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Fish, human health and marine ecosystem health: policies in collision

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Background Health recommendations advocating increased fish consumption need to be placed in the context of the potential collapse of global marine capture fisheries.

Methods Literature overview.

Results In economically developed countries, official healthy eating advice is to eat more fish, particularly that rich in omega-3 oils. In many less economically developed countries, fish is a key human health asset, contributing >20% of animal protein intake for 2.6 billion people. Marine ecologists predict on current trends that fish stocks are set to collapse in 40 years, and propose increased restrictions on fishing, including no-take zones, in order to restore marine ecosystem health. Production of fishmeal for aquaculture and other non-food uses (22 MT in 2003) appears to be unsustainable. Differences in fish consumption probably contribute to within-country and international health inequalities. Such inequalities are likely to increase if fish stocks continue to decline, while increasing demand for fish will accelerate declines in fish stocks and the health of marine ecosystems.

Conclusions Urgent national and international action is necessary to address the tensions arising from increasing human demand for fish and seafood, and rapidly declining marine ecosystem health.

Keywords Fish, Omega-3 fatty acids, Food policy, Food security, Health inequalities, Sustainability

Introduction

This article sets out some of the public health and marine ecosystem problems surrounding human consumption of fish. It addresses (i) the health benefits and risks of eating fish, (ii) the status of fisheries, fisheries management and aquaculture and (iii) related social and environmental justice issues. We discuss these issues and the related research priorities. We argue that there is urgent need for policies that recognize the conflict between growing human demand for fish and the need for sustainable fisheries that protect marine ecosystems and promote social and environmental justice.

Health benefits and risks of eating fish

Fish as a health asset

It has long been recognized that fish is a valuable food. Compared to meat, poultry and eggs, fish is low in saturated fatty acids and a good source of protein and selenium; oily fish in particular is an excellent source of long-chain omega-3 fatty acids. In rich countries much attention is being given to the related health benefits, and official recommendations for Europeans and North Americans are to eat more

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fish. For much of the world's population, in contrast, fish contributes to nutrition because it is part of the established food economy. Several of the world's poorest communities are highly dependent on fish to fulfil their dietary needs.[1]

Omega-3 fatty acids

The human health effects of omega-3 oils are the subject of much scientific and policy interest. The specific roles of α-linolenic acid (ALA, 18:3n-3), eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3) in preventing cardiovascular disease[2,3] and cancer[4] are the subjects of active research.[5] ALA is an essential nutrient which humans convert inefficiently to EPA and DHA. In relation to the cardioprotective effects of fish oils, a systematic review shows there is more heterogeneity in the trial findings than previously recognized.[5,6] For example, the large DART-2 trial did not confirm the hypothesized anti-arrhythmic action of omega-3 oils.[7] Among men with stable angina, oily fish or omega-3 supplements reduced neither mortality nor major cardiovascular events. In other tests of the anti-arrhythmia hypothesis, three trials of 1- to 2-year duration evaluated the effects of fish oil in patients with implantable cardioverter defibrillators and did not show clear evidence of any benefit.[8,9] Despite the basic science suggesting triglyceride-lowering, anti-thrombotic and anti-arrhythmic omega-3 effects,[10] and continuing recommendations with respect to secondary prevention, there is a need for definitive trial evidence that heart patients obtain benefit from oily fish or from supplements.

Other potential health benefits of omega-3 oils are being investigated. There are putative roles in prevention of atopic disease and asthma, related to modulation of eicosanoid and inflammatory cytokine production.[11,12] Omega-3 oils may help delay cognitive impairment and dementia, and the first results of controlled trials are expected in 2008.[13] Recent well-publicized studies claim improvements in behaviour and reading age among schoolchildren taking omega-3 oil supplements,[14] but definitive evidence is lacking. These substantive areas of research are complicated by the problem that the relative advantages of ALA, EPA and DHA are inadequately understood.[3] If it is established that plant-derived ALA, the parent fatty acid, is a poor substitute for direct ingestion of the longer chain marine fatty acids, human demand for EPA and DHA could increase rapidly.

