This possibility was hinted at in a previous issue of *State of the World’s Fisheries and Aquaculture* (SOFIA; FAO 2012b), but although overreporting of fisheries catches was alluded to, the potential overreporting of mariculture production was not touched on in the last SOFIA (FAO 2014). Thus, whether or not China’s mariculture data suffer from the same overreporting problems previously identified for China’s wild capture fisheries (Watson and Pauly 2001) remains to be determined.

GEOGRAPHY OF GLOBAL MARICULTURE

The mariculture data in the *Sea Around Us* GMD were attributed to more than 600 different “provinces” (i.e., subnational entities) in 112 coastal countries and territories between 1950 and 2004, with an additional half-dozen countries initiating commercial production between 2005 and 2010 (figure 12.2). By comparison, the FAO distributes this historical production across a total of 21 large FAO areas (FAO 2012a).

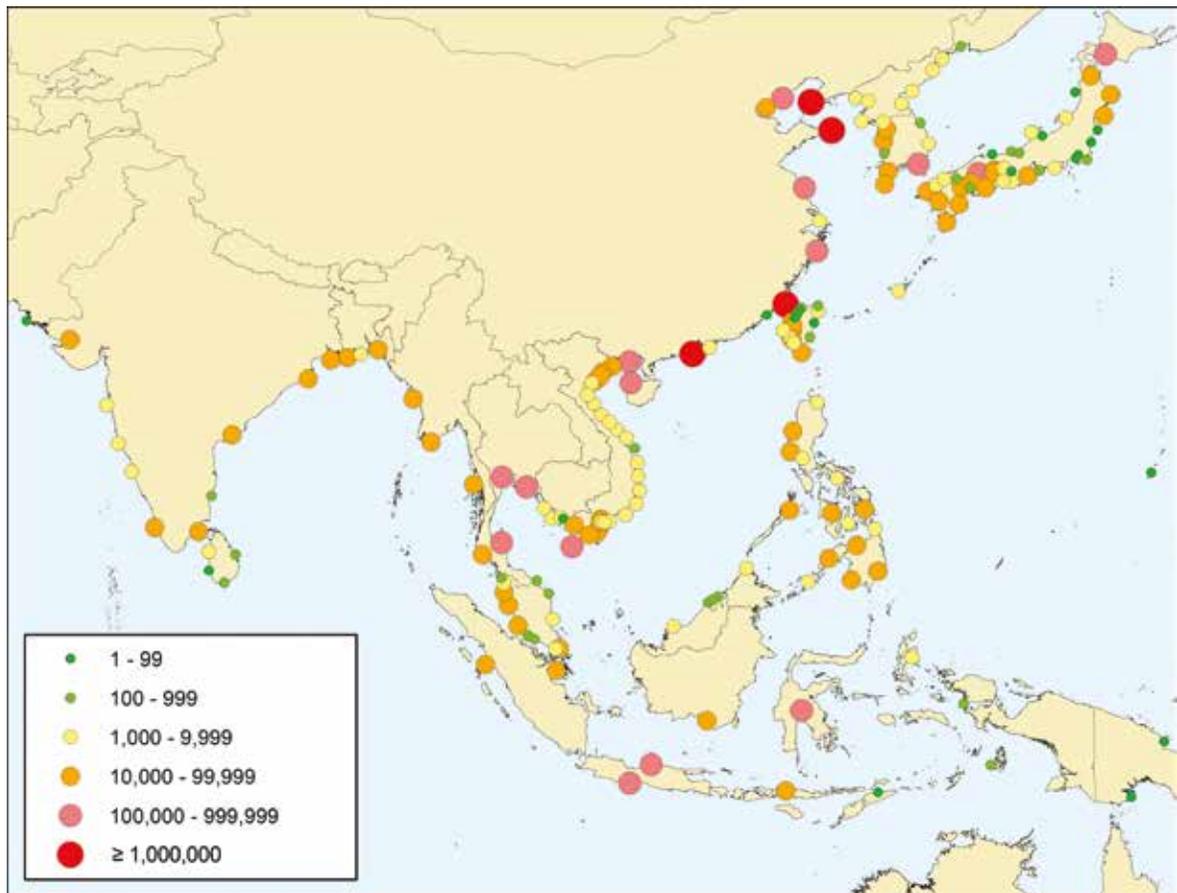


Figure 12.3. Average annual mariculture production (t; all species combined) in Asia for 2000 to 2010. Asia west of Pakistan is not shown here, because its mariculture production is negligible. (Adapted from Campbell and Pauly 2013.)

