ANTHROPOGENICALLY-INDUCED CHANGES IN THE ENVIRONMENT: EFFECT ON FISHERIES

Katherine RICHARDSON

ABSTRACT

In considering "responsible fisheries," the focus is usually on potential effects of fisheries on ecosystems and habitats (i.e. effects of fisheries on the environment). For most, the term "responsible fisheries" implies a need for a change in fishing practices to improve the state of the environment. The state of the environment, however, also inevitably affects fish and therefore fisheries. Many societal activities influence the state of aquatic environments. Thus, in moving towards "responsible fisheries," changes in societal activities other than fisheries alone may also need to be considered.

The indirect (i.e. non-fishing) effects on fish and fisheries can be divided into two types: those that affect ecosystem structure or population processes, such that recruitment to the fishable stock is reduced, and those that affect the quality (and hence marketability) of the fish product. Environmental changes that can influence recruitment include land use changes that may alter habitats for fish. Damming and re-routing of streams and rivers may reduce access to spawning grounds for fishes that migrate between salt and freshwaters. Erosion (leading to increased turbidity) and eutrophication lead also to changes in habitats and food availability that can also affect recruitment. Intentional and unintentional introductions of new species to a region can alter ecosystems to the point that fisheries are severely affected. All of these influences are well described for individual stocks or local regions. However, a global assessment of the quantitative impact of such changes on fisheries is lacking.

Chemical contamination of aquatic ecosystems can influence the physiology of organisms and thus both the recruitment and the marketability of fish products. Many studies dealing with the potential toxicity of contaminants to physiological processes at the cell and organism level have been carried out. However, few studies have dealt with the effect of contaminants at the population level and thus attempted to quantify the effects of environmental contamination on fisheries. Monitoring of contaminant concentrations in fish meat is, in many regions of the world, standard protocol as part of public health protection measures, and some fisheries, especially in fresh and semi-enclosed marine waters, have been restricted as a result of such contamination. Although, in most cases, contaminant concentrations in wild fishes have been found to below the levels considered to be safe for human consumption, recent studies have shown that, for example, PCB contaminant levels in the muscle of wild fishes are higher than those found in meat produced in commercial agriculture. As knowledge concerning the effects of contaminants on human physiological processes increases, the contaminant concentrations considered as safe for human consumption are being reconsidered and, in some cases, reduced. Thus, the fact that wild fish meat is among the most contaminated with respect to PCBs of the common meat protein sources for the human population suggests that environmental effects on fisheries will be an area of increasing concern in coming years.

Katherine RICHARDSON

Dept. of Marine Ecology, University of Aarhus
Finlandsgade 14
DK-8200 Aarhus N
Denmark

Tel: INT+45+ 89 42 43 80
Fax: INT+45+ 89 42 43 87
E mail: Richardson@biology.au.dk

Introduction

[1] Fish and shellfish for human and animal consumption are taken through harvest of natural stocks, harvest of "ranched" (released) stocks, and a variety of aquaculture activities. All of these types of fishing activities affect the environment and, for most, the term "responsible fisheries" implies efforts to ensure that the environmental interactions and consequences of fishing activities are brought into or kept within levels deemed acceptable by current standards of society. Thus, there are both natural science (identification of environmental effects of fisheries) and social science (quantification of the acceptable social norms) components to the consideration of "responsible fisheries."

[2] There is, however, yet another aspect of natural science investigation that is relevant to, but often overlooked in, the consideration of responsible fisheries: changes brought about by human activities in the state of the environment and the influence of these changes on the health and size of fish stocks and/or the marketability of fish products. That the state of the environment affects both the survival and recruitment of fish stocks is well known, and considerable research effort has been devoted to a description of the effects of fluctuations in, for example, temperature, salinity, food and predator abundance on fish stocks. The assumption in considering the influence of these fluctuations in environmental variables on fish stocks is, however, as a rule, that that the root causes of the observed fluctuations are not under anthropogenic control. There is, however, increasing evidence that human activities are influencing climate as well as other aspects of the environment important for the recruitment and survival of fish stocks (see Steffen and Tyson, 2001, for review).

[3] Responsible fisheries should, then, include "responsible (i.e. socially acceptable) care or conservation" of the stocks to be fished. Thus, the influence on fish stocks of anthropogenically-induced changes in the state of the environment is an obvious and important consideration when developing a strategy for carrying out "responsible fisheries."