Sources of marine omega-3 fatty acids

At present, human dietary intake of omega-3 oils is largely derived from the flesh of marine pelagic oily fish, such as mackerel, salmon, anchovy, sprat, pilchard and herring. EPA and DHA accumulate in the fish from the lipids obtained from marine algae, the primary producers. Omega-3 oils are also found in demersal white fish such as cod and in large apex predators such as billfish (swordfish, spearfish, marlin) and tuna. There are particular concerns relating to large apex predators as stocks are severely depleted.[15,16] Other marine fauna, such as shrimp and krill, could potentially provide a significant supply of omega-3 oil but extensive harvesting at lower trophic levels is likely to have substantial negative impact on the food supplies of higher predators.[17]

Methylmercury and polychlorinated biphenyls

With media attention on this research, public perception in the UK and other developed economies is that fish and fish oils are valuable sources of nutrition. This view is not necessarily accompanied by intake at recommended levels. One countervailing influence on consumption is growing awareness of the risks—real and perceived—linked to trace contamination of fish and seafood with neurotoxic methylmercury and carcinogenic organochlorine compounds.[12,18–20] Fat-soluble methylmercury accumulates up the marine food chain, with the highest levels found in large predatory species. Mother–child studies suggest maternal omega-3 intake during pregnancy is associated with improved cognitive performance in the infant and child, but maternal mercury burden has an opposing effect.[21,22] Dioxins and polychlorinated biphenyls (PCBs) are also lipophilic compounds which accumulate in the flesh of oily fish. Other environmental chemicals that may present a hazard to human consumers need to be considered. They include the brominated flame retardants and the nitro- and polycyclic musks, which are widely used as fragrances in domestic products and not removed by sewage treatment.[23,24]

Balancing benefits and risks

The nutritional and toxicological considerations related to fish consumption were brought together in two major reviews published in 2004 in the UK and USA. The assessments draw particular attention to the maternal requirement for DHA during pregnancy and lactation, estimated at some 25 g, to support fetal and infant brain development.[12] The UK report considered that one portion of swordfish, shark or marlin (140 g), while rich in omega-3 oils, would result in a dietary methylmercury exposure close to or above 3.3 μg/kg bodyweight per week limit. Intake at this level could harm the fetus of women who are pregnant or become pregnant within a year, given the half-life in humans of methylmercury of about 70 days. Intake limits were set to encompass the hazards linked with dioxins and PCBs, which have half-lives of several years.

On the basis of this opinion, the Food Standards Agency (FSA) advises women of childbearing age to eat no more than two portions of oily fish per week (0.4–0.8 g/day omega-3 oils) and if intending to get pregnant to avoid eating swordfish and large predatory species. Limits of four oily fish portions and no than one portion of the large predators were advised for other adults. This assessment raises the problem of balancing risk communication in populations that in general consume little oily fish. In the UK, average

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intake is one-third of a portion per week and widespread adoption of advice to eat at the recommended level of one portion per week would increase demand substantially.

The US Food and Drug Administration (FDA) and Environment Protection Agency advisory statement also took a precautionary view on mercury contamination of fish for women who might become or who are pregnant, nursing mothers and young children.[25] Following the short-term decline in sales after their statement, the FDA advised Americans, including young women and children, to continue eating fish, even large predatory species.

The conflicting nature of policies on fish intake led to another review by the Institute of Medicine, part of the US National Academy of Science, which sought to present a more balanced view of the benefits and risks of consumption.[26] The report was commissioned by an agency of the Department of Commerce, the preface stating that 'the seafood industry contributes a large part of the nation's economic health'. Notwithstanding the commercial context, the chair of the scientific committee was sceptical in his assessment of the literature: 'In many cases, we have deemed the evidence for benefit as insufficient or too preliminary. Similarly, the Committee reviewed the data on contaminants and risks they imply. We were surprised at the lack of good data on the distribution of some contaminants in the seafood supply'. Debate continues among US agencies on appropriate consumer recommendations that balance the benefits and risks of fish consumption.