Figure 12.3 illustrates the average annual coastal mariculture production in Asia, distributed by province, between 2000 and 2010. Asia, both including and excluding China, has consistently produced the largest quantity of farmed marine and brackish species worldwide since 1950. Since 2000, China’s top four mariculture-producing coastal provinces (Liaoning, Shandong, Fujian, and Guangdong) each produced more than any other maritime country, an annual average of more than 1 million t. Since 1980, three of these provinces experienced reported production increases of 1.5 to 3 million t, primarily bivalves such as Pacific cup oyster (*Crassostrea gigas*) and Manila clam (*Ruditapes philippinarum*). Note that although finfish and crustacean production is substantial in Asia, regional mariculture production is consistently dominated by bivalves.

FARMING UP THE MARINE FOOD WEB CONFIRMED

As the total number of farmed taxa has increased over time, so has the (production weighted) mean trophic level (TL) of the species produced (figure 12.4). Put differently, greater quantities of predator species are being farmed around the world. This phenomenon, previously observed in studies of FAO data that analyzed total global aquaculture (Pauly et al. 2001), as well as mariculture production in the Mediterranean (Stergiou et al. 2008; Tsirlikas et al. 2014), has been described as “farming up the food web” (Tacon et al. 2010). Farming up the food web is also apparent regionally (figure 12.4B). However, a decline in the mean TL of mariculture production occurred between 1980 and 2010 in Brazil, Denmark, Finland, Germany, Hong Kong, Nigeria, Norway, Peru, Singapore, and the United Kingdom; that is,

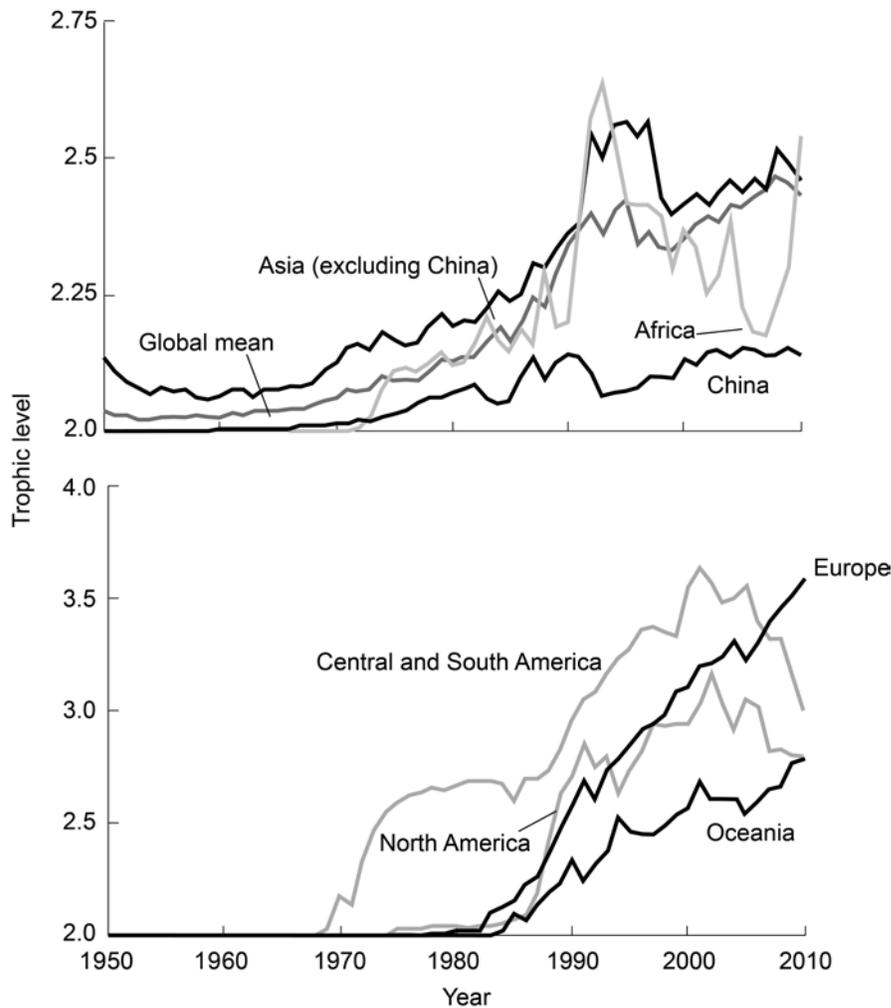


Figure 12.4. Change in the weighted mean trophic level (TL) of mariculture production in the GMD, demonstrating farming up the food web. (A) Change in the world on average and in regions where the weighted mean TL is stable or has decreased since the 1990s. (B) Change in regions with a marked increase in weighted mean TL since 1990. (Adapted from Campbell and Pauly 2013.)