[4] The state of the environment can influence fisheries in two fundamentally different ways: either by changing the state of the stock to be fished (numbers, condition and/or health), or by affecting the marketability of the fish products, themselves (i.e. contaminant content in excess of public health standards for human consumption). Of course, natural as well as anthropogenically-induced changes in the state of the environment influence the status of fish stocks. Thus, a major challenge in quantifying human impact on the status of fish stocks is differentiating the anthropogenically-induced from the naturally occurring changes in the state of the environment. In some cases, especially those involving construction projects (i.e. dams) that have impeded the passage of diadromous species between marine and freshwaters (e.g. salmon fishes in many regions of the world), it is relatively easy to quantify the human influence on fish stocks and fisheries. However, in most cases, differentiating the natural and anthropogenically-induced environmental change signals one from the other is not yet possible.

[5] In the case of the influence on fisheries of the introduction via human activities of contaminants to aquatic systems, separating the anthropogenically-induced from the natural signal in environmental change is more straightforward. Here, however, the scientific challenge is quantifying the effect of contaminants at the level where fisheries may be affected (i.e. the population level). Tens of thousands of studies have been carried out during recent decades in which the effects of various contaminants on the physiology of fish and shellfish have been examined. However, in almost all cases, the effects being examined have been at the level of the cell or individual organism. Studying effects of contaminants at these levels is essential in order to understand the mechanisms by which contaminants may influence fish stocks. However, it is not possible to directly extrapolate results from studies carried out at the level of the cell or individual to the fisheries-relevant level of populations. Again, this is, at least in part, because of the fact that the population is being influenced by other environmental factors rather than the contaminant exposure alone.

[6] The purpose of this paper is to review the current state of knowledge with respect to the effect on fishes and fisheries of anthropogenically-induced changes in the environment. The primary focus of the paper is contaminants and their effects on fish and fisheries. However, the influences of other human activities on fish and fisheries, as well as some efforts to quantify the effects in economic terms of selected activities or events on specific fisheries, are also briefly reviewed in order to present a complete outline of the potential influence of non-fisheries-related human activities on fisheries and to provide the reader with relevant references for further study of this complex aspect of responsible fisheries.

Land use changes and their impacts on fisheries

[7] The largest and therefore economically most important commercial fisheries in the world are marine. The oceans also extend over large regions of the earth and are characterized by large water volumes and rapid water circulation. This means that the footprint of human activities on the environment will be relatively easily eroded in marine environments. Thus, marine regions and the most important world fisheries will be the last of the aquatic ecosystems to be obviously affected by human activities. Nevertheless, there is now evidence from many coastal and semi-enclosed sea areas that changes in land use practices are influencing the state of the marine environment and, potentially, fisheries (e.g. Caddy, 1993). This realization has put the consideration of anthropogenically-induced changes in the environment on the global agenda. However, examples of the influence of land use change on fish and fisheries in freshwater systems are plentiful and well documented. Loss of or changes in fish stocks resulting from human activities have been documented in thousands of lakes and rivers (Maitland, 1995). In considering the potential influence of human activities on marine fisheries, much can be learned from the historical experience in freshwater systems (e.g. Caddy, 1993).

[8] From freshwater systems, it is well documented that land use changes can seriously affect fish stocks and fisheries (see, for example, Maitland, 1995). River obstructions such as dams can block migration routes for diadromous species and change habitats in such a manner as to make them unsuitable for fish stocks (i.e. increase sedimentation in spawning habitats). Land drainage schemes can change (or even eliminate) the water content of ponds and lakes and alter flow and siltation rates in adjacent waterways. Land use changes that increase erosion to surrounding waters can not only affect siltation rates but also the turbidity of the water, that may influence predator-prey interactions crucial to the survival of fishes.

[9] Farming activities lead to the runoff of nutrients and pesticides to adjacent water bodies. This nutrient enrichment can lead to eutrophication. In freshwater systems, this phenomenon has been well studied and it is now realized that eutrophication is also occurring in many coastal marine areas (see Jørgensen and Richardson, 1996). In its mildest form, it affects fish and fisheries by changing the availability and type of food for the fishes. In some cases, mild eutrophication may increase food availability for food-limited fish stocks and actually increase the fish available for harvest by the fishery (e.g. Nielsen and Richardson, 1996). Thus, anthropogenically induced changes in the environment need not necessarily be negative for fisheries. In more severe cases of eutrophication, however, hypoxia and anoxia develop making the environment uninhabitable for some or all fishes. There is also some evidence (see Richardson, 1997) that nutrient enrichment of coastal areas may have increased the incidence of toxic algal blooms. Some of these blooms contain ichthyotoxins that have a direct impact on fish. Others contain toxins that endanger the human consumer of fish or shellfish products. Thus, the presence of these latter algal toxins in fish or shellfish can affect the marketability of these products.

