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The impacts of fishing on marine birds

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Birds are the most conspicuous, wide-ranging, and easily studied organisms in the marine environment. They can be both predators and scavengers, and they can be harmed by and can benefit from fishing activities. The effects of fishing on birds may be direct or indirect. Most direct effects involve killing by fishing gear, although on a lesser scale some fishing activities also disturb birds. Net fisheries and hook fisheries have both had serious negative effects at the population level. Currently, a major negative impact comes from the by-catch of albatrosses and petrels in long-lines in the North Pacific and in the Southern Ocean. High seas drift nets have had, prior to the banning of their use, a considerable impact on seabirds in the northern Pacific, as have gillnets in south-west Greenland, eastern Canada, and elsewhere. Indirect effects mostly work through the alteration in food supplies. Many activities increase the food supply by providing large quantities of discarded fish and wastes, particularly those from large, demersal species that are inaccessible to seabirds, from fishing vessels to scavengers. Also, fishing has changed the structure of marine communities. Fishing activities have led to depletion of some fish species fed upon by seabirds, but may also lead to an increase in small fish prey by reducing numbers of larger fish that may compete with birds. Both direct and indirect effects are likely to have operated at the global population level on some species. Proving the scale of fisheries effects can be difficult because of confounding and interacting combinations with other anthropogenic effects (pollution, hunting, disturbance) and oceanographic factors. Effects of aquaculture have not been included in the review.

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Key words: by-catch, discards, fishing, indirect effects, mortality, seabirds.

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Introduction

Marine birds, including species that primarily use intertidal (shorebirds) and littoral areas (e.g. seaducks) as well as seabirds, many of which feed further offshore, are the most conspicuous, wide-ranging, and most easily studied organisms in the marine environment. There are around 320 species of seabirds and a greater number of shorebird and seaduck species, depending on which avian groups are included, and on taxonomy. Birds can be predators (and prey) and scavengers. As inhabitants of the maritime environment, marine birds are affected by human use of the sea and its coasts, and because fisheries are one of the most widespread uses, by fishing activities in particular. Birds can be harmed by, and can benefit from, the fishing activities of humans and some of the effects can be shown to operate at the population level.

Direct impact: by-catch

Any net set within the feeding range of seabirds carries the risk of an unintentional by-catch. Similarly, lines of hooks, particularly those with bait, may catch seabirds.

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The scale of the by-catch varies with many factors, including time and location of fishing, precise fishing method (many measures to reduce or mitigate effects work through subtle alterations in method), behaviour of the target species, nature and abundance of seabird prey, and demography of the seabird populations.

Long-lines

Long-line fishing is one of the world's major fishing methods, taking place in all oceans and seas. For some fish species, 90% of the commercial catch is taken by this gear (Bjordal and Løkkeborg, 1996). Pelagic long-lining concentrates on tuna (*Thunnus* spp.), broadbilled swordfish (*Xiphias gladius*), tuna-like fishes, and sharks, in tropical and temperate seas. Demersal long-lining, which can be either commerical or artisanal, concentrates on cods, halibuts and hakes (*Merluccius* spp.), and other species of groundfish in the cold and temperate waters of the continental shelves of the North and South Atlantic, North and South Pacific, and around Australasia, as well as on Patagonian toothfish (*Dissostichus eleginoides*) in the Southern Ocean (Bjordal and Løkkeborg, 1996; Brothers *et al*., 1999).

Most seabirds (penguins, alcids, and cormorants are exceptions) are essentially surface foragers, obtaining their prey from the top metres of the water column. Most surface-foraging seabirds will scavenge on dead or moribund prey, making them 'pre-adapted' for supplementing natural diets by following fishing boats for discarded material and by stealing bait from hooks during line setting (Brothers *et al*., 1999). Many birds become hooked in this way and subsequently drown as the line sinks below the sea surface. The world's attention has been drawn to this conservation problem only in the last decade, following pioneering observations of high albatross mortality caused by Japanese tuna long-liners fishing within the Australian Exclusive Economic Zone (EEZ) (Brothers, 1991). Concerted efforts are now under way in several international, regional and national fora to address the problem. The testing and adoption of mitigation measures has led in some fisheries to a decrease in the incidental catch. The regional accounts that follow are summarized from Brothers *et al*. (1999), who provide full details and original information sources. The regions have been chosen as ones known to have significant seabird mortality. Ongoing work may reveal other long-line fisheries to be important in this regard.