these countries are currently producing greater quantities of lower-TL (herbivorous and omnivorous) species than they were in 1980. In contrast, China’s weighted mean TL, with the majority of its production attributable to bivalves with a TL of 2.0, has remained stable since the mid-1980s. The large quantity of low-TL bivalves, brackish finfish, and crustaceans produced in China, and in Asia more broadly, are responsible for the low overall weighted mean global TL for mariculture.

GLOBAL ANALYSIS OF THE SUSTAINABILITY OF MARICULTURE

Currently, there are a number of codes of conduct and protocols for improving the sus-

tainability of aquaculture (see the Aquaculture Stewardship Council at www.asc-aqua.org). Implementation of some of these codes is under way in a number of countries, with differing levels of commitment, especially in the developing world. However, given the growing consumer awareness of the long-term benefits of sustainable production (Costa-Pierce 2002), it might be useful to present here a set of explicit criteria that would allow consumers to determine whether the mariculture sector operates in a sustainable manner.

The *Sea Around Us* assessed the sustainability of mariculture in sixty-four major countries that involved eighty-six farmed finfish, crustacean, mollusc, and seaweed species and was

Table 12.1. Global summary statistics for the 13 indicators of mariculture sustainability (Trujillo 2008).

Indicator	Average	Standard deviation	Minimum	Maximum
Native/introduced	7.3	3.63	1	10
Export levels	4.5	1.87	1	10
Fishmeal use	5.2	3.62	1	10
Stocking intensity	4.8	2.63	1	10
Nutrition	7.6	2.46	2	10
Hatchery use	5.0	1.84	1	10
Antibiotic use	5.2	3.40	1	10
Habitat modification	5.0	2.04	1	10
Genetically modified organism use	6.4	1.78	2	10
Code of conduct compliance	5.2	1.44	1	9
Traceability	5.5	1.87	1	10
Employment	5.4	1.26	3	8
Waste management	5.4	3.08	1	10

performed based on thirteen indicators of performance covering ecological, economic, and social aspects of the industry (Trujillo 2007, 2008). This suite of indicators and the criteria that informed them were developed and adapted from peer-reviewed and industry literature and are roughly similar to the indicators and criteria developed by Volpe et al. (2010) for the twenty-two countries covered by the Global Aquaculture Sustainability Index. A single Mariculture Sustainability Index (MSI) was then derived by combining thirteen indicators, weighted by production to analyze differences between countries and species. An MSI score ranges between 1 and 10; a score of less than 6 is considered “unsustainable,” between 6 and 8 is “approaching sustainability,” and greater than 8 is “sustainable.” For further detail on the scoring method and on the indicators and data sources used in the development of the assessment framework, see Trujillo (2007, 2008; Alder et al. 2010).

USING THE MSI TO ASSESS COUNTRIES' PERFORMANCE

Of the 64 countries assessed and the 361 country–species combinations generated, the lowest calculated weighted (by production) MSI score was 1.7. This was for whiteleg shrimp (*Litopenaeus vannamei*) farmed in Thailand, and

the highest calculated weighted MSI score was 8.4, for seaweed farmed in Chile. Thirteen country–species combinations were greater than or equal to an MSI of 8 (sustainable), 112 cases were between 6 and 8 (approaching sustainability), and 236 cases were less than or equal to 6 (not sustainable). The average score for each indicator was between 4.5 and 7.6 (table 12.1).

Based on the weighted MSI and combined ecological and socioeconomic indicators, the ten highest-scoring countries (i.e., those with the most sustainable mariculture industries) were Germany, the Netherlands, Spain, Japan, Russian Federation, North Korea, South Korea, Ireland, France, and Argentina (table 12.2). Six of these top ten countries are developed and European, and three of the remaining countries are considered to be economies in transition.