Introduction of non-indigenous species: impact on fisheries

[10] Non-indigenous species can be introduced intentionally (i.e. with the intent of developing a new fishery) or non-intentionally (with ballast water; through biofouling of ship hulls, etc.; the

building of canals; or in association with organisms migrating or actively transferred between different regions). Most non-indigenous species do not survive when introduced to a new environment. However, there are numerous examples of introductions that have had unexpected and dramatic consequences on fisheries.

[11] The most often quoted example of fishery effects following the introduction of a new species is that of the Black Sea, where the ctenophore, *Mnemiopsis leidyi,* was introduced (presumably with ballast water) in 1992. Russian scientists documented that in some years following the introduction, up to about 95% of Black Sea wet weight biomass was comprised of this organism (Travis, 1993). In Azov Sea, fish (primarily anchovy) catches dropped by an estimated 200 000 tons, with the estimated loss to the fishery estimated at US$ 250 million (Travis, 1993).

[12] Another important and well documented example of an accidentally introduced alien species influencing a fishery is the introduction, in the 1970s, of *Gyrodactylus salaries* into Norwegian rivers with salmon released from infected hatcheries. The *Gyrodactylus* acts as a parasite on salmon and has seriously reduced catches in infected rivers (Johnsen and Jensen, 1991). This parasite continues to pose a problem for the sports fishery on salmon in Norway. As it affects a sports fishery, the economic consequences of the introduction of this species are far-reaching and include the tourism industry and the local communities that relying on this tourism.

[13] Intentional introductions of alien species can also have unpredicted effects on the ecosystems into which they are introduced, including effects on other fish species and fisheries. Some the best documented examples of intentional introductions are those of the Nile perch (*Lates niloticus*) and the Nile tilapia (*Oreochromis niloticus*) and other tilapia to the large African lakes, Lake Victoria and Lake Kyoga, in the 1950s and 1960s. These species were introduced with the purpose of establishing a fishery on these species and, indeed, successful fisheries were established on these species. Concomitant with the development of the new fisheries, however, the stocks of many of the indigenous fishes collapsed. These collapses have widely been attributed to predation by and competition with the introduced species. This interpretation has, however, been questioned by some authors (e.g. Ogutu-Ohwayo, 1990; Kudhongania *et al.,* 1992). Both of these studies suggest that lack of effective fisheries management, the use of destructive gear and overfishing may also have had a profound effect on the state of the indigenous stocks. It has also been pointed out that even before the introductions, eutrophication was altering the lakes (Kaufman. 1992) and that eutrophication effects may also have contributed to the demise of the indigenous stocks. Thus, while it is not possible to isolate the effect of the introduction of the new species on the indigenous stocks in these lakes, the introductions of the new species was certainly one of a number of anthropogenic modifications of the environment that, ultimately, led to the collapse of the indigenous stocks.

[14] Far fewer introductions of fish species have occurred in marine waters than in freshwaters. Nevertheless, at least 120 fishes have been introduced to marine waters foreign from their source of origin (Baltz, 1991). Many of these introductions were intentional, and introductions designed to improve fisheries in marine waters have been carried out since the late nineteenth century. The Soviet Union was, during the twentieth century, most active in terms of attempting introductions of fish species in an attempt to create new fisheries. In all, 42 attempts at introducing 29 different species were attempted by the Soviet Union. Of these attempts, large populations of the introduced species developed in only 11% of the cases, and small populations in 5%. In many cases, however, the introductions had a serious impact on the endemic fish species. This was particularly true in closed ecosystems (Baltz, 1991).

[15] An interesting modification on the theme of introduction of alien species is when a genetically modified (either by selective breeding in captivity or actual gene manipulation) organism is released to the wild and begins interacting and breeding with its wild counterpart (e.g. salmon in the River Vosso, Norway: Sægrov *et al.*, 1997). Technically speaking, this example

does not represent the introduction of a non-indigenous species as the salmon are already a part of the river ecosystem. However, the replacement of wild stock with the reared salmon does have potential repercussions for the fishery as the genetic composition of the reared salmon may not be as robust over time for environmental variability as the wild stocks. Thus, recruitment in mixed wild/reared stock could potentially differ from than that which would be achieved by the unadulterated wild stock.