(i) North-east Atlantic

Norway, Iceland, and the Faeroes are major users of long-lines to catch Atlantic cod (*Gadus morhua*) and many other bottom fish, and taking northern fulmars (*Fulmarus glacialis*) as primary bird by-catch. Mortality rates as high as 1.75 birds/1000 hooks (95% fulmars) have been recorded, but observers on trips where lines were set by night have reported levels as low as 0.02 birds/1000 hooks. Nevertheless, when these figures are multiplied by the large numbers of hooks set (476 million in 1996 by the 63-vessel Norwegian autoline fleet alone), the annual mortality of fulmars must be very large. However, because its breeding distribution and population size (which is in the millions) is expanding (perhaps helped by the availability of discards; Camphuysen *et al*., 1995), long-line mortality is not currently regarded as a serious threat to the species.

(ii) North Pacific

There are two important long-line fisheries: for demeral fish – mainly Paciifc cod (*Gadus macrocephalus*) and Pacific halibut (*Hippoglossus stenolepis*) – concentrated in the Bering Sea, Sea of Okhotsk, and the Gulf of Alaska by the USA, Canada, and Russia, and for pelagic tuna and swordfish in EEZs and international waters by the USA (Hawaii), Japan, the Republic of Korea, and Taiwan. Information on seabird mortality is available only for the US fisheries, which hampers any reliable estimates for the region. The US demersal and pelagic fisheries kill an estimated several thousand black-footed (*Phoebastria nigripes*) and Laysan (*P. immutabilis*) albatrosses annually. The US demersal fishery also kills northern fulmars (annual average 8450, 1993–1996) and a few (but significant in conservation terms) individuals of the rare short-tailed albatross (*P. albatrus*).

(iii) Southern continental shelf

Long-line fisheries for cold-water bottom fish work on the continental shelves of the Pacific and Atlantic coasts of South America, on the Atlantic coast of southern Africa, and off Australia and New Zealand. All of these kill significant numbers of seabirds, although the available information varies. Nearly all birds killed are procellariiforms (albatrosses and petrels) with mollymawk albatrosses (*Thalassarche* spp.) and *Procellaria* petrels predominating in all fisheries. Serious concern has been expressed for the conservation status of the recently described spectacled petrel (*P. conspicillata*), which is endemic to Inaccessible Island in the Tristan da Cunha group (Ryan, 1998). Its breeding population is now probably under a thousand pairs and the mortality caused by long-lines off the coast of Brazil may reach a few hundred birds annually.

(iv) Southern Ocean

A mere decade ago, only ichthyologists knew the Patagonian toothfish. Its commercial discovery as a high-value fish has led to massive over-exploitation throughout its known range, which is concentrated around the sub-Antarctic islands and sea mounts of the Southern Ocean. Concerted management efforts by the Commission for the Conservation of Antarctic Marine

Living Resources (CCAMLR) has not halted illegal, unregulated, and unreported fishing (and non-compliance with measures to mitigate by-catch of birds) by CCAMLR nations and especially non-CCAMLR ones. Catch rates of seabirds by Patagonian toothfish long-liners are high and an estimated 265 000 birds have been killed between 1996 and 1999, mainly mollymawk albatrosses and white-chinned petrel (*Procellaria aequinoctialis*), with lesser numbers of wandering albatrosses (*Diomedea exulans*) and giant petrels (*Macronectes* spp.). For some of these species, long-lining has been blamed for 1–16% annual reductions of breeding populations. Such losses are not sustainable in the long term.