There is no consistency between countries scoring high for the ecological indicators and countries scoring high for socioeconomic indicators. This is illustrated by Iceland, which was ranked thirteenth, with an MSI of 6.2 overall, but ranked twenty-second for its ecological score (5.4) and second for its socioeconomic score (7.1). The ten lowest-scoring countries (i.e., the least sustainable overall) were Guatemala, Cambodia, Bangladesh, Honduras,

Table 12.2. Rankings and mean weighted MSI scores of the top and bottom 10 countries, with ecological and socioeconomic scores by country; 10 indicates high sustainability and 1 indicates low sustainability of mariculture (Trujillo 2008).

Country	Rank			Score		
	Ecological	Socioeconomic	MSI	Ecological	Socioeconomic	MSI
Germany	1	1	1	9.0	7.1	8.0
Netherlands	2	2	2	9.0	7.1	8.0
Spain	3	3	3	8.7	7.1	7.9
Japan	5	6	4	7.5	6.5	7.0
Russian Federation	4	27	5	8.4	5.4	6.9
Korea, North	6	8	6	7.4	6.4	6.9
Korea, South	10	9	7	7.1	6.4	6.8
Ireland	7	12	8	7.4	6.1	6.8
France	14	5	9	6.4	7.0	6.7
Argentina	8	17	10	7.4	5.9	6.6
India	54	39	50	2.8	5.0	3.9
Faeroe Islands	40	56	51	4.5	3.0	3.8
Brazil	57	46	52	2.5	4.8	3.7
Norway	50	53	53	3.5	3.7	3.6
Chile	53	51	54	2.9	4.1	3.5
Belize	56	52	55	2.7	3.8	3.3
Myanmar	55	54	56	2.8	3.7	3.2
Honduras	52	57	57	3.2	3.0	3.1
Bangladesh	58	58	58	2.3	2.7	2.5
Cambodia	59	59	59	2.3	2.7	2.5
Guatemala	60	60	60	2.3	2.7	2.5

Myanmar, Belize, Chile, Norway, Brazil, and Faeroe Islands. Eight of the ten countries are developing and spread across Latin America and Asia. Most of these countries scored low for both ecological and socioeconomic indicators.

A principal component analysis undertaken after development of the indicators (Trujillo 2007) suggests that the indicators are a valid measure of overall sustainability in the mariculture industry, and the indicators selected in this analysis are capable of differentiating between high- and low-sustainability practices.

Countries that ranked high for overall mariculture sustainability are primarily from the developed world. In Europe, this high overall ranking is in part a reflection of consumer demand for sustainable seafood products and their desire for products free of contamination

(Beardmore and Porte 2003; Volpe et al. 2010). In Japan and Korea, high scores reflect both a demand for high-quality seafood products (Bridger and Costa-Pierce 2002) and the production of substantial quantities of molluscs and plants. Most of the countries that scored high on the six ecological indicators did so because of their limited use of introduced species and fishmeal and their adequate treatment of waste and water. These countries also farm a high proportion of bivalves relative to their total production.

Mariculture in the lowest-ranking countries may not be sustainable; much of the production consists of semi-intensive to intensive production of crustaceans, in particular prawns, or carnivorous finfish, notably Atlantic salmon (*Salmo salar*). Production of these species relies heavily on the use of aquafeeds,

which are rich in fishmeal and fish oil. Low scores for stocking density and insufficient waste treatment were also common among the lowest-scoring countries. Low ecological indicator scores suggest a higher risk of negative impacts to surrounding habitat, especially when these farms are open system cultures. The five lowest-scoring countries for socioeconomic indicators (i.e., Myanmar, Honduras, Bangladesh, Cambodia, and Guatemala) are all developing countries that intensively farm penaeid shrimps. Other low-scoring developed countries are European and produce large quantities of Atlantic salmon. The species-country combinations used in this assessment represent more than 95% of global mariculture production and thus represent the industry as a whole. Overall, most mariculture operations are not sustainable using current practices, in both developed and developing countries alike. Many policy makers promote the expansion of aquaculture for improving the economies of developing countries, including the creation of employment opportunities. However, this analysis suggests that this may not be a sustainable strategy because of the externalization of environmental costs. The future of the industry in developing countries in the short term (next 2 to 3 decades) will be a trade-off between short-term socioeconomic development and sustaining ecosystems. Overall, we hope with Pullin et al. (2007) “that use of broad biological, ecological and intersectional indicators will contribute to progress towards the sustainability of aquaculture.”