Impact on fisheries of conservation measures

[16] Changes in the relative abundance of organisms in the various trophic levels of the marine food web will, clearly, influence the function of the web. In recent years, large predators that feed on fish such as marine mammals and birds have been the objects of considerable conservation interest. Protection measures have been taken in the EU, for example, with respect to whales, seals and many marine birds. In a number of cases, these protection measures have been highly successful and the previously diminished or endangered stocks of top predators are now thriving. Examples are some seal populations in the Baltic, and cormorants along the Baltic and Kattegat coasts. As these large predators often feed exclusively on fish, an increase in population size will certainly imply a greater predation pressure on fish stocks affected by these predators. The magnitude of the increased predation pressure on fish stocks due to increased predator abundance has not been determined. However, some – especially coastal fishermen working, for example, in areas in close proximity to large cormorant colonies – are convinced that the competition for fish resources between these large predators and fishers is intense. Thus, for these fishers, at least, the conservation of species at the higher trophic levels of marine food webs represents an anthropogenically-induced environmental effect on fisheries.

[17] In the wake of the Earth Summit Meeting in 1992 and the subsequent ratification by many countries (178 as of August 2000) of the Biodiversity Convention, whereby countries commit themselves to the preservation of the Earth's biodiversity, many countries are establishing or considering the establishment of marine protected areas, where mechanical intervention in the ecosystem (i.e. fishing activities) is restricted and nature is allowed to develop according to its own premises. Although there are anecdotal reports of improved fisheries in waters abutting such protected areas, most fishers perceive the establishment of marine protected areas as an anthropogenically-induced environmental effect on (restriction of) fisheries.

Conflict with other users of aquatic ecosystems: Impact on fisheries

[18] A number of fishers are concerned about the possible influence on fish behaviour and/or survival of disturbance caused by non-fishing users of aquatic environments. For example, seismic activities carried out in association with oil and gas prospecting have attracted particular attention from fishers in some areas, as activities that may potentially interfere with fish survival and behaviour. The significance of seismic activity for fisheries has not been quantified, although some workers have reported mortality of larval fishes located in close proximity to the air guns used to generate acoustic signals (Dalen and Knudsen, 1987).

[19] Sand and gravel dredging, either for the purpose of extracting the sand and gravel for use on land or as a part of construction projects (i.e. establishment of artificial islands or bridges) at sea can also affect fisheries by, for example, increasing water turbidity, frightening fish away and/or releasing contaminants to the water column from disturbed sediments. DeGroot (1979) estimated the cost to the Dutch shrimp and sole fisheries of a proposed establishment of some artificial islands in the North Sea at 10 million guilders.

Contaminants in the environment: Impact on harvestable marine organisms

General responses to contamination:

[20] Contaminants are substances that are toxic to living organisms. They may occur naturally in the environment or they may be chemicals produced through human activities. Both naturally

occurring and anthropogenically introduced contaminants can influence fisheries. For example, Shilts and Coker (1995) report on a commercial trout fishery in a remote area which had to be closed due to high levels of mercury from a geological source (i.e. mercury not anthropogenically introduced into the environment). Some contaminants are required at low levels in living organisms (i.e. metals such as copper, zinc and iron) and only become toxic at high concentrations. Metals such as cadmium, lead and mercury have no biological function and generally are toxic at much lower concentrations than copper, zinc or iron. Contaminants are often referred to as "xenobiotics" or "micropollutants."

[21] Of the contaminants produced by human, the most toxic are generally the chlorinated or brominated compounds. Examples of these include pesticides (DDT, lindane), brominated flame retardants, dioxins and PCBs. These compounds are very persistent in the environment – which explains why chlorinated and brominated compounds are found in Arctic animals – far from the sites of production and entry into the environment.

[22] Two different approaches can be used to examine the effects of contaminants on fishes. The effect of individual contaminants on fish can be examined in toxicity studies carried out in the laboratory, where the fish are exposed to controlled concentrations of the contaminants under investigations. Such studies can help elucidate the responses to specific contaminants at the level of the cell or individual. However, in nature, fish are not simply exposed to single contaminants but to a variety of natural and anthropogenically induced environmental stresses. Therefore, laboratory exposure studies are seldom very informative with respect to responses to contamination at the population level (i.e. the level relevant to fisheries). For understanding responses at this level, field studies are much more useful. Several general observations can be made concerning the results from field studies comparing fish from areas of relatively high and low contamination, respectively. The first concerns fish health.

[23] Individual fish have always been susceptible to disease and infection. However, there are increasing reports of disease outbreaks involving large numbers of fish. Many studies (e.g. Malins *et al.*, 1984, 1985; Couch and Harshbarger, 1985; Murchelano and Wolke, 1991; Vethaak and ap Rheinallt, 1992; Chu and Hale, 1994; Myers *et al.*, 1994; Vethaak and Jol, 1996) have shown correlations between contamination levels or exposure to water taken from contaminated regions. As noted, cause and effect are not necessarily demonstrated by such correlation studies, but toxicity studies carried out under controlled laboratory conditions (see below) are now identifying physiological mechanisms whereby the immunological system of fishes are influenced by some contaminants, thus confirming a link between fish health and contaminant exposure.