Status of world fisheries, fisheries management and aquaculture

There has been a longstanding dependence on marine fish for nutrition in many human populations, but the unprecedented level of exploitation means that supply cannot be taken for granted in the future. There is increasing evidence that large-scale fishing can have ruinous effects on marine ecosystems and their fish populations.[27,28] Recent assessments indicate that we have reached the point at which over three quarters of fish stocks are fully exploited (52%) or overfished (24%).[29] In the NE Atlantic the proportion of stocks considered to be within 'safe biological limits' fell from 26% to 16% between 1996 and 2001.[30] Unless the current trajectory is altered decisively, human predation is predicted to lead to complete collapse of all economically important species by the mid 21st century, potentially causing irreversible damage to marine ecosystems.[28]

Peak fish

Food and Agriculture Organisation (FAO) data suggest that global yields from marine capture fisheries increased more than fourfold since 1950, and peaked in 2000 at 87 megatonnes (MT) per annum (Figure 1).[31,32] This trend has involved depletion of higher trophic level stocks,[15,33] leading to shifts in fishing effort to species at a lower trophic level.[17]

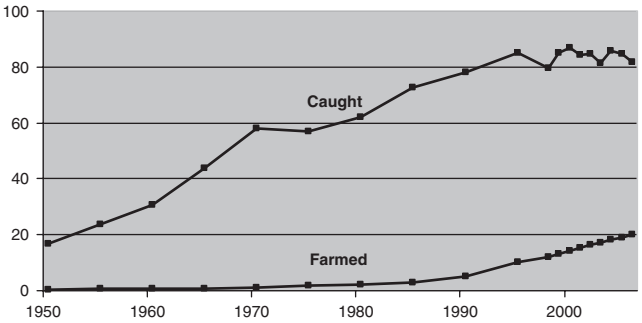

Figure 1 Global marine fish catch and aquaculture 1950–2006 (Mtonnes). *Source*: Food and Agriculture Organisation FISHSTAT Plus database. Marine capture fisheries resources are considered close to full exploitation worldwide with about 52% fully exploited, 24% overfished or depleted and 24% with some capacity to produce more than they presently do. *Source*: ref.[29]

A pivotal study by marine ecologists is based on extrapolation of catch trends around the world.[28] FAO and other data on fish and invertebrate catches from 1950 to 2003 were analysed for ocean regions that collectively produced over 80% of global catches, together with species diversity data for each of the 64 large marine ecosystems. Fishery collapses, defined as catches dropping below 10% of the recorded maximum, are accelerating. Cumulative collapses reached 65% in 2003, and extrapolation of the regression model predicts global collapse of all commercially exploited fish populations in 2048. Combined yield for all the fisheries studied has fallen since the peak, despite greatly increased fishing effort.

Marine reserves and ecosystem management

An ecosystem approach to management is increasingly being recommended as the required policy solution to declines in the health of marine ecosystems and the size of fish populations.[28] Species-by-species stock management has been the main device employed by the European Commission and other regulators in attempts to maintain sustainable yields, but FAO figures and related analyses indicate that this policy has not been effective.[28,34] Marine reserves, in which all fishing is banned, present a realistic alternative that allows disrupted ecosystems and less migratory fish stocks to recover.

Analysis of experimental and observational data addressing the effects of marine biodiversity on a variety of outcome measures shows that productivity, stability and resilience is enhanced by higher diversity of species, as it is in terrestrial ecosystems.[28] In large offshore zones, and smaller estuarine and coastal areas, fishery collapses are more frequent in species-poor ecosystems than in species-rich ones. These effects

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operate both for primary producers (plants and algae) and consumers (herbivores and predators). Recognizing this, a consensus is emerging among marine ecologists that marine reserves often enhance biodiversity and constituent fish populations. Such reserves hold the prospect of recovery beyond as well as within their boundaries, while also addressing broad societal concerns about the failure of stock management based on quotas.[35,36] The UK Marine Bill, published in April 2008, contains proposals to designate and protect Marine Conservation Zones. At the time of writing, the Bill is subject to pre-legislative scrutiny in the UK Parliament.

