Food for Thought

Feeding the world: what role for fisheries?

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Fisheries (wild capture and aquaculture) deliver more than 110 million tonnes of food and around 15% of the dietary protein to the 7 billion people currently living on the planet. With the global population expected to peak at 9 billion by 2050, and 80% of global fish stocks currently fully or overexploited (and aquaculture is at least in part dependent on capture fisheries), the contribution of fisheries looks set to decline. The challenge is therefore determining how better management, an ecosystem perspective, and more efficient utilization of fisheries waste can support fisheries products continuing to contribute significantly to “feeding the world” up to and beyond the population peak.

Keywords: ecosystem approach, global food security, global population, starvation, sustainability.

Introduction

At the turn of the Millennium, the global human population stood at > 6 billion (UN, 2009). This figure is predicted to exceed 9 billion by 2050. Of the nearly 7 billion people currently on the planet, more than 1 billion are officially designated as starving (FAO, 2010a), and at least twice that number suffer from micronutrient deficiencies (Barrett, 2010). Although agriculture will need to contribute the greatest part of the solution to the looming global food crisis that these values predict, fisheries (including aquaculture) can make a notable contribution. This essay examines how that contribution might be delivered, its scale, and in particular how it might be done in a sustainable manner cognizant of the need for the protection of biodiversity and healthy functioning ecosystems.

Rice and Garcia (2011) recently considered the developing body of work seeking to address the issues of human population growth, global food security, and biodiversity conservation against a background of anthropogenic climate change. Their analyses concluded that the policy actions being proposed for biodiversity conservation are incompatible with those advocated to meet future food-security needs. Rice and Garcia (2011) do not offer a solution to the problem, but conclude that there is a pressing need for policy-makers and experts from both spheres to work together to find a solution.

Here, we critically examine this potential conflict and ask to what extent can food security needs be drawn from aquatic ecosystems while still meeting biodiversity commitments and to what extent do some of them need to given precedence over food-security issues. This is a global challenge, but we draw on specific examples from two regions of the world. Europe, a productive fisheries area with a long history of fisheries and biodiversity legislation, has limited population growth and developed economies able to secure food in the global market. In contrast, China has a growing population and increasing per capita energy and food demands. Its economy is growing rapidly and has significant fisheries and aquaculture sectors.

The current annual yield of European capture fisheries is 5.2 million tonnes of fish, and another 1.3 million tonnes is produced by aquaculture. European fisheries production (catch plus aquaculture) amounts to around 4% of the global production. Some 3.8 million tonnes of the catch (74% in 2008; http://epp.eurostat.ec.europa.eu/portal/page/portal/product_details/data_set?p_product_code=FISH_LD07) was used for human consumption, and the remainder in industrial processes such as the production of fishmeal and oil. In contrast, China has a growing population and increasing per capita energy and food demands. Its economy is growing rapidly and has significant fisheries and aquaculture sectors.

Where we are now

Capture fisheries

Production from global marine capture fisheries peaked in the late 1980s and in Europe a few years earlier. Subsequently, improved
exploitation technology and the opening up of new stocks held annual global production at \(\sim 80-90\) million tonnes. The latest values suggest that \(>80\%\) of global fish stocks are either fully or overexploited and in need of recovery (FAO, 2009). It is generally accepted that there are no major new fishing grounds to be exploited (Godfray et al., 2010).

In addition to producing material for human consumption, capture fisheries also generate significant quantities of “waste”. The return to the sea of waste from fish processing at sea (heads, guts, offal) and the parts of the catch that are not landed for legal or market-demand reasons (i.e. undersize or overquota fish, species of low/no economic value, and invertebrates) further alters marine foodwebs by favouring scavengers such as seabirds, starfish, and small scavenging fish and crabs. Detailed data on the levels of discards are not available, but global estimates suggest a discard rate of \(\sim 8\%\) (Kelleher, 2005), equating, at current levels of catch, to \(\sim 7\) million tonnes globally (FAO, 2010b), or \(>410 000\) t of wasted production in European fisheries, 1.5 million tonnes in North America, and 2.5 million tonnes in SE Asia/China. However, in low-income food-deficit countries (LIFDCs), discarding is a minor practice because the entire catch is utilized either directly, with high-value species going to market and low-value items being retained for the fisher’s own use or processed into fish pastes, etc. These variations are taken account of in the global estimates, but such wide variation in practice has implications for the appropriate solutions to the challenges identified here.