[24] Another general observation that can, in some cases, be made at the population level is endocrine disruption, which occurs when natural or synthetic chemicals interfere with the normal hormonal activity in wildlife. Among the synthetic chemicals that may cause endocrine disruption are PCBs (polychlorinated biphenyls) and organochlorine pesticides. The most publicized example of endocrine disruption is that of the influence of tributyltin (TBT), a herbicide contained in anti-fouling paints, on some marine gastropods. The TBT induces imposex in these snails and, ultimately, may reduce or remove the population's ability to reproduce itself. This phenomenon was first discovered in the North Sea on gastropods not used in fisheries or aquaculture. However, in, for example, southeast Asia, where gastropods are more extensively used in aquaculture, endocrine disruption caused by TBT contamination could potentially directly affect the production from these aquaculture facilities.

[25] For finfish, endocrine disruption has been most noted and studied in freshwater fishes. Downstream of some sewage treatment plants in the UK, male fish have been observed to produce the yolk-precursor protein, vitellogenin (Harries *et al.*, 1996; 1997). Natural and synthetic steroid human hormones that are found in sewage effluent appear to be an important source of potentially endocrine-disrupting compounds in the environment (Desbrow *et al.*, 1998). The occurrence of

endocrine disruption in the natural environment has only recently been realized and its ecological significance, if any, has not yet been quantified.

[26] Another general response to contamination (and one which may be related to endocrine disruption) is alteration in reproductive behaviour. Relatively few studies have considered reproductive behaviour in relation to contamination: Jones and Reynolds (1997) reviewed existing literature and found that out of the about 20 000 reported scientific investigations on the effects of contaminants on fishes that have been carried out over the last two decades, only about 0.1% have considered the effect of contaminants on reproductive behaviour. Behaviour abnormalities that have been noted in association with contaminants or thermal pollution include effects on courtship (changes in the frequency of displays or the duration of courtship or male-like activity in females) and parental care (changes in nest-building activity, defence of the young, or changes in the parental care role). Bioassays where test fishes are monitored for changes in reproductive behaviour following exposure to potentially contaminated water have been suggested as possible supplemental tests in routine monitoring for contaminants (see review by Jones and Reynolds, 1997).

[27] Finally, it should be noted that, in some freshwater systems, a general acidification resulting from industrial contamination of the atmosphere and subsequent acidification of precipitation has had serious ramifications for fishes and fisheries. Arctic char may be particularly sensitive to acidification (Hesthagen and Sandlund, 1995). The whole process of lake acidification demonstrates that fish and fisheries need not be in the immediate vicinity of an environmental contamination source to be affected. The industrial emissions responsible for the acidification of rain are often located far from the site of the resulting acidification. Marine systems are less prone to acidification than freshwater systems because of the carbonate buffering system in seawater.

Specific types of contamination and their effects:

Pesticides

[28] Pesticides are usually organoclorines and can be extremely toxic to fish. An estimated 50 000 kg of dead fish were reported in 1985 in the Miranda River in South America as a result of pesticide exposure, although, in that case, the pesticide may have been deliberately introduced to the river as part of a political gesture (Alho and Vieira, 1997). Pesticides are considered to be one of main reasons for the demise of the commercial fishery in the Azov Sea. In the late 1980s, pesticide input to this sea was about 100 000 t/yr and consisted primarily of compounds from the DDT group (Semenov *et al.*, 1998).

[29] Pesticides have a recognized effect on biology, although the mechanism of the effect may be different for each stage of an organism's development (Kobayashi *et al.*, 1991). Pesticide exposure (to chlordane, DDT, lorsban, and lindane) decreases the protein content in shrimp and increases their respiration (Reyes *et al.*, 1996). Concern about the potential effects of pesticides on the production of fish products is particularly relevant for countries, such as Egypt, where aquaculture activities are carried out using runoff water from agricultural activities and, indeed, considerable research concerning the effects of pesticides on fishes used in aquaculture have been carried out here (e.g. Shalaby *et al.*, 1995).