Prospects for aquaculture

Between 1970 and 2006 the proportion of total marine fish production derived from aquaculture grew from 2% to 20% (Figure 1). Aquaculture has grown more rapidly than other animal protein-producing sectors[29] and has become an important supplier of marine and freshwater fish for human consumption.[31] Related to this growth, about a quarter of captured marine fish is now utilized for non-food uses including the production of fishmeal (22 MT in 2003) as a source of feed for agriculture and aquaculture.[31] Farmed fish are generally fed on a diet based on or supplemented with fishmeal derived from oily marine pelagic fish, from which the health benefits of eating farmed fish are largely derived. There are growing concerns about the impact of increasing demands for fishmeal by this sector.[37,38] Unless aquaculture and marine fishing can be decoupled, particularly through development of alternative sources of feed that maintain the human health value of farmed fish, aquaculture is unlikely to provide a solution to the problem of maintaining a sustainable supply of fish.

Related social and environmental justice issues

Overfishing undermines food security by reducing the supply of a vital source of dietary protein, particularly in the coastal regions of less economically developed countries (LEDCs). Demand in rich countries is being stimulated by official recommendations that emphasize the health benefits of fish and seafood, in particular those species with high long-chain omega-3 fatty acid content. These dynamics are likely to increase health inequalities within and between populations.

Fish consumption and food security

As international demand grows,[39] competition between rich and poor countries for fish and other foods tends to increase the nutritional and economic vulnerability of those with few resources.[40,41] Meanwhile, richer and already healthier populations continue to enjoy a high level of food security.

Fish and seafood makes a substantial contribution to the human food supply, but, as described above, there are indications that supply is at the limit. Fish contributes >50% of the total animal protein intake in LEDCs such as Bangladesh, Cambodia, Indonesia, Sri Lanka and Sierra Leone, and contributes >20% of the total animal protein intake for 2.6 billion people (41% of world population). The share of fish proteins in total world animal protein supplies grew from 13.7% in 1961 to a peak of 16.0% in 1996.[31] The share declined to 15.5% in 2003.

Economic development as well as population growth is linked with rising fish consumption across the globe. A recent World Bank analysis of national fish consumption shows a clear correlation with per capita GDP.[39] For each $1000 extra in GDP, annual per capita consumption in African, Middle Eastern and Western populations is 0.8 kg higher (Figure 2). Among Asian countries the corresponding increase is larger (2.3 kg). Globally, rising demand for fish as a health and food-cultural asset in LEDCs together with richer countries is likely to generate ever higher prices as scarcity increases.

European Union fisheries access agreements

The emerging global market in food fish favours richer above poorer regions. The European Commission reports that 40% of EU fish supplies are caught in 'distant waters',[42] mainly off the coasts of LEDCs. Among the consequences, depletion of fish supplies to

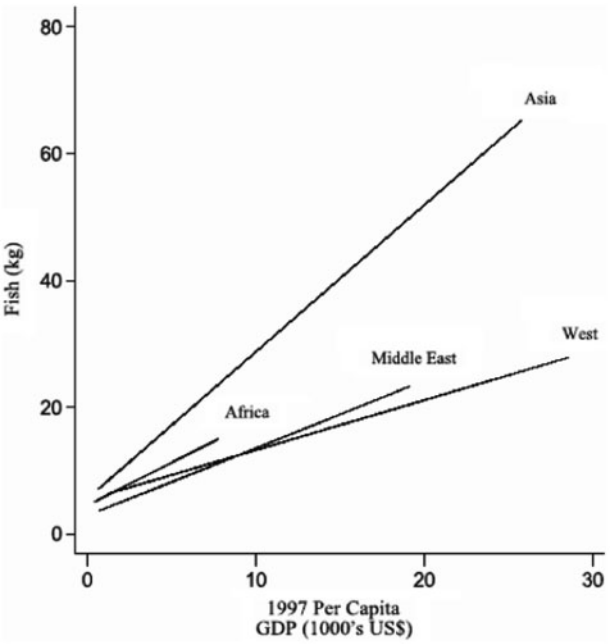

Figure 2 Per capita annual fish consumption and per capita GDP in purchasing power parity by region. Regression lines are adjusted for water area per capita, percentage urban population and latitude. *Source*: ref.[39]