Much of the pressure on food resources in the next 2–3 decades will come from population growth in Asia. Fisheries in Asia already provide a large proportion of the global catch and are generally fully or overexploited, so although focus here is on the global use of fisheries production, solving the food-security crisis will actually involve significant economic and technical challenges to ensure free global trade without spoilage.

Aquaculture

Aquaculture is an increasingly important source of food globally. In 2008, 45.7% of the fish consumed by humans came from aquaculture. Its importance varies globally, but in some countries, particularly those in Asia, aquaculture represents a vital source of food. In 2008, 80.2% of the fish consumed by the Chinese population was derived from aquaculture, up from 23.6% in 1970 (FAO, 2010b).

Some species used in aquaculture, particularly high-value finfish, require manufactured diets that include significant quantities of marine lipids and proteins. The fishmeal and oil used to formulate these diets are derived from several sources, including the fisheries targeting species not for human consumption, landed non-marketable fish (i.e. where discarding is restricted), and waste (trimmings) from fish processing. Hence, aquaculture and capture fisheries are not totally independent sources of dietary material.

Naylor et al. (2000) calculated a typical global aquaculture feed conversion ratio of 2, i.e. 2 t of dry feed being required to raise 1 t of fresh weight of product (similar to industry estimates; Seafeeds, 2003). This conversion ratio is similar to that often observed in natural systems and would suggest that the efficiency of humans consuming prime fish directly, compared with eating animals fed on fishmeal and oil, is about equal.

The total waste arising from the fishery includes high-quality (protein and lipid) material, i.e. non-marketable fish, and lower-quality material, such as invertebrates. In Europe, for example, the use of the 410 000 t of discards produced annually potentially implies a production of an additional 82 000 t of fishmeal. This could support an additional 50 000–60 000 t of fish production from aquaculture through the more efficient use of currently exploited marine produce. In North America, the equivalent figures are 300 000 t of fishmeal and 150 000–200 000 t of fish in aquaculture. As noted above, in much of Asia and Africa, discarding is limited and material of a low market value is either retained for use by fishers or processed into fish paste/powder or other marketable product. It is in the fisheries of the developed nations, wherever they operate, that production is currently being wasted in the form of discards.

Globally, \(~25\%\) of the raw material used to produce fishmeal is derived from fishery trimmings (http://www.iffo.net/default.asp?contentID=730; last accessed 13 February 2011), this proportion including trimmings from fish raised in aquaculture. The utilization of trimmings varies widely, primarily being a reflection of the proximity of a factory to take the waste from fish-processing sites. In Denmark, for example, it is estimated that 80% of the trimmings from fish processing enter the fishmeal and oil industry, although this figure is just 10% in Spain. Between 33 and 50% of fish trimmings from the UK, Germany, and France enter the fishmeal and oil industry, differences suggesting that even in highly developed regions, there is considerable scope to increase the production of aquaculture feed from fish processing waste.

Given the recycling of waste and the poor recording of some fisheries for industrial species, it is difficult to estimate the true fisheries production involved in supporting aquaculture. However, the figure is likely to be \(~40.7\) million tonnes (33 million tonnes of industrial fish and 13% of 59 million tonnes of fish used for human consumption). This calculation assumes that all the industrial fisheries landings go into aquaculture feed and that globally the utilization of processing wastes by the fishmeal production sector approximates to that utilized in Europe \((912 500\) t from a catch of 7 million tonnes, or 13%; Frid et al., 2003).

FAO data show that of the 51 million tonnes of aquaculture yield, marine fish accounted for 3%, diadromous fish for 6%, and freshwater fish for 54%. Therefore, across the fish aquaculture sector and using the Naylor et al. (2000) conversion ratio, \(~12.7\%\) of the industry is support by fisheries-derived production. This value means that some species, in particular carp and catfish, are not carnivorous and that even carnivorous fish diets incorporate soya protein.

The limits to production

The recent crisis in global economies and the role of the banking sector in precipitating the crisis has received much attention and has led some to draw analogies between economics and ecology (May et al., 2008). The central argument is that economic growth cannot be sustained indefinitely and that it will run into a “limit to growth” in the form of resource/production limits. Systems based on biological resources are the one area where such limits, potentially at least, are flexible. This has led to the development of the concept of a “bioeconomy”. In Europe, there is a move to grow out of recession using a strategy to develop a knowledge-based bioeconomy (KBBE), emphasizing that the model includes advanced biosciences such as biotechnology, as well as agriculture, forestry, fisheries, and aquaculture. The strategy seeks to carry out this development while protecting natural resources/biodiversity through meeting the obligations of the
UN Convention on Biological Diversity (CBD; UN, 1992). In the terrestrial environment, large areas were transformed into production systems for food and fibre thousands of years ago, and conservation areas are recent developments. In the seas and oceans, current efforts to intensify production follow the adoption of international frameworks (particularly the CBD) that set out requirements for the protection of biodiversity and the maintenance (conservation) of natural system dynamics. The environmental lobby needs to consider how the overarching moral imperative to feed the global population can be addressed within these constraints. Therefore, policy for the marine environment is developing within a different framework from that which delivered current terrestrial landscapes and production systems.

Policy drivers to stimulate a shift to a bio-based economy are required. There is plenty of evidence that unregulated fisheries will be overexploited and unsustainable, so a bioeconomic policy featuring strong regulation/directing will require strong and effective fisheries management to deliver sustainable fisheries. Key aspects of this approach will require (i) an ecosystem-based approach to fisheries management, (ii) multi-annual management regimes, (iii) adaptive management procedures, (iv) the establishment of a network of marine protected areas (MPAs), (v) good environmental data systems, including extended observer and VMS coverage, and (vi) discard-reduction programmes and waste-reduction strategies.

Similarly, strong regulation and policy support will be required in the aquaculture sector, for example, to prevent the transfer of discard-reduction programmes and waste-reduction strategies. A simple analysis would suggest that a rebuilding of the currently overexploited stocks might lead to an overall increase in production. In 2008, it was estimated that 32% of global stocks were overexploited, depleted, or recovering (FAO, 2010b), though this estimate could be offset by a reduced yield from fisheries that are currently overexploited but not yet collapsed if they were also managed at their sustainable levels. The FAO also estimated that 15% of stocks are not being fully exploited (i.e. yielding less than maximum sustainable yield, MSY), so there is further scope for increased yield from those stocks (FAO, 2010b). Therefore, a conservative assumption would be that current total yield is close to global MSY. However, with such a large proportion (>45%) of stocks either exploited beyond their individual MSY or not fully exploited, there would appear to be some scope for growth in total yield as all fisheries move to MSY rather than concentrating on losses in production from fisheries whose yields are reduced. How much additional resource would become available, though, is difficult to estimate.

A recent study of long-term records of the UK cod (Gadus morhua) fishery suggests that annual landings historically were four times their recent (1980s) maxima (Thurstan et al., 2010). However, it would be unrealistic to suggest that even if this estimate is robust and, disregarding any environmental change over the intervening centuries, that all fisheries could show that degree of recovery. Nature abhors a vacant niche as much as a vacuum, and as fish stocks are exploited, the production not used by the exploited species will have been utilized by other components of the ecosystem. These may also be exploited such that the total MSY of the mixed fishery is not the sum of the MSY values of the component species assessed in isolation.

Rebuilding of stocks of predatory species, for example, could well reduce the yield available from their prey species, including small pelagic forage fish and invertebrates. Reduced yield of the former in particular would then reduce the availability of fishmeal for aquaculture. If aquaculture is currently, in part, operating to convert low-value species into high-value product for the market, a recovery of predatory fish species transfers that process back to the wild. In the context of global food security, it might create a further gap in the feed supply to aquaculture.

An alternative approach to looking at total fisheries yields is to calculate potential yields from the bottom up. As early as the 1960s, estimates of marine primary production were being used as a basis for estimating the productivity of marine fish (Ryther, 1969). An estimated global annual fish production of 240 million tonnes fresh weight meant that global fisheries even then were removing a biomass equivalent to some 25% of total production each year. More recent estimates, based on the latest satellite-derived data on global marine primary production (Chassot et al., 2011) and a pattern of spatial resolution that accords with major ecosystem boundaries, concluded that the global fish catch was already constrained by the available primary production and that in some areas the catch greatly exceeded current levels of production (Chassot et al., 2010). The latter situation implies that current fisheries are utilizing production from a number of years integrated into the bodies of larger fish. This lends weight to the assumption that a reduction in effort, while improving sustainability and reducing some of the unintended ecosystem effects, will not greatly increase total catch.

Model-based studies suggest that global exploitation increased rapidly in the 1980s and 1990s and that in many areas it now exceeds the equivalent of 10% of primary production (Swartz et al., 2010). This model-derived pattern is consistent with the maintenance of total global catch from the 1980s to the present despite many important fisheries suffering major collapses. Therefore, rebuilding of those collapsed stocks should deliver a greater total yield.

In addition to their impact on target species, fisheries exert notable impacts on the ecosystem through modification of the foodweb, mortality of non-target species, and, for some types of fishing gear, direct damage to marine habitats. Designation of some areas as MPAs allows protection of habitats and biodiversity of low-mobility species and, combined with more efficient regulation of the fisheries in other areas, should lead to more sustainable levels of exploitation on target species and habitat protection. However, given the pressure from growing populations to increase food production, the case for large areas to be set aside as protected is difficult to sustain. The IUCN has suggested that 20% of habitats globally should be set aside for nature conservation. The most recent meeting to support the implementation of the CBD (www.cbd.int) has set the target for 2020 of at least 17% of terrestrial and inland water areas and 10% of coastal and marine areas to be conserved by area-based conservation measures. This target for protected areas is supported by multiple processes and by criteria agreed upon in 2008 for the selection of ecologically

**Looking ahead to 2050**

**Capture fisheries**

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Aquaculture represents a route by which marine food production can definitely be increased. Globally, aquaculture accounts for some 47% of total fisheries production, and growth in aquaculture in the past 20 years has more than offset the growth in the global population, so that despite the static level of capture fisheries production, the per capita food supply from fisheries globally has increased (FAO, 2009). In Europe, aquaculture accounts for \( \approx 1.3 \) million tonnes per annum, or \( \approx 20\% \) of total fisheries production.

Aquaculture requires land or sea space, and water of sufficiently high quality, both in limited supply and also required for agriculture. There is a clear scope for aquaculture growth in lower-trophic level species that are not constrained by fisheries dependence (e.g., shellfish). However, the scope for growth in the aquaculture of predatory (marine) fish is more limited but possible. There are three mechanisms for expansion: (i) better feed conversion ratios and more use of non-fish material in the diet, (ii) increased supply of fish material from more effective waste-management strategies, and the removal of the ecological damaging practice of discarding, and (iii) the use of polyculture and the cultivation of low-value species to either feed directly to the stock or for entry into the fishmeal supply chain (e.g., filter-feeding shellfish).

Extensive suspended rope aquaculture could, for example, be co-located with existing farms and with offshore wind energy sites, utilizing areas of sea otherwise rendered off-limit to fisheries. There are many technological constraints to the further development of European aquaculture; some biological and some engineering (i.e., for farms located offshore). However, growth in aquaculture to global levels, with production delivering similar quantities of food as capture fisheries, is a major opportunity for the development of a KBBE (http://cordis.europa.eu/fp7/kbbe/home_en.html). The opportunities for expansion are notable if the differences in aquaculture production rates are compared globally. In Norway, the average annual production per person employed in the aquaculture sector is 172 t, in Chile \( \sim 72 \) t, in China 6 t, and in India just 2 t (FAO, 2010b). These differences largely reflect the different availability of technology and energy. Intensive aquaculture requires both, and these are not readily available in LIFDCs.

Probably the most critical environmental challenge for aquaculture development is to reduce the dependence of aquaculture production on capture fisheries. Intensive production systems for plant-eating fish such as Tilapia still often use fishmeal as a dietary supplement to achieve fast growth to marketable size. (Fast growth reduces both the time in culture and the risk of disease.) Recent restrictions on the use of fishmeal in animal feeds (e.g., poultry and pigs) have meant that global levels of fishmeal use have remained almost constant for a decade despite the growth in aquaculture (FAO, 2010b). While there has been notable development of fish diets not based on fisheries products in recent years (e.g., the substitution of soya for some fish protein in aquaculture diets), there is little scope for further expansion of production based on that source. Two solutions appear to offer opportunity, however: first, the continued substitution of fish oil and protein in the meal by the use of soya and potentially essential marine fatty acids produced in genetically modified organisms; and second, a more-robust approach to fisheries waste that could see ecological subsidies to scavengers reduced by the landing of discard. These could then be processed into fishmeal. Any changes to the regulatory regime would need to ensure that there was an incentive to land material captured incidentally, without creating an economic incentive to target these ecosystem components.

Integration of offshore energy collection and aquaculture facilities would seem to offer engineering and environmental efficiencies. For example, offshore wind farms usually exclude mobile fishing gear form the area, but the space between turbines could be used for static-gear fisheries for crabs and lobsters, and as sites for aquaculture moorings. Recent years have seen aquaculture production globally grow by 3–7% annually, with no sign of slowing (FAO, 2009). It would therefore seem reasonable to anticipate an annual figure of 70 million tonnes globally from aquaculture by 2050. For instance, Brugeré and Ridler (2004) estimated annual growth of 4.5% during the period 2010–2030, if it was supported by better use of fisheries waste, more use of vegetable protein in feeds, and more-efficient husbandry (Table 1). Greater production would be achievable if current technology for intensive...

**Table 1.** Food for human consumption from fisheries and aquaculture in the decade of the 2000s, projected forward to the 2050s (see text for explanation of the assumptions).

<table>
<thead>
<tr>
<th>Decade</th>
<th>Source and parameter</th>
<th>Production (t)</th>
<th>Food for human consumption (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000s</td>
<td>Capture fisheries (marine and freshwater)</td>
<td>92 000 000</td>
<td>59 000 000</td>
</tr>
<tr>
<td></td>
<td>Aquaculture</td>
<td>–</td>
<td>51 700 000</td>
</tr>
<tr>
<td></td>
<td>Non-food use (oil, meal, bait, etc.)</td>
<td>33 000 000</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Discards</td>
<td>7 360 000</td>
<td>72 000 000 (8% of 92 000 000)</td>
</tr>
<tr>
<td></td>
<td>Total food for human consumption</td>
<td>–</td>
<td>110 700 000</td>
</tr>
<tr>
<td></td>
<td>Food per citizen (6 billion)</td>
<td>–</td>
<td>18.45 kg</td>
</tr>
<tr>
<td>2050s</td>
<td>Capture fisheries (marine and freshwater)</td>
<td>110 000 000</td>
<td>85 000 000</td>
</tr>
<tr>
<td></td>
<td>Aquaculture</td>
<td>–</td>
<td>70 000 000</td>
</tr>
<tr>
<td></td>
<td>Total food for human consumption</td>
<td>–</td>
<td>155 000 000</td>
</tr>
<tr>
<td></td>
<td>Food per citizen (9 billion)</td>
<td>–</td>
<td>17.22 kg</td>
</tr>
</tbody>
</table>
Feeding the world: what role for fisheries?

Aquaculture could be implemented in all parts of the world and energy costs were lower.

The road ahead

Although it is clear that better use of marginal land and freshwater for food production hold the key to global food security (FAO, 2010a), there is definite scope for fish to continue to make a significant contribution to maintaining healthy diets and fisheries-dependent communities and socio-economic structures.

At present, human demands on the planet’s resources mean that we are living outside our means. Globally, the human population is utilizing the resources of 1.5 planets, while European lifestyles imply a use of three times the planet’s capacity to sustain (Ecological Footprint Index, 2011). With a billion people facing starvation and a further 2 billion expected to share the planet by 2050, there is great imperative to move to more-productive and sustainable food supply systems. Clearly, fisheries have a major role to play, but only if we can deliver on the challenges of operating within the constraints of the ecosystem, i.e. being sustainable, efficient, and aware of the ecological links.

Rice and Garcia (2011) urge scientists and policy-makers to confront four questions:

(i) how do we meet food security needs in a world with a changing climate?
(ii) what role do aquatic ecosystems have in meeting those food security needs?
(iii) what objectives for conservation of aquatic biodiversity are appropriate in a world with a changing climate?
(iv) what does “conservation” mean if the past becomes irrelevant and the baselines move from behind us to in front of us?

We suggest that the answers to (i) and (iii) are bound up in (iv). The world is changing, there are more people, more urbanization, more waste, more demands on freshwater, and an altered climate. Policy-makers, supported by robust science, need to address these issues simultaneously. One can make a societal case for conservation of threatened and declining habitats, species, and genetic material (biodiversity per se), but the imperative must be to maintain functioning ecosystems. More than half the oxygen we breathe is produced by marine ecosystems (Kasting and Siefert, 2002). In this context, conservation is not in conflict with food security but complementary. As long as we utilize the seas mainly as sites for exploitation, rather than as intensively bio-engineered systems (i.e. “agricultural land”), then we need to ensure that they supply food to eat and air to breathe. Hence, we need to protect functioning ecosystems.

Our consideration here has focused mainly on (ii) above, and our conclusion is that although fisheries and aquaculture are unlikely to be able to expand to support the predicted increases in the global population, better management of fisheries and the continued growth of aquaculture will mean that fisheries can realistically continue to be a major source of protein for that population. There would appear to be three barriers to this, detailed below.

(i) The economic and regulatory structures that surround capture fisheries management have proven to be rather ineffective at delivering well-managed fisheries. Climate change provides a major additional challenge for fisheries managers as well as agriculturalists, because the changes in production on land may greatly exceed those in the oceans (Rice and Garcia, 2011).

(ii) Expansion of aquaculture will be energy and technologically demanding and these may be limiting factors in LIFDCs.

(iii) Inequalities in access to processing, markets, and preservation, because spoilage accounts for considerable losses between capture and consumption, and restricted access to processing limits the recycling of fisheries waste into aquaculture feeds.

This paper has focused on biological production; huge challenges remain over making it optimally available to consumers. Most estimates suggest that global food production is currently more than sufficient to feed the world, but that in the developed west there are surpluses and huge food-waste issues, whereas much of Africa and Asia face continued food shortages. Harvesting sufficient fish is not alone the solution to feeding the world! What is needed is fisheries exploited sustainably, more production from aquaculture, better preservation and distribution, and healthy functioning ecosystems.

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