[30] Tributyltin (TBT) is a well known pesticide used in anti-fouling paints. However, organotins are also used as stabilizers in PVC and can enter the environment in connection with PVC production. Organotins are ubiquitous in the marine environment and can threaten coastal fisheries (e.g. Davis *et al.*, 1999; Manning *et al.*, 1999)

[31] Fish and crustaceans have enzymes that may facilitate a more rapid elimination of TBT than molluscs and other organisms (Lee, 1991) and TBT may be less prone to bio-accumulation than some other organotin compounds. Nevertheless, organotin concentrations in fishes collected in

the Netherlands suggest that the survival of these fishes might be threatened as a result of the concentrations they had accumulated (Stäb *et al.*, 1996).

[32] Other studies have also suggested that fish population exposed to naturally occurring concentrations of TBT may suffer effects that could influence the fishes at the population level. The maximum concentrations of TBT in Chesapeake Bay have been reported to be sufficient to lead to larval mortality and, hence, influence recruitment in striped bass (Pinkney *et al.*, 1990). Potential risks of mortality for both fish and zooplankton have been calculated at the concentrations of TBT predicted in marinas during and after TBT clean-up operations (Traas *et al.*, 1996).

[33] TBT exposure has also been related to a reduction in the efficiency of the immune response in fish. Exposure of flounder to TBT concentrations similar to the highest found in nature caused mortality after 7 – 12 days. This was associated with gill lesions, reduced immune activity and a reduction in the volume of the thymus (Grinwis *et al.*, 1998, 2000). These same authors have suggested that TBT might have a causal role in the prevalence of lymphocystis viral infections in nature. Also shellfish have been identified as showing a reduction in immune efficiency following exposure to TBT. Exposure increased susceptibility of oysters to a parasite pathogen (*Perkinsus marinus*). In addition, animals exposed to TBT may succumb at lower levels of pathogen infection than non-TBT- exposed animals (Fisher *et al.*, 1999).

Oil contamination

[34] In areas with chronically high concentrations of oils, mortalities of fish and shrimp fry have been recorded (Ramamurthy, 1991). Oil spills provide a unique opportunity to examine responses of fish populations to unique contamination events rather than to chronic exposure of a contaminant that is more common. There are also often resources available for monitoring of biological impacts following an oil spill. Perhaps the most dramatic of an oil pollution event on fisheries occurred in the Saudi Arabian shrimp fishery following the 1991 Gulf War. In the Gulf, the effect of oil spills was most noticeable along the Saudi Arabian coast. In the summer of 1991 (i.e. following the oil spills occurring in connection with the war in February 1991), the landings of shrimp fell dramatically and the landings contained only a small proportion of sexually mature adults (Mathews *et al.*, 1993). In the subsequent period, spawning stock biomass fell to approximately 1.8% of pre-war level and the total biomass to <1.5% of the pre-war biomass (landings in 1989: 4000 t; 1992: 25 t). A man-made recruitment failure of the shrimp resulting from the oil spills is suspected. However, due to lack of monitoring data and research activity, the mechanism(s) leading to the recruitment failure has(have) not been identified (Mathews *et al.*, 1993).

[35] Other oil spills have also provided opportunities to investigate the influence of oil contamination on fish and shellfish, both at the individual and the population level. Squire (1992) considered possible effects of a 1969 oil blowout in the Santa Barbara Channel on three pelagic fisheries: northern anchovy, jack mackerel and Pacific bonito. Although the latter two species exhibited a reduced abundance in the area during the months immediately following the oil blowout, Squire concludes that pelagic fish species are relatively lightly affected by such a contamination event.

[36] Following the *Exxon Valdez* spill in 1989 in Prince William Sound, suitability of the sediments as spawning grounds for salmon were monitored for a number of years. Leaching of polycyclic aromatic hydrocarbons (PAHs) from the substrates in several rivers exceeded the concentrations believed to be lethal to salmon embryos up to and including the year 1993 (Murphy *et al.*, 1999).

[37] The fish and shellfish fisheries in proximity to the *Sea Empress* Oil spill in Wales (1996) were closed as a precautionary measure for consumers. Associated monitoring showed that fish and crustacea only took up small concentrations of PAHs, but molluscs took up whole oil into

their tissue. This, and a number of earlier studies, indicates that filter feeders more readily accumulate oil than other feeding types (Law *et al.*, 1999).

[38] The responses of both salmon and dab were recorded in the aftermath of the *Braer* oil spill at the Shetland Islands in Scotland in 1993. Salmon, and to some extent dab, responded immediately to the spill by producing detoxification enzymes. The fact that dab were less inclined to produce these enzymes may suggest that the PAHs harboured in the sediment following the incident were not directly bio-available to the fish. There was also some evidence of liver pathology in the dabs taken from the most contaminated sites in the year following the spill. However, a cause-and-effect relationship between the oil contamination and the liver pathology was not established (Stagg *et al.*, 1998).