(v) Southern bluefin tuna

Australian, Japanese, New Zealand, Korean, and Taiwanese long-liners fish for southern bluefin tuna (*Thunnus maccoyi*) in international waters between 30° and 40°S and, under licence, in the EEZs of Australia, New Zealand, and South Africa. Overfishing has substantially reduced the stock, so there are now fewer vessels operating than previously. Observations of albatrosses, especially the wandering albatross, killed by this fishery in Australian waters (Brothers, 1991) have been important in raising consciousness on the issue of by-catch. To an extent, management is complicated by the fact that the tens of thousands of albatrosses and petrels killed are non-breeding visitors from farther south. The adoption of mitigation measures has led to lower catch rates in recent years.

Gillnets

Monofilament gillnets are generally the type of fixed fishing gear that produces the largest by-catches of birds and mammals (Lien *et al.*, 1988).

(i) East coast Canada

The inshore fishery in Newfoundland has been concentrated during a few weeks in June and July, when massive schools of capelin (*Mallotus villosus*) move into coastal waters to spawn on beaches (Carscadden, 1984). These schools are pursued by predatory cod that are caught in traps, gillnets, trawls, and on hand-lines. At this time year, capelin, too, is the major prey of seabirds, whales and seals, which thus suffer considerable by-catch (Lien *et al.*, 1988). Gillnets are also set in surface waters from salmon and in deeper waters for cod up to 100 km or more from the coast.

Among the seabirds, the pursuit-diving alcids, common guillemots (*Uria aalge*), and Atlantic puffins (*Fratercula arctica*) are the primary consumers of capelin in the area. These species are also the most vulnerable to entrapment in gillnets and other fixed gear. Brunnich's guillemots (*Uria lomvia*), black guillemots (*Cepphus grylle*), razorbills (*Alca torda*), great shearwaters (*Puffinus gravis*), sooty shearwaters (*P. griseus*), and northern gannets (*Morus bassanus*) are also drowned.

Mortality was probably relatively low in the 1950s and early 1960s, then climbed as gillnet fishing effort and local common guillemot populations increased during the 1960s. Annual mortality in Witless Bay (Newfoundland) was estimated at 13–20% (around 20 000–30 000 guillemots) of the local breeding population in the early 1970s, falling to about 3–4% by the 1980s (Piatt *et al.*, 1984). By contrast, only about 0.25–1.6% of the much larger local breeding population of Atlantic puffins were caught in fixed gear. Piatt and Nettleship (1987) estimated that around 12% of Newfoundland's razorbill population was killed annually between 1981 and 1984, and 2% of the western Atlantic gannet population. Most of the gannel mortality affected one colony where losses were estimated to be more than 9% in 1982. Offshore gillnets set during summer, autumn, and winter also drowned non-breeding seabirds, including little auks (*Alle alle*).

During the 1990s, closure of the Atlantic salmon fishery and the moratorium on groundfish in eastern Canada resulted in a virtually complete removal of fixed gear along the coasts of Newfoundland and Labrador. In a sense, these closures may be viewed as a large-scale experiment to elucidate the effects of by-catch on local breeding populations of seabirds as well as marine mammal populations. While no systematic counts of the breeding populations of common guillemots have been published during the 1990s, the definite impression among ornithologists is that their populations have indeed increased.

(ii) Greenland

An offshore drift-net fishery for Atlantic salmon was prosecuted off western Greenland during the 1960s and 1970s (Reddin and Burfitt, 1980) and high by-catches of migrant Brunnich's guillemots during autumn were reported (Christensen and Lear, 1977). Concern was expressed that the combined annual mortality resulting from by-catch, hunting, oil pollution, and disturbance exceeded annual recruitment for the western Greenland populations that had exhibited significant declines over the previous 20 years (Evans and Waterston, 1976). By-catches were shown to be fairly variable over space and time, and exceptionally high catches were considered to result from feeding convergences of guillemots and salmon on capelin (Christensen and Lear, 1977).

In 1975, the non-Greenland offshore drift-net fishery was closed, and quota and seasonal restrictions were placed on the Greenlandic fishery (Reddin and Burfitt, 1980). Consequently, salmon catches were reduced, and the reduction in drift-net fishing effort appears to have benefited guillemots (Piatt and Reddin, 1984). However, fishing efficiency increased in the 1980s when fleets of up to 100 drift nets extending for 2–3 km could be used.