MARICULTURE DEVELOPMENT SCENARIOS FOR THE NEXT DECADES

Aquaculture, particularly the mariculture subsector, is a growing contributor to global fish supply (FAO 2009a). This trend is anticipated to continue in the future as fish demand increases (FAO 2008c, 2010). This potential increase in global mariculture production has led to concerns about the sustainability of the sector (Pullin et al. 1992; Naylor et al. 1998, 2000; Naylor and Burke 2005; Pauly et

al. 2002; Delgado et al. 2003; Primavera 2006; Goldburg 2008; Liu and Sumaila 2010). However, few forecasts and scenario exercises exist that explicitly examine the future of global aquaculture (Delgado et al. 2003; Brugère and Ridler 2004).

The UN Global Environmental Outlook (GEO) “story and simulation” scenarios assessment method is a departure from more traditional predictive models, which contain almost exclusively quantitative and price-mediated drivers of change. This is accomplished by providing both quantitative and replicable assessments of possible futures as well as a range of well-reasoned qualitative storylines (UNEP 2002; Ghosh 2007; Peterson et al. 2003; Pauly et al. 2003; Raskin 2005). The most comprehensive UN report on the environment and development to date, the GEO-4 “environment for development” assessment is primarily a capacity-building process (UNEP 2007). Its four overarching global development themes—*Markets First*, *Policy First*, *Security First*, and *Sustainability First*—and their underlying drivers, uncertainties, and critical assumptions were conceptualized and developed through a comprehensive process (UNEP 2007).

Key sources used in the construction of mariculture scenario storylines include the International Food Policy Research Institute’s *Fish to 2020* (Delgado et al. 2003), *Global Aquaculture Outlook in the Next Decades* (Brugère and Ridler 2004), *State of World Aquaculture 2006* (FAO 2006), and *The State of World Fisheries and Aquaculture* (FAO 2010). Through qualitative narrative storylines and quantitative simulations of potential future production, the underlying purpose was to explore how the future of the global mariculture industry might unfold along four different possible development pathways to 2030. The analysis then relates the changes brought about by this development to the broader global seafood market.

- In the *Markets First* scenario, with a focus on the sustainability of markets rather than human–environment systems, the priority in commercial fisheries is maximizing profits.

- In the *Policy First* scenario, with a focus on the social and economic dimensions of development, the priority in fisheries is to find a balance between increasing profits, total catch, and jobs.
- In *Security First* total catch is emphasized.
- In *Sustainability First* the focus in fisheries is on ecosystem restoration.

However, emphasis is also given to increasing jobs and landings.

For further information on the GEO-4 scenarios work, refer to UNEP (2007). For the detailed mariculture scenarios, outcomes, and analysis, refer to Campbell (2010).

Markets First

In a *Markets First* world in 2030, key private sector actors, with active government support, are focused on improving the well-being of people and the environment through maximized economic growth and efficiency in the mariculture sector (UNEP 2007). This emphasis on economic drivers of sustainable development has led to an increased liberalization, strengthening, expansion, and creation of international and regional trade agreements, particularly within Asia but also between Asia and the rest of the world (UNEP 2007).

By 2030, the growing Indian and Chinese middle classes are a driving force behind increases in both total and per capita global demand for diversified and high-value marine seafood (Delgado et al. 2003; FAO 2009b). The widespread removal of trade barriers and technological constraints to increased production increases overall mariculture production more than the other global development scenarios. However, the overarching social priority of this scenario is to sustain profit rather than to sustain and improve the availability and accessibility of seafood for people (UNEP 2007). Therefore, seafood markets remain dictated by traditional supply and demand economics with few government controls (UNEP 2007), and the bulk of economic and social benefits derived from production still flows predominantly from poorer to richer

countries and private entities (Kent 1997; Delgado et al. 2003).

Policy First

Under a *Policy First* scenario in 2030, government institutions worldwide, with active private and civil support, make efforts to resolve many of the issues facing humanity and the environment through top-down, policy-based reforms (UNEP 2007). Although economic growth remains a focal point for global mariculture development, it is acknowledged that such growth cannot be sustained without a stronger consideration of the negative social and environmental impacts that can accompany development. However, in practice most reform initiatives focus first and foremost on social considerations such as jobs and total production (UNEP 2007).