[39] Finally, it has been suggested that offshore drilling may be a possible source of hormone mimics or endocrine disrupters in the marine environment, as PAHs and alkylphenols are released through these activities. Newer studies, however, suggest that, in the North Sea, accumulation of endocrine disrupters in wild fish is more likely to be as a result of estuarine exposure to these chemicals than from offshore oil extraction activities (Lye, 2000).

Contamination of fisheries products and public health standards

[40] Heavy metal contamination was the first form of contamination recognized as a threat to human health, and many areas routinely monitor fish products for heavy metal contamination and have established public health standards that fish products, by law, must meet. Many examples can be cited from around the world of fish products containing heavy metals in concentrations that exceed established public health standards. For example, choosing examples randomly to show the geographic extent of the problem: 50% and 35% of fishes from two rivers in the Pantanal (floodplain western Brazil and Bolivia) have mercury levels above the recommended standards (Alho and Vieira, 1997). Eels in some eastern English rivers exceeded standards for metal contamination, but as eels are not generally eaten in England, this is not considered to be a problem (Barak and Mason, 1990). Molluscs in Ria Formosa Lagoon, Portugal, contain metal concentrations considered unsafe for human consumption (with mass mortalities attributed to environmental degradation, but mechanism not specifically described) (Bebianno, 1995).

[41] As indicated, these examples are far from unique. Most countries can identify areas near harbours or industrial effluent outlets where metal contamination is a problem, especially for shellfish and more stationary fish species that remain in the area of contamination. In some areas, such as the Aswan Lake, metal concentrations in fish are used as bioassay indicators for contamination (Rashed, 1999).

[42] Mercury contamination in fish is a problem being awarded increasing public awareness. Recent studies have indicated that children of mothers in the Faeroe Islands with a heavy body burden of mercury (in the case of Faeroese women, resulting primarily from the consumption of whale meat) have children demonstrating a statistically significant reduction in intelligence (P. Grandjean, University of Southern Denmark, pers. comm.). In the USA, health authorities have warned pregnant women and women of childbearing age who might become pregnant not to eat more than 12 oz of certain types of fatty marine fish per week because of mercury contamination (Anon., 2001). Thus, despite the fact that the dangers associated with consumption of mercury contaminated fish have been known for decades and legislation has been in effect to reduce the input of mercury and other metals to the aquatic environment, the perceived public health risks associated with eating wild fish are, due to mercury contamination, greater than they have ever been. This is, of course, in part due to a greater awareness of effects of these metals at low concentrations, but can also be attributed to a greater accumulation of metals in some marine organisms than could be could be predicted on the basis of contamination levels alone.

[43] Similar concerns are now also being raised concerning the dioxin concentration in wild and cultured fishes. Dioxins enter the environment with industrial waste and as products of

incineration and they are considered to be carcinogenic. A recent report from the EU (http:/europa.eu.int/comm./food/fs/sc/scf/outcome_en.html) indicates that contamination by dioxin of fish products (both wild and farmed) in the European Union is much greater than in commercially farmed terrestrial sources of meat protein. The contamination is greatest in fatty fishes and fish meal, and for fishes coming from the Baltic and North Seas. The fact that the aquaculture industry relies on fish meal as a staple in the feeds used in culturing activities almost certainly explains the high concentrations recorded in cultured fishes. A European official has been quoted in the popular press (Simons, 2000) as follows: "Nobody is saying we can't eat fish anymore, but consumers must be made aware that fish contributes significantly to the intake of dioxins" and "…if you eat fish every day, you are likely to have a problem."

[44] In contrast, radioactive contamination of fishes seems unlikely to pose a threat to the public health quality of fish products. Radionuclides originating from anthropogenic activities enter the marine environment from nuclear weapons testing, global fallout, releases from nuclear facilities, dumping of radioactive waste, and accidental delivery (nuclear submarine and aircraft accidents at sea, as well as terrestrial accidents such as the Chernobyl incident). Considerable public concern and attention has been focused on radioactive contamination of the sea and its resources (see, for example, Klungsøyr *et al.*, 1995). Not surprisingly, the concentrations of anthropogenically introduced radioactivity (^{137}Cs) are highest in those seas nearest the site of the Chernobyl accident (Baltic, Irish, Black Seas and the northeast Atlantic). Nevertheless, a recent review suggests that, even in these areas, the contribution of anthropogenically introduced radioactivity to the total radioactive contamination of marine fishes is very small (100-1000 times lower) and that the radioactivity consumed with marine fishes is well below the established "safe" levels for consumption (Livingston and Povinec, 2000).