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economically weak populations is a major concern. Low cost access agreements with West African nations such as Senegal and The Gambia, where fish provides over 50% of dietary protein,[34] permit EU trawlers to take tens of thousands of tons of prawns, tuna and hake and other high-value fish annually for European consumers. This practice impoverishes African fishermen and their families, deprives the local population of food and threatens the viability of marine ecosystems and their fisheries on the narrow continental shelf.[43] International agreements provide for EU fishermen to harvest the seas of poor countries, whose people rely heavily on fish for their nutrition, to feed relatively healthy and wealthy Europeans encouraged to increase fish consumption by public health advice.

Are such fisheries access agreements consistent with the principles of social and environmental justice? Debates on sustainable development point to the social inequities fostered through transfer of vital dietary resources from poorer to richer countries, and the environmental inequities generated as a result of exporting the ecological impacts of fishing from richer to poorer countries.

An inverse consumption law?

Within as well as between the rich nations, it appears that an 'inverse consumption law' is in wide operation. The 'inverse care law', formulated 37 years ago, observed that the 'availability of good medical care tends to vary inversely with the need for it in the population served'.[44] The affordability and quality of fish in the diet, in terms of nutrition and contamination, is likewise greatest for the better off. Health inequalities persist within rich economies, and the health benefits of fish potentially contribute to those inequalities throughout the life course. Starting with maternal nutritional status, access to high-quality fish and omega-3 oils is a potential health asset continuing during infant and child development through to older ages when protection from chronic and degenerative disease becomes important. In Britain, there is evidence for social disparity in oily fish intake from a recent dietary survey.[45] Male and female respondents in households receiving social security benefits were less likely to have eaten oily fish in the previous week than their better-off counterparts (men 26 vs 43%, women 27 vs 51%).

Unresolved tensions

The US National Academy of Science addressed the human health implications of fish but, despite good evidence of dwindling supply, the committee was not asked to consider related environmental concerns.[26] Such unresolved tensions point to the prospect of widening spatial and social inequalities in the availability of food fish. Reduced availability in the poorer segments of the world's population is one important impact.[42,43] In addition, if economic pressures increase within fishing communities in LEDCs, sustainable fishing practices will become harder to defend and enforce. This dynamic is even observed in the EU, which has systematically disregarded warnings from marine scientists in favour of industry demands to maintain the size of quotas. Fisheries Ministers consistently set total allowable catches (TACs) 15–30% higher than recommended by the scientists. For cod, signficant TACs remain in place around the UK although marine scientists have warned since 2002 that cod fisheries should be closed to prevent collapse. At best, this is likely to lead to the cod stocks bumping along the bottom in terms of size and yield. At worst, they could crash in a replay of the well-known Grand Banks scenario (Box 1).[33]

What can be done?

Recommendations to promote human health collide with those to promote the health of marine ecosystems and sustainability of fish stocks. In the UK, this problem is recognized in the Royal Commission on Environmental Pollution's report, *Turning the Tide* which recommends that 'studies are undertaken to examine the full environmental implications of the Food Standards Agency's advice on eating fish' (ref.[30] para 11.51). A policy review of consumer recommendations is underway. Other policy problems and areas of uncertainty are outlined below.

Box 1

The collapse of the Grand Banks cod stocks off the Newfoundland coast led to closure of the fishery in 1992. Northern cod had been fished sustainably between 1805 and 1950 with an annual yield of ~150 000 T. Factory trawlers arrived in the 1950s and yield peaked at 810 000 T in 1968. In 1992, the Canadian fisheries department found the northern cod population had declined from an estimated 1.6 MT in 1962 to 22 000 T and the stock was recognized as having crashed.