Piatt and Reddin (1984) predicted that the later and more northerly prosecution of the fishery in the 1980s (where by-catch mortality had been greatest in the past; Christensen and Lear, 1977), may have resulted in the reappearance of significant by-catches of guillemots. However, as salmon quota have been greatly reduced to 11 000 t, seabird mortality is also expected to have been reduced considerably.

(iii) North Pacific

Prior to the 1992 moratorium on high seas drift netting, some 500 000 birds were drowned annually in the North Pacific (DeGange *et al*., 1993). The majority of these were sooty and short-tailed (*Puffinus tenuirostris*) shearwaters which bred in the Southern Hemisphere. Two main fisheries were involved, one for salmon (between 60 000 and 137 000 km of net set per year) and one for squid (an estimated 2.85 million km of net set per year). The abundant shearwater populations declined in the early 1990s with significant reductions in numbers recorded at sea off California (Veit *et al*., 1996). Mortality of black-footed albatross amounted to about 2% of the world population per annum (DeGange *et al*., 1993).

Gillnet kills in inshore areas are fewer, but may be having a proportionately greater impact on seabird populations. Off Japan, Ogi *et al*. (1993) found 1650 ancient murrelets (*Sythliboramphus antiquus*) drowned in inshore nets in 1990. Further offshore, Piatt and Gould (1994) recorded a by-catch of Japanese murrelets (*S. wumizusume*) in the Korean squid fishery. They consider that the by-catch would represent 1.5–15.2% of the breeding population of this endangered species. Carter and Sealy (1984) found that nets killed about 8% of marbled murrelet (*Brachyrampus marmoratus*) autumn populations in Barkley Sound, British Columbia; however, this fishery does not operate every year.

(iv) California

Takekawa *et al*. (1990) found a decline of over 50% in common guillemots in central California over 4–6 years in the early 1980s, whereas the adjacent population of northern California remained relatively unchanged. The decline in the former was caused primarily by the rapid growth of an intensive nearshore gillnet fishery (combined with a switch from twine to monofilament nets [CDFG, 1987]), compounded by mortality from oil spills and a severe El Niño event.

(v) Northern Norway

Gillnets set for cod off northern Norway killed very large numbers of Brunnich's and common guillemots between 1965 and 1985 (Vader *et al*., 1990). In early spring 1985, the estimated kill of both species combined exceeded 100 000 birds. In the same area, summer drift-net fisheries for salmon drowned thousands of local breeding birds (Vader and Barrett, 1982). Numbers of common guillemots in the colony at Hjelmsøy declined from 220 000 in 1965 to 10 000 by 1985, and Brunnich's guillemot declined from >2000 to 220 (Vader *et al*., 1990). The fishery has been closed since 1989 to conserve salmon stocks.

(vi) Baltic Sea

In the Baltic, seaducks – e.g. common eider (*Somateria mollissima*) and common scoter (*Melanitta nigra*) – grebes and auks (mainly guillemot and razorbill) are affected mostly by fixed nets (Kies and Tomek, 1990). Mortality can be substantial locally. Thus, Stempniewicz (1994) estimated that some 16 000 long-tailed ducks (*Clangula hyemalis*) and velvet scoter (*Melanitta fusca*) were dying annually in fixed-net fisheries for flatfish and cod in the Gulf of Gdańsk, Poland (about 10–20% of the wintering populations combined). Meissner (1992) noted that drowning in nets was the commonest source of mortality of seabirds on the Polish coast. A similar proportion was killed annually in the same type of fisheries along the eastern coast of Schleswig-Holstein, Germany: some 14 000 ducks, chiefly eiders and common scoters, representing up to 17% of the maximum winter population (Kirchhoff, 1982).

(vii) Seas around Britain and Ireland

Around Britain and Ireland, impacts of seabird by-catch tend to be localized. Gillnets set in late winter for bass (*Dicentrarchus labrax*) in St Ives Bay, Cornwall, have taken an annual by-catch of hundreds of razorbills and guillemots, possibly reaching 1000 (Robins, 1991), although the birds probably derive from a wide catchment area