Quantifying the consequences of anthropogenic activities on fisheries

[45] Marine resource availability is, of course, dependent on many factors. These include climate and availability of food and abundance of predators. Much research has been focused on identifying the influence of factors such as temperature, food availability and ecosystem structure (including predator abundance) on recruitment to the fishable stocks. Much less effort has been devoted to assessing the impact of anthropogenic activities (both terrestrial and marine) on fish stocks and fisheries. Clearly, however, the status of fish and shellfish stocks is not independent of the conscious and unconscious use by humans of aquatic environments. Quantifying the effect environmental degradation due to anthropogenic activities is not always straightforward.

[46] Boreman (1997) discussed methods of comparing the impacts of habitat degradation due to pollution as opposed to fishing of fish populations. He concludes that the science of aquatic environmental impact assessment on fish stocks is clearly not yet at the same level as traditional stock assessments and admonishes administrators not to use additional harvest restrictions as an alternative to trying to further understand the environmental influences on fish stock sizes.

[47] Lipton and Strand (1997) provide a very accessible overview for the non-economist of the factors to be taken into account and the theory behind estimating the economic costs for fisheries of a pollution-related event. These authors point out that a major problem in making such estimates is the lack of any baseline data to describe what the earnings would have been from the lost fishery. Another problem they identify is that the economic loss with respect to a polluted fishery will also depend on the availability of alternative fishing sites. Using standard economic modelling techniques, the losses will be greater for those fishers who have no alternative fishing area than those who have, even though the cost in biological terms will be the same following a pollution event regardless of proximity to alternative fishing grounds.

[48] Using standard economic models, several authors have attempted to place a market value on the economic losses experienced by fisheries as a result of specific environmental catastrophes or pollution events (e.g. Kahn, 1987; Clites *et al.*, 1991). Estimating the economic consequences of oil spills and accidents has attracted considerable attention from the economic community and a

number of models for making these estimates have been developed (e.g. Reed *et al.*, 1984; Spaulding *et al.*, 1985; Gringalunas *et al.*, 1986, 1988). Heen and Andersen (1994) describe a general approach for identifying regional impact of environmental incidents such as oil spills on, for example, fish farms.

[49] Cohen (1995) estimated the economic losses of the 1989 *Exxon Valdez* spill to the south-central Alaskan Fishery (salmon, shellfish, herring, halibut and groundfish). The upper estimates of cost established in that study were US$ 108 million during the first year and US$ 47 million during the second year. Kahn and Buerger (1992) considered the effects of two different forms of environmental stresses on the striped bass fishery of the Hudson river: general environmental deterioration of the river; and PCB contamination of the bass. They concluded that the environmental deterioration of the river generated annual losses of US$ 2.3 – 7.7 million and the PCB contamination between US$ 0.745 –3.7 million.

Conclusions

[50] Anthropogenically-induced changes in aquatic environments are having an effect on natural fish populations and, ultimately, on fisheries. Usually, however, these effects are not possible to quantify. This is often because natural changes or fluctuations in the environment are occurring simultaneously with the anthropogenically-induced changes. Fish are exposed to a variety of environmental stressors at all times and identifying the effect of individual stressors on the fishable population is seldom feasible. This makes the signal from the anthropogenically-induced changes impossible to separate from the signals of other stressors. This is especially true in cases where the anthropogenically-induced effect is related to ecosystem interactions that are poorly described or understood.

[51] It is more feasible to estimate the (economic) consequences of individual environmental incidents resulting from human activities (such as oil spills) on specific fisheries, and a number of economic models have been developed for that purpose. The effects of human activities on fish and fisheries are most obvious and easiest to elucidate in enclosed freshwater system and in estuarine systems where the impact of human activities is greatest. However, there is now considerable evidence that wild fishes in marine stocks – even in what has previously been considered open waters, relatively free from human impact – are also influenced by changes in the environment brought about by human activities.

[52] Much of this evidence is in the form of chemical contamination. Some disturbing signs of endocrine disruption are being observed in wild fish stocks. It is not clear what chemical(s) are responsible for this disruption or whether this endocrine disruption has ecological consequences. However, elucidating the causes and consequences of this disruption must be a top priority for further research. Increased concern has recently been expressed about the relatively high concentrations of some well-known contaminants (i.e. mercury and dioxin) in wild fishes. Pregnant women are being advised against eating large quantities of some fishes in the USA due to mercury contamination. As knowledge concerning the effects of low-dosage exposure to certain chemicals increases, the concern about contamination in wild fishes may be likely to increase. Thus, an important aspect in establishing a “responsible fishery” in the future may be to further restrict the input to aquatic environments of chemical contaminants.

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