Policy reforms for mariculture are led by national governments and international institutions, including the FAO. These lead to improved resource sharing, a better alignment between social and political institutions, and greater political cohesion with international agreements such as the *Code of Conduct for Responsible Fishing* of the FAO. However, the slow pace of institutional reform and the inflexibility of a more centralized approach to implementing change mean that few major reforms to the mariculture industry are widely implemented by 2030 (Lake 1994; UNEP 2007).

Security First

In a world where security comes first, the benefits of mariculture production and development are available only to a privileged few (UNEP 2007). By 2030, to better control and monitor the movement of people, goods, and services within and across their respective borders, governments around the world, with support from powerful private actors, have implemented stronger restrictions on migration and trade.

The internal security focus of many government policies has led to a reduction in international cooperation and trade by 2030. Both Official Development Assistance for aquaculture extension activities and interna-

tional trade in seafood are reduced, and what remains is strongly dependent on the interests of powerful governments, multinational corporations, and other powerful private interests (UNEP 2007). There is a growing distrust in the role and effectiveness of the United Nations and its specialized organizations such as the FAO, and these institutions are increasingly marginalized. The World Trade Organization becomes a leverage tool to gain more political and economic control (Smith 2006; Lynn 2010). As has occurred in capture fisheries (Alder and Watson 2007), countries unable to gain sufficient political and economic autonomy are strong-armed into expanding and intensifying mariculture production for export to economically developed foreign countries. The revenue from exported sales is brokered by, and primarily returned to, governments and private actors; poor and rural communities are marginalized.

Sustainability First

In a *Sustainability First* world in 2030, all government, private, and civil sector actors across all institutional levels are following

through on their individual and collaborative commitments to address the most pressing social and environmental sustainability issues (UNEP 2007). In response to a growing social movement over the past 20 years that advocates for a more equitable treatment of social, economic, and environmental issues in development policies, both national and international institutions have collaboratively begun to rework their institutional and trade governance mandates to incorporate more than drivers of economic growth and efficiency (UNEP 2007). Globally, increases in jobs and total production are socially valued in the fisheries and aquaculture sectors, but only if the underlying marine ecosystem is maintained or restored (UNEP 2007). This new approach to governance increases the global focus on ecosystem restoration, includes a stronger emphasis on decision-making inputs from the private sector and civil society, and results in significant improvements to general cooperation and compliance in resource use issues worldwide (UNEP 2007).

Among wealthier major seafood consumers in the United States, Canada, and

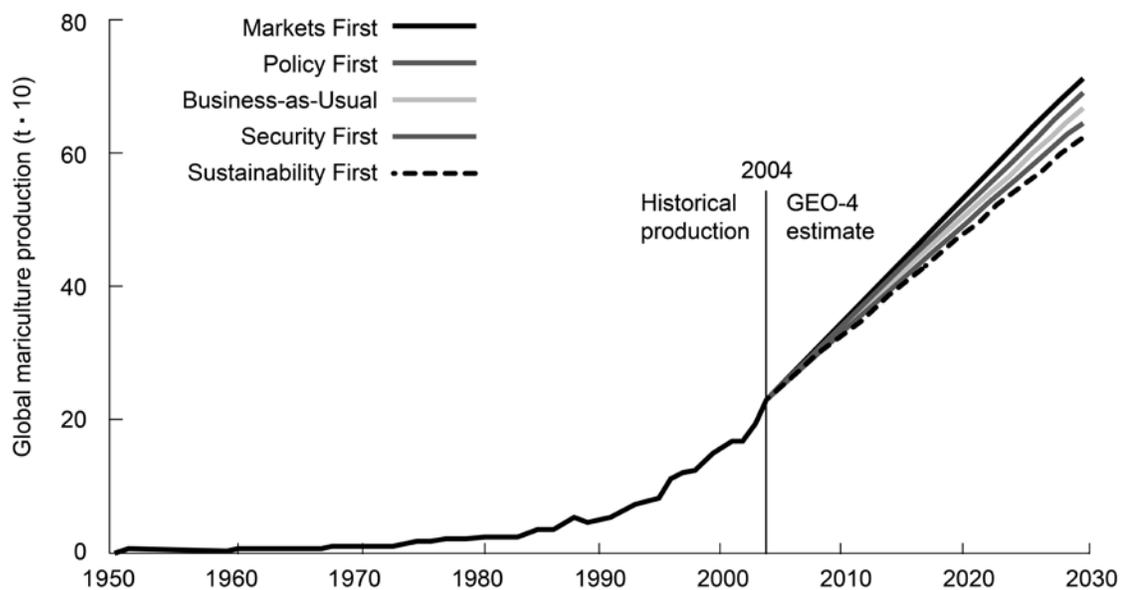


Figure 12.5. Extrapolation of global mariculture production trends, based on historical trends. Represented is a business-as-usual scenario, with all rate-changing factors held constant from 2004 forward, and the four GEO-4 scenarios, with production growth varying by increment rules described in Campbell (2010). Note that the extrapolation from the 2004 baseline (linear rather than exponential, to avoid absurdly high estimates) “predicts” the most recent estimate (FAO 2014), that is, a production of 40 million t in 2012 suggested by the *Market First* scenario. (Adapted from Campbell and Pauly 2013.)

the EU, there is an increasing growth and diversification in the demand for more responsible, ecologically sustainable, and ethically produced seafood products. This is a trend carried over and strengthened from previous decades (Lebel et al. 2002; Jansen and Vellema 2004).

PROJECTED MARICULTURE PRODUCTION UNDER DIFFERENT SCENARIOS

As a complement to the qualitative narrative storylines of possible production and sector futures, quantitative simulations of potential future production were generated to 2030, using past trends in mariculture production extrapolated forward (figure 12.5). As with other quantitative models developed in the GEO-4 assessment, this analysis uses historical time series data standardized to a common base year of 2000 (UNEP 2007).

If business-as-usual (BAU) rates of mariculture production continue onward from the 2004 baseline year (holding all else constant), by 2030 the quantity of farmed marine and brackish products worldwide could reach 67 million t, of which China might contribute nearly 70%. When this is compared with production simulations under the lowest growth rate scenario (*Sustainability First*) and the highest growth rate scenario (*Markets First*), the total difference in global mariculture tonnage is ± 4.3 million t from the BAU baseline in 2030, with China contributing slightly less in the lowest-growth scenario. This implies an average increase in production of more than 1.5 million t per year.

When this simulated estimate of BAU mariculture production is combined with an estimate of freshwater aquaculture production that is based on total production proportions reported by the FAO between 2004 and 2006, total annual global aquaculture production from all production environments could be 172 million t of food fish by 2030. When total global aquaculture production estimates are then combined with the GEO-4 simulations of future marine fisheries landings (UNEP 2007), total simulated global fisheries and

aquaculture production in 2030 range between 281 million t/year under the *Sustainability First* scenario and 317 million t/year of seafood under *Markets First*. These values seem exceedingly large.

CONCLUSIONS

As in the original GEO-4 assessment (UNEP 2007), a number of overarching policy messages can be summarized from the exploratory scenario outcomes. Notably, even under the overarching thematic influence of “environment for development,” all but one of the development scenarios (*Sustainability First*) continue to prioritize a worldwide expansion, production increase, and intensification of high-value, high-environmental input, carnivorous marine finfish and crustacean species. Although market-driven choices are likely to increase total global mariculture production over the next two decades (as well as profits and some jobs), longer-term production growth may ultimately decrease in countries around the world because of rising environmental constraints. With many of the most serious negative ecological and social effects likely to be experienced by developing countries, the perceived benefits of market-driven pathways of action risk benefiting only a privileged few people.

However, if the global human population surpasses a projected 8.3 billion people by 2030 (UN 2009), an increase in the pressure on the world’s marine resources under any scenario is inevitable. Furthermore, a *Sustainability First* approach to mariculture development does not overcome global inequities in the distribution of production and profit (UNEP 2007), nor will it eliminate the demand for high-value carnivorous species for consumption. Although a *Sustainability First* future may increase the total global production of higher-MSI bivalves (in the place of higher-trophic-level taxa with a lower MSI) and contribute to an increase in total global seafood tonnage, the actual availability of meat for consumption could be dramatically reduced because bivalve pro-

duction is typically reported in shell weight (Ye 1999; Wijkstrom 2003). In addition, the lower comparative economic value of bivalves to finfish and crustaceans could mean that the overall profits derived from mariculture may decline in some countries even though production is increasing. Ultimately, this simulated variation highlights the uncertainty in dealing with the future, as well as the range of effects that individual and

collective decisions can have on future global mariculture development.

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NOTE

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