- The scientifically based fisheries management programme was not effective in preventing collapse of the cod stock, due to a combination of crude stock assessment science and a failure to heed scientific advice in setting quotas;
- Some 40 000 people lost their jobs;
- Two Bn Canadian dollars was spent to support devastated coastal communities;
- The stocks still show no significant signs of recovery and there are concerns that overfishing has pushed the ecosystem into an 'alternative stable state' in which cod are unable to recover.

Source: Ref.[33]

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The health benefits and risks of eating fish

Research on the health effects of fish consumption and omega-3 oils

Definitive studies are needed to resolve uncertainties about the health benefits of consumption of fish and the long-chain omega-3 oils. The absolute human requirement for long chain omega-3 oils is not in question.[46] Research is needed in respect of primary and secondary prevention of chronic and degenerative disease. The human requirement for long chain omega-3 oils over the life course is an important research priority, since the size of that requirement will be a key influence on food policies that address population growth.

Alternative sources of long chain omega-3 oils

Cultivated algal oils are free of contaminants and satisfy ethical considerations, but their value as a health asset remains uncertain. Oil from *Schizochytrium* for example, is rich in DHA (380 mg/g) and DPA (155 mg/g) but contains little EPA (18 mg/g). A 12-week supplementation trial found the oil was well tolerated but did not improve an array of cardiovascular risk factors.[47] Around one-third of adult omega-3 oil intake is derived from non-marine sources, particularly cereals, meat and eggs.[48] Novel alternatives deserve increased research funding. Further sources include wild and farmed terrestrial plant species such as purslane[49] and other greens (*horta*). While rich in ALA, it is unclear whether such plants could provide significant amounts of EPA or DHA. The EU-funded LIPGENE project is taking a GM approach to producing high omega-3 linseed.

The status of fisheries, fisheries management and aquaculture

Adopting the ecosystem approach

Total catch from the world's marine fisheries has reached a plateau. Adoption of an ecosystem approach to the management of the seas and their constituent populations, including designation of a network of marine reserves covering 20–30% of the total marine area, deserves careful consideration.[35]

Decoupling aquaculture and marine fishing

Further development of oilseeds rich in long chain omega-3 oil is needed as an alternative to aquaculture feed derived from marine pelagic stocks, coupled with the development of selectively bred fish that thrive on a fully or part vegetarian diet, and convert ALA to longer chain omega-3 fatty acids more efficiently.[50]

Related social and environmental justice issues

European Union and other distant waters fisheries policies

The EU must review its policy on fishing in distant waters, particularly with regard to the food security of LEDC populations. There is pressing need to address tensions between fishing policies in rich countries and commitments to promote international social and environmental justice.

Sustainability and justice

Further research is needed to identify the implications for human and ecosystem health of sourcing fish at differing trophic levels in temperate and tropical waters. Assessment is needed of the global human requirement for long-chain omega-3 oils and marine-sourced proteins, and the extent of fishing that would be required to meet this requirement. Strategies are needed to reduce demand for fishmeal for aquaculture. Non-human uses of marine capture fish products, particularly for pet food, fertilizers and as a fuel source are ethically questionable. The social and environmental equity issues arising from projected demands for caught and farmed fish and seafood need to be related to regional sources and destinations of such products. Increased funding is needed for policy development to promote social and environmental justice in relation to global marine food resources.

Conclusion

We have sought to place public health and nutritional considerations about omega-3 oils in the context of the prospects for fisheries yields and the pressing need to conserve the marine environment. Health recommendations to eat more fish add to existing pressures on the marine environment, and require a firmer evidence-base than presently exists. Population and economic growth mean there is little time left to continue fishing on the present scale without risking irreversible collapse of animal life in the oceans. Health gains based on increased fish consumption by the peoples of rich nations are likely to be at the expense of those of poor nations who already have a lower health status. Poor populations face the greatest threat from a collapse in capture fisheries, while growing awareness of risks linked to toxic contamination of fish tends to divert the highest quality produce to the elite of healthy consumers.

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