Animal Frontiers
www.animalfrontiers.org

doi: 10.2527/af.2013-0005
Animal Frontiers **January 2013** vol. 3 no. 1 **28-34**

Fish, feeds, and food security

James F Muir

Author Affiliations

Correspondence: j.f.muir@stir.ac.uk

Implications

- Fish or aquatic foods are an important but often little recognized element in food security and nutrition, and fish supply will have to be expanded significantly if future population needs are to be met.
- Prices will probably rise with increasing demand, and there are concerns that fish can be accessible and affordable to poorer and more vulnerable people, particularly those who are highly dependent on fish for nutrition or income.
- Capture fisheries are under increasing pressure from overfishing, climate change, and other impacts, and future supply increases will have to come from aquaculture, which may have to double or triple in output.
- This is potentially feasible with available land and water resources, but dependence on fish-based feeds, a significant feature of the recent growth of aquaculture, will have to be reduced substantially, using species feeding lower in the aquatic food chain, and more terrestrially derived feeds for more demanding species.
- With a diverse range of species, and a well placed selection of systems and production approaches, access to lower cost aquatic foods also has the potential to be sustained and expanded.

Key words:

aquaculture **fish consumption** **fisheries** **fishmeal** **food security**

Introduction

Food security can be based on food or grain self-sufficiency, as in China, where a 95% grain self-sufficiency level has recently been adopted as a strategic goal for agricultural output (Ye et al., 2012). More broadly however, as defined by the 1996 World Food Summit, food security is a "situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and preferences for an active and healthy life." Various indicators have since been used to quantify global food security, its overall status, and its regional discrepancies (Schmidhuber and Tubiello 2007). With a primary policy focus on access to food calories, fish or aquatic foods have been relatively under-recognized in their contribution to global food supply and food security (FAO, 2012a). However, in 2009, fish accounted for 16.6% of the world's intake of animal protein and 6.5% of all protein consumed, providing around 4.3 billion people with about 15% of their animal protein. With growing recognition of the need to define global targets of food sufficiency and security by nutritional quality (Shetty, 2009, FAO, 2012a), particularly in maternity and early life stages, the role of fish is becoming much more clearly appreciated.

The story of fish and food security is complex. There are more than 29,000 aquatic species, and more than 1,500 recorded species are caught globally, in inland, coastal, and marine waters (Figure 1). Traditionally supplies have been based on capture fisheries, subject to substantial temporal and spatial variation, and increasingly burdened by overfishing, often in areas where dependence on fish for food and livelihoods is at its greatest (FAO/SFLP, 2008). Aquaculture is now estimated to produce more than 600 food fish and algal species in more than 190 countries (FAO, 2012a, 2012b), and is increasingly assuming a dominant role in supply. In 2010, capture fisheries and aquaculture supplied about 148 million tonnes of fish, valued at $217.5 billion, of which about 128 million tonnes was directly consumed. Initial data for 2011 suggest an increase to 154 million tonnes, with direct use of 131 million tonnes (FAO, 2012a, 2012b). Supplies have grown at an average of 3.2% annually over 1961–2009, exceeding the world's 1.7% annual population growth. The sector also provides important employment and purchasing power, offering direct livelihoods and income for some 54.8 million people in 2010, 16.6 million of whom were in aquaculture. Employment in fisheries has grown faster than that in agriculture, reaching some 4.2% of the 1.3 billion people economically active in global agriculture by 2010, from 2.7% in 1990. Employment in capture fisheries rose by 0.8% per year while that in aquaculture rose by 5.5% annually (FAO, 2012a).

View larger version:
In this page   In a new window

Figure 1.

A woman in South Korea considers her options at a local fish market. (source: flickr.com/hoks)

In the face of continued population growth, potentially negative impacts of climate change, and growing resource constraints, and with increasing concern about volatile food prices and the potential impacts of food access and security among poorer and more vulnerable communities, a number of recent reviews and strategic projections have been developed to explore growth and productivity options in the food sector (see e.g., Godfray et al., 2010; Foresight, 2011; Godfray, 2011; Tilman et al., 2011). While terrestrial production justifiably occupies an important role, the role fisheries play is also coming into view (see also Frid and Paramor, 2012). This paper highlights some of the emerging issues concerning the sector, its potential contributions to food security, and the routes by which these may be better established in coming decades.

Trends in Fish Consumption

Over the last half century, in human benefit terms, global fish consumption can be seen as a major success, average per capita food fish supply increasing from some 9.9 kg (live weight equivalent) in the 1960s to 18.4 kg in 2009. However there are distinct regional differences; the lowest consumption is in Africa (9.1 kg/capita; Figure 2), followed by 9.9 kg for Latin America and the Caribbean, 20.7 kg for Asia, 22.0 kg for Europe, 24.1 kg for North America, and 24.6 kg for Oceania (FAO, 2012a, 2012b). Although consumption has grown steadily in developing regions (5.2 kg in 1961 to 17.0 kg in 2009) and in low-income food-deficit countries (**LIFDC**; 4.9 kg in 1961 to 10.1 kg in 2009), levels are still considerably less than in more developed regions.

View larger version:
In this page   In a new window

Figure 2.

A local fish market in Libya, North Africa. Africa has the world's lowest per capita food fish supply at 9.1 kg/capita (source:

flickr.com/16675423@N07/).

These aggregate figures cover a very wide variation in consumption, influenced by location, tradition, household customs, fish access, trade connections, market power, and emerging consumption drivers such as urbanization, income distribution changes, and retail development. Here also, specific issues such as poverty and wider indices of vulnerability are important (FAO/SFLP, 2008), and access to fish, even in small quantities, can create significant benefits. However, unless bartered, available through social exchange, or unmarketed for quality or other reasons, the purchasing power of specific consumer groups is critical, and the price of fish, from whatever source, becomes an essential issue in whether today's consumption can translate into further or better opportunities in the future.

Though food-price mediated linkages between consumption, population, and income growth have been modeled for major crops and livestock commodities, the IFPRI Fish 2020 program was the first to incorporate fish consumption within wider food markets (Delgado et al., 2007). This provided regional projections for prices and consumption levels for broad product category groups across a number of scenarios for capture fish supply and aquaculture growth, and is currently being updated. A key feature, consistent with other food groups, is that prices will rise in real terms, and consumption will be strongly influenced by regional economic growth. The FAO Fish Price Index (Tveteras et al., 2012) showed that after falling 7% from 2008 to 2009, prices increased by 9% in 2010 and more than 12% in 2011 (FAO, 2012a, 2012b). It was proposed that prices for fished species increased more than those for farmed species due to higher fuel prices for vessels, but market impacts of aquaculture expansion may also have been important. More detailed price and supply projections become more difficult to define, and income distribution associated with economic growth will have significant effects on consumption opportunities. Though fish is generally found to have a positive consumption response to rising income, this varies strongly with income, emerging food preferences, and the influence of social and economic trends. Whether associated with concern for health, animal welfare, carbon, or other environmental footprint, there may be strong drivers toward higher fish consumption, particularly as economic growth moves to medium-income countries (see e.g., Foresight 2011)

Closely associated with global and regional patterns of consumption is the growing trade in aquatic products, already the most widely traded food group, with substantial flows from lower to higher income countries. World imports reached $111.8 billion in 2010, 12% greater than 2009 and 86% more than 2000, with a further 15% growth projected to 2011 (FAO, 2012a, 2012b) The EU is by far the largest single market, with imports reaching $44.6 billion in 2010, accounting for some 40% of total world imports. The US and Japan are the largest single country importers, depending on imports for some 60% and 54% of their consumption, respectively. China, the world's largest fish producer and exporter, is the third largest importer, partly due to strong growth in domestic demand, but also due to Chinese processors importing raw material from all major regions for re-processing and export. In 2010, developed countries accounted for 76% of the total import value, compared with 86% in 1990, reflecting the greater importing presence of a wider range of countries. However, developed countries accounted for only 58% of traded volume (live weight equivalent), due to the greater unit value of their imports. The overall pattern of wealthier countries importing greater value fish, and poorer countries retaining lower value species for domestic consumption looks set to continue, though lower and middle-income countries with large and growing populations are likely to exert increasing demand on low to mid value species if current consumption levels are to be sustained.

Contribution of Fish to Human Health and Food Security

The consequences for fish access are therefore critical, and if the future world of 9 billion people contains 2 to 3 billion people with inadequate or marginal incomes, their potential for gaining benefits from fish consumption will require close attention. The specific role of fish varies widely with the social and economic context, with culture and traditions, and with the changing access to supplies. Consumption can play a key role in access to proteins, minerals, and essential fatty acids, and can have a significant impact for maternal and early child health (see e.g., Kawarazuka and Béné, 2011). The role of small indigenous fish species, often given less prominence in fishery or aquaculture development, can also be very critical for poorer households (see e.g., Thilsted et al., 1997), and programs can be targeted with specific objectives such as reducing vitamin and mineral deficiencies (Roos et al., 2007). However, not all species are similar with respect to food value, and the processes of cooking and post-harvest treatment also have an impact. Intra-household distribution can also have an important bearing on nutritional impact of fish (Gomna and Rana, 2007), particularly for access by children. Nonetheless, the use of whole small fish in soups or stews, the sale of small portions of fish products in markets, or as street foods, all have important nutritional potential for poorer households.

Interactions between fishing and food security are also critical in many parts of the world, where small-scale and often seasonal fishing activity provides both income and household food supply, and there is common concern that over-zealous regulation and removal of fishing capacity may cause more negative social and nutritional impact than the resource efficiency gains being sought (Béné et al., 2010). However, though aquaculture might supplement or compensate for capture fisheries, Beveridge et al. (2010) note its constraints of meeting lowest income social objectives, as small- and medium-scale commercial producers and wealthier market/retail consumers are more likely to benefit. However, through market displacement, by producing smaller indigenous species in polycultures, and/or by providing occasional employment for cash or food, additional benefits may be provided for poorer groups.

There are also important consequences of trading fish for other food items, either locally or at the market economy level (Kurien, 2004). In favorable conditions this can create advantages for all parties, widening and expanding nutritional options for catchers/producers of fish while improving access to key foodstuffs. This is particularly valuable for peri-urban supplies and urban markets, though there may be issues of reduced local market access where higher urban prices drive out purchasing options. The development of infrastructure-road access, ice production, and market facilities may also accelerate the shift to urban markets. However, there are also specific challenges with meeting needs of poor urban dwellers (see e.g., Ruel et al., 2008), particularly where urbanization is rapid and is not accompanied by strong employment opportunities.

It is clear that expansion of fish supplies will be essential to meet future food needs. However, given that 80% of 523 world fish stocks for which assessment data are available are reported as fully or over-exploited, with continued problems of IUU (illegal, unregulated, and unreported) fishing (Agnew et al., 2009), major disruptions associated with climate change (Cheung et al., 2010), and abounding challenges of governance and management (Österblom et al., 2010, O'Leary et al., 2011), prospects for expanding or even retaining current output from capture fisheries are at best uncertain (see e.g., Garcia and Rosenberg, 2010). Though there are likely to be substantial levels of unrecorded output in inland fisheries, the prospects for further expansion are unlikely, with increasing demands for water for food supplies (Jägerskog and Jønch Clausen, 2012), urban and industrial use, and increasing functional disruption of aquatic habitats (Welcomme et al., 2010). The questionable issues of stock recovery apart (see Worm et al., 2009), or the limited enhancement of specific fisheries through restocking and habitat improvement (Lorenzen, 2008), the primary expectation is therefore that aquaculture (Figure 3) will contribute the bulk of future needs (STAQ, 2009, Muir et al., 2010, Bostock et al., 2010, Hall et al., 2011).

Figure 3.

Aquiculture research being done at Ohio State University's Agriculture Research and Development Center (source: OARDC).

View larger version:
In this page In a new window

Based on current human use levels of some 128 million tonnes, and dependent on income and food preference projections, total consumption levels of some 200 to 250 million tonnes could be foreseeable by 2050. Given that capture fisheries might not supply more than 70 million tonnes of food fish, aquaculture production would need to rise to some 130–180 million tonnes annually, two to three times the present output. In 2010, the top ten producing countries accounted for 87.6% by volume and 81.9% by value of global aquaculture output. Asia accounted for 89% of this (Table 1), led by China, with more than 60% of global output. Other major Asian producers are India, Viet Nam, Indonesia, Bangladesh (Figure 4), Thailand, Myanmar, the Philippines, and Japan. Much of the production is based on relatively simple pond-based production of carp and tilapia, together with coastal mollusc culture, neither system requiring substantial feeding input. Growth in output and value over the last decade has been relatively strong, and with the exception of Africa, value per unit output has also increased (FAO 2012a, 2012b). Outside Asia, key producer countries are Norway and Chile (Atlantic salmon), and Egypt (tilapia).

View this table:
In this window In a new window

Table 1.

Aquaculture production, value: 2000–2009.

View larger version:
In this page In a new window

Figure 4.

Top: Fish harvest ready for market in Bangladesh, a key fish producer in Asia. *Bottom*: Fresh fish are then sold in fish markets like this one in Khulna, a large city in Bangladesh (source: flickr.com/theworldfishcenter).

Feeding Future Fish Supplies

The primary issues for the expansion of aquaculture are where and how this might be done. Here the concept of sustainable intensification (Foresight, 2011) is likely to apply, in that yields from existing production locations and systems could be increased before significant extension would be required into new systems or zones. Closely related to this is the issue of feed requirements associated with increased yields (see e.g., Deutsch et al., 2007, Naylor et al., 2009), and whether or how these could be met.

To date aquaculture has been a major user of fish as food. From 1970 to 2006 the volume of fish for non-food use increased from 26.7 to 33.3 million tonnes, and aquaculture was estimated to use some 24 million tonnes of small pelagic forage species in 2006, much greater than the 4.25 million tonnes of global imports of small pelagic food fish for human consumption (Tacon and Metian, 2009). From only 10% of global fishmeal being used in aquaculture feeds in 1980, this had risen to 60% by 2008 with an average annual increase in fishmeal prices of 6 to 8% over 1992 to 2006.

However, while feed is widely considered to be a major constraint to further expansion, some 20 million tonnes of current aquaculture output, one-third of the total, is not fed. This includes oysters, mussels, clams, scallops and other bivalve species feeding on planktonic feeds, and fish such as silver and bighead carp feeding on plankton in fertilized ponds or water bodies, or using wastes and leftover feed materials of fed species grown in the same multispecies systems (FAO, 2012a, 2012b). However, the percentage of non-fed species in world production has declined from more than 50% in 1980, strongly influenced by intensification in Asia, with faster growth of production of fed species, and wider availability of formulated feeds.

In terms of fish input, Bostock et al. (2010) note that up to 25% of fish meal is now derived from fish processing waste, and ingredient substitution is also increasing the efficiency of fish meal and oil utilization. Compared with theoretical trophic level conversions of 10:1 in the wild (fish intake to fish output, FIFO), input/output ratios for salmon improved from 7.5 to 4.9, trout from 6.0 to 3.4, marine fish from 3.0 to 2.2, and shrimp from 1.9 to 1.4. Herbivorous and omnivorous finfish and some crustacean species show net gains in output, with ratios in 2006 of 0.2 for non-filter feeding Chinese carp and milkfish (Figure 5), 0.4 for tilapia, 0.5 for catfish, and 0.6 for freshwater crustaceans. Quoted FIFO values for the global aquaculture industry include 0.7 (Tacon and Metian 2008), 0.63 (Naylor et al. 2009), and 0.52 Jackson (2009).

View larger version:
In this page In a new window

Figure 5.

Milkfish hatchery in Hazipur, Bangladesh. (source: flickr.com/theworldfishcenter)

Based on lowest current FIFO values of 0.52, an additional 100 million tonnes of output would require more than 50 million tonnes of extra fish; more realistically the average FIFO for an expanded level of 160 million tonnes, using no more fish than at present, would need to fall to around 0.2. Much of the future direction in feed use for aquaculture will depend on future consumer preferences, with tradeoffs between cost of production based on lower cost species such as carp, tilapia, or catfish using mainly terrestrially derived feeds, and higher market and/or nutritional quality, with marine species using fish-based diets. With a distinct shift toward lower food-chain species and more terrestrial feed sources and the possible use of genetically modified technologies to enhance options for key nutrients (McAndrew and Napier, 2010), expanded production could be viable. Though sourcing terrestrial feeds would have to compete with other parts of the livestock sector, the quantities are not overwhelming, and the efficiency of feed used would make aquaculture an effective user of these raw materials.

Environmental Implications

The sustained delivery of greater quantities of aquatic foods has a number of environmental implications beyond those of feeds alone (Asche et al., 2008), chief of which would be that of water supplies (Verdegem and Bosma, 2009; Turral et al., 2011) and their quality and access. Greater integration of land and water use, and increased production in coastal margins, particularly in areas becoming more salinized due to hydrological changes and/or sea level rise, would all be important in widening options.

The environmental issues concerning the development of aquaculture have been widely discussed (e.g., Barbier, 2007; Naylor et al., 2009; Hall et al., 2011), and the extent of necessary tradeoffs for further expansion can be explored if not yet fully committed into policy and action. Key areas of strategic interaction concern large production zones, major ecosystem health issues (e.g., Buschmann et al., 2009), and the means by which ecosystem risks can be effectively identified and managed.

A wide range of issues concern the potential impacts of broader external change on the means by which fish production can be sustained, whether through fisheries or aquaculture. The impacts of climate change are of significant concern, and constitute the primary source of uncertainty about future production potential, as well as that for food security in general (Parry et al., 2005; FAO, 2008; Cochrane et al., 2009). A number of scenarios have already been developed to set out potential impacts (e.g., Allison et al., 2009, Cheung et al., 2010). In combining potential oceanic climate change impacts with food security related vulnerability, Table 2 identifies those countries most at risk (Huelsenbeck, 2012). Though not specifically addressed, such analyses can also be ranked in terms of potential numbers of people impacted.

View this table:
In this window In a new window

Table 2.

Countries most vulnerable to climate change and ocean acidification food security risk.

In practice, these interactions are yet to be fully understood or explored, and it is likely that some regions will become more favored for fisheries and aquaculture than before. Given adequate political will and with specific strategies for protecting and rebuilding fishery stocks, the potential resilience of these important ecosystems could be enhanced (Worm et al., 2009; California Environmental Associates, 2012; Pikitch et al., 2012) to complement expanded aquaculture output.

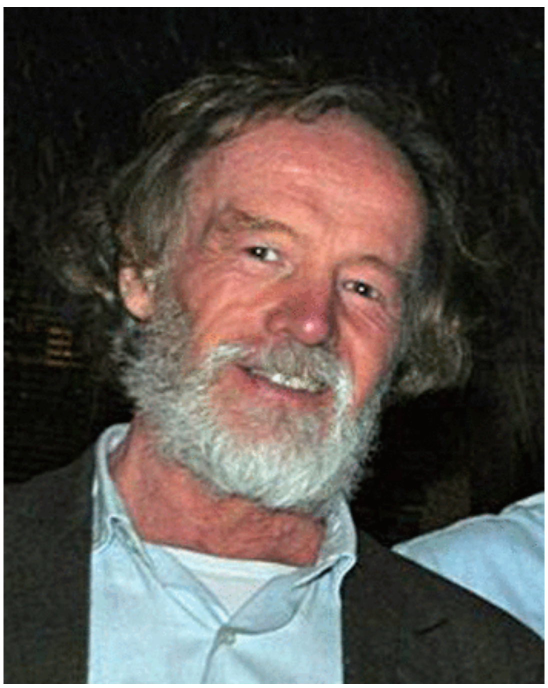
Conclusions and Future Directions

Within the overall context of global to community level food security, aquatic foods deserve much greater attention, due both to their importance in the overall mix of nutrition aims and outcomes, and to their critical dependence on ecosystem function, management, and interactions with other food system processes. It is feasible for fish supplies to be increased to meet forthcoming demands, whether to meet the needs of expected population growth, or to expand further to respond to demand arising from income growth and/or shifts in preference against other animal protein foods. Although climate change is likely to have notable impacts across the sector, and will create much greater variability in ecosystem conditions, productivity responses and social benefit, there is at least the adaptation potential for most of the definable processes and outcomes over the first half of this century.

In this respect, fisheries' stocks, substantially redistributed in many areas, are likely to have broadly similar levels of potential productivity, though some stocks may be lost, and ocean acidification will have critical impacts in some ecosystems. Inland fisheries' resources are also likely to be increasingly pressured, not just by hydrological shifts, but by human impacts of water extraction, soil erosion, and waste discharges (Welcomme et al., 2010). As noted in Foresight (2011), governance of aquatic natural resource systems will be an increasing challenge, and will need to be purposefully addressed. The consequent growth in aquaculture will demand extensive and increasing interactions with other resource systems. While not as important a driver of resource demand as many forms of biofuel, plant crop raw materials will assume a greater importance as aquaculture expands, and will be influenced in turn by climate-change-crop interactions (Tubiello et al., 2007)

While the issues of food security associated with aquatic foods can be set out, the future development of the sector and the greater focus on aquaculture will require specific attention in policy and practice to ensure that vulnerable groups are not further disadvantaged. To date there has been little direct involvement of the fishery sector in various food supply and hunger reduction commitments, nor in practical areas of nutrition delivery, though the opportunities and potential benefits could be significant. Also in this respect, a range of community based options linking aquatic foods with climate change adaptation and mitigation, and responsible resource management, could be valuable in widening opportunities for poorer households and societies to gain from better livelihoods and food access.

In discussing adaptation in marine fisheries, Perry et al. (2011) note that over the long term, adaptive changes in policy and fisheries governance can interact with social and ecological change toward new fisheries and economic diversification, and that robust governance approaches, maintaining the diversity of response capabilities on short and longer time scales, among both ecological and human fishing systems, should be a key policy objective. In a wider sense this concept applies equally to the more holistic challenges of linking future fish supplies, from whatever source and process, with resource systems, human and institutional capacities, through supply, value, and benefit chains toward positive and durable outcomes of food security.



James Muir is an international development and research advisor and evaluator specializing in aquatic systems and future strategies for resources, climate change, food and development. With a background in environmental engineering and economics, he is a Professor Emeritus in the University of Stirling, UK, and a recent member of the UK Foresight Lead Expert Group on the Global Future of Food and Farming. He has more than 30 years experience in academic, commercial and public sectors, including staff and advisory work with FAO, UK and other development agencies, and with international research and development bodies.

Literature CIted

Agnew D.J., J Pearce C., Pramod T., Peatman Watson R., 2009. Estimating the Worldwide Extent of Illegal Fishing. *PLoS ONE* **4**(2):E4570.

Search Google Scholar

Allison E.H., Perry A.L., Badjeck M.-C., Adger W.N., Brown K., Conway D., Halls A.S., Pilling G.M., Reynolds J.D., Andrew N.L., Dulvy N.K., 2009. Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fish.* **10**(2):173–196. **Search Google Scholar**

Asche F., Roll K., Tveteras S., 2008. Future trends in aquaculture: Productivity growth and increased production. Pages 271–292 in Agriculture in the Ecosystem. Holmer M., Black K., Duarte C.M., Marba N., Karakassis I., ed. Springer, Berlin. **Search Google Scholar**

Barbier E.B. 2007. Valuation of ecosystem services supporting aquatic and other landbased food systems. Pages 71–86 in Comparative assessment of the environmental costs of aquaculture and other food production sectors: Methods for meaningful comparisons. FAO/WFT Expert Workshop, 24–28 April 2006. FAO Fisheries Proceedings. Bartley D.M., Brugère C., Soto D., Gerber P., Harvey B., ed. Vancouver, Canada. **Search Google Scholar**

Béné C., Hersoug B., Allison E.H., 2010. Not by Rent Alone: Analysing the Pro-Poor Functions of Small-Scale Fisheries in Developing Countries. *Dev. Policy Rev.* **28**(3):325–358. **CrossRef**

Beveridge M., Phillips M., Dugan P., Brummett R., 2010. Barriers to aquaculture development as a pathway to poverty alleviation and food security: Policy coherence and the roles and responsibilities of development agencies. OECD Workshop, 12–16 April 2010, Paris, France. **Search Google Scholar**

Bostock J., McAndrew B., Richards R., Jauncey K., Telfer T., Lorenzen K., Little D., Ross L., Handisyde N., Gatward I, Corner R., 2010. Aquaculture: Global status and trends. *Phil. Trans. R. Soc.* **B 365**(1554):2897–2912. **Search Google Scholar**

Buschmann A.H., Cabello F., Young K., Carvajal J., Varela D.A., Henriquez L., 2009. Salmon aquaculture and coastal ecosystem health in Chile: Analysis of regulations, environmental impacts and bioremediation systems. *Ocean & Coastal Manage.* **52**(2009):243–249. **CrossRef**

California Environmental Associates. 2012. Charting a Course to Sustainable Fisheries

Cheung W.L., Lam V.W.Y., Sarmiento J.L., Kearney K., Watson R., Zeller D., Pauly D., 2010. Large scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Glob. Change Biol.* **16**:24–35. **CrossRef**

Cochrane K., De Young C., Soto D., Bahri T., ed. 2009. Climate change implications for fisheries and aquaculture: Overview of current scientific knowledge. Fisheries and Aquaculture Technical Paper No. 530. Rome, FAO. **Search Google Scholar**

Delgado C.L., Wada N., Rosegrant M.W., Meijer S., Ahmed M., 2007. Fish to 2020: Supply and Demand in Changing Global Markets. International Food Policy Research Institute, Washington, D.C., and WorldFish Center, Penang, Malaysia. **Search Google Scholar**

Deutsch L., Graslund S., Folke C., Troell M., Huitric M., Kautsky N., Lebeld L., 2007. Feeding aquaculture growth through globalization: Exploitation of marine ecosystems for fishmeal. *Glob. Environ. Change* **17**:238–249. **CrossRef**

FAO. 2008. Climate change and food security: A framework document. Food and Agricultural Organization of the United Nations, Rome.

FAO/SFLP. 2008. Achieving poverty reduction through responsible fisheries. Lessons from West and Central Africa. FAO Fisheries and Aquaculture Technical Paper 513. Westlund L., Holvoet K., Kébé M., eds. Food and Agricultural Organization of the United Nations, Rome.

FAO. 2012a. The State of World Fisheries and Aquaculture. Food and Agriculture Organization of the United Nations, Rome.

FAO. 2012b. The State of Food Insecurity in the World. Food and Agriculture Organization of the United Nations, Rome.

Foresight. The Government Office for Science. 2011. *The Future of Food and Farming*. Final Project Report, London.

Frid C.L.J., Paramor O.A.L., 2012. Feeding the world: What role for fisheries? *ICES J. Mar. Sci.* **69**:145–150 **Abstract/FREE Full Text**

Garcia S.M., Rosenberg A.A., 2010. Food security and marine capture fisheries: Characteristics, trends, drivers, and future perspectives. *Philos. Trans. R. Soc. B* **365**:2869–2880. **Abstract/FREE Full Text**

Godfray H.C.J. 2011. Food for thought. *Proc. Natl. Acad. Sci. U. S. A.* **108**(50):19845–19846. **FREE Full Text**

Godfray H.C.J., Beddington J.R., Crute I.R., Haddad L., Lawrence D., Muir J.F., Pretty J., Robinson S., Thomas S.M., Toulmin C., 2010. Food security: The challenge of feeding 9 billion people. *Sci. J.* **327**:812–818. **CrossRef**

Gomna A., Rana K., 2007. Inter-household and intra-household patterns of fish and meat consumption in fishing communities in two states in Nigeria. *Br. J. Nutr.* **97**(1):145–152. CrossRef Medline

Hall S.J., Delaporte A., Phillips M.J., Beveridge M., O'Keefe M., 2011. Blue Frontiers: Managing the Environmental Costs of Aquaculture. The WorldFish Center, Penang, Malaysia. Search Google Scholar

Jackson A., 2009. Fish in-fish out ratios explained. *Aquacult. Eur.* **34**:5–10 Search Google Scholar

Jägerskog A., Jønch Clausen T., eds. 2012. *Feeding a Thirsty World – Challenges and Opportunities for a Water and Food Secure Future*. Report Nr. 31. SIWI, Stockholm. Search Google Scholar

Huelsenbeck M. 2012. Ocean-Based Food Security Threatened in a High CO2 World: A Ranking of Nations' Vulnerability to Climate Change and Ocean Acidification. Briefing document. **http://www.Oceana.org**. Accessed October 16, 2012.

Kawarazuka N., Béné C., 2011. The potential role of small fish species in improving micronutrient deficiencies in developing countries: Building evidence. *Public Health Nutr.* **14**(11):1927–1938. CrossRef Medline

Kurien J. 2004. Fish trade for the people: Toward understanding the relationship between international fish trade and food security. Report of the study on the impact of international trade in fishery products on food security. Food and Agriculture Organization and Royal Norwegian Ministry of Foreign Affairs, Rome, Italy. Search Google Scholar

Lorenzen K. 2008. Understanding and managing enhancement fisheries systems. *Rev. Fish. Sci.* **16**:10–23. CrossRef

McAndrew B.J., Napier J., 2010. Application of genetics and genomics to aquaculture development: Current and future directions. *J. Agric. Sci.* **149**:143–151. Search Google Scholar

Muir J.F. Little D.C., Young J.A., Bostock J.C., 2010. Growing the wealth of aquaculture. Pages 39–107 in Advancing the Aquaculture Agenda: Workshop Proceedings. OECD Publishing, Paris, France. Search Google Scholar

Naylor R.L., Hardy R.W., Bureau D.P., Chiu A., Elliott M., Farrell A.P., Forster I., Gatlin D.M., Goldburg R.J., Hua K., Nichols P.D., 2009. Feeding aquaculture in an era of finite resources. *Proc. Natl. Acad. Sci. U.S.A.* **106**(42):18040. FREE Full Text

O'Leary B.C., Smart J.C., Neale F., Hawkins J.P., Newman S., Milman A.C., Roberts C.M., 2011. Fisheries mismanagement. *Mar. Pollut. Bull.* **62**(12):2642–2648. CrossRef Medline

Österblom H., Sumaila U.R., Bodin Ö., Hentati-Sundberg J., Press A.J. 2010. Adapting to regional enforcement: Fishing down the governance index. *PLoS ONE* **5**(9), e12832. Search Google Scholar

Parry M., Rosenzweig C., Livermore M., 2005. Climate change, global food supply and risk of hunger. *Phil. Trans. R. Soc. B* **360**:2125–2138. CrossRef Medline

Perry R.I., Ommer R.E. Barange M., S Jentoft, B Neis and U R Sumaila. 2011. Marine social-ecological responses to environmental change and the impacts of globalization. *Fish and Fish.* **12**:427–450. Search Google Scholar

Pikitch E., Boersma P.D., Boyd I.L., Conover D.O., Cury P., Essington T., Heppell S.S., Houde E.D., Mangel M., Pauly D., Plagányi É., Sainsbury K., Steneck R.S., 2012. Page 108 in Little Fish, Big Impact: Managing a Crucial Link in Ocean Food Webs. Lenfest Ocean Program. Washington, DC. Search Google Scholar

Roos N. Wahab M. A., Chamnan C., Thilsted S., 2007. The role of fish in food-based strategies to combat vitamin A and mineral deficiencies in developing countries. *J. Nutr.* **137**(4):1106–1109. Abstract/FREE Full Text

Ruel M.T., Garrett J.L., Haddad L., 2008. Rapid urbanization and the challenges of obtaining food and nutrition security. Pages 639–656 in Nutrition and Health in Developing Countries. Semba R.D., Bloem M. W., eds. Humana Press, Totowa, NJ. Search Google Scholar

Schmidhuber J., Tubiello F.N., 2007. Global food security under climate change. Proc. Natl. Acad. Sci. U.S.A.**104**:19703–19708. Search Google Scholar

Shetty P., 2009. Incorporating nutritional considerations when addressing food insecurity. *Food Secur.* **1**(4):431–440. CrossRef

STAO. 2009. Report to the European Parliament: European Aquaculture Competitiveness: Limitations and Possible Strategies.

Tacon A. G. J., Metian M., 2008. Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. *Aquaculture* **285**:146–158. CrossRef

Tacon A.G.J., Metian M., 2009. Fishing for feed or fishing for food: Increasing global competition for small pelagic forage fish. *Ambio* **38**(6):294–302. Medline

Thilsted S.H., Roos N., Hassan N., 1997. The role of small indigenous fish species in food and nutrition security in Bangladesh. *NAGA, ICLARM Quarterly* **20**(3–4):82–84. Search Google Scholar

Tilman D., Balzer C., Hill J., Befort B.L., 2011. Global food demand and the sustainable intensification of agriculture. *Proc. Natl. Acad. Sci. U.S.A.* **108**(50):20260–20264. Abstract/FREE Full Text

Tubiello F.N., J.-Soussana F., Howden S.M., 2007. Crop and pasture response to climate change. *Proc. Natl. Acad. Sci. U.S.A.* **104**(50):19686–19690. Abstract/FREE Full Text

Turral H., Burke J., Faurès J.-M. 2011. Climate change, water and food security. FAO Water Reports 36. FAO, Rome. Search Google Scholar

Tveteras S., Asche F., Bellemare M.F., Smith M.D., Guttormsen A.G., Lem A., Lien K., Vanuccini S., 2012. Fish Is Food: The FAO's Fish Price Index. *PLoS ONE* **7**(5):E36731. CrossRef Medline

Verdegem M.C.J., Bosma R. H. 2009. Water withdrawal for brackish and inland aquaculture, and options to produce more fish in ponds with present water use. *Water Policy* **11**(S1):52–68. CrossRef

Welcomme R.L., Cowx I.G., Coates D., Béné C., Funge-Smith S., Halls A., Lorenzen K., 2010. Inland capture fisheries. *Phil. Trans. R. Soc.* **B 365**(1554):2881–2896. Search Google Scholar

Worm B., Hilborn R., Baum J.K., Branch T.A., Collie J.S., Costello C., Fogarty M.J., Fulton E.A. Hutchings J.A., Jennings S., Jensen O.P. Lotze H.K. Mace P.M., McClanahan T.R., Minto C., Palumbi S.R., Parma A.M., Ricard D., Rosenberg A.A., Watson R., Zeller D., 2009. Rebuilding global fisheries. *Science* **325**:578–585. Abstract/FREE Full Text

Ye L., Xiong W., Zhenguo L., Peng Y., Wenbin W., Cuixia Y., Yijiang F., Jinqiu Zou Z., Chen Z., Van Ranst E., Huajun T., 2012. Climate change impact on China food security in 2050. *Agron. Sustain. Dev.* doi:10.1007/s13593-012-0102-0. Search Google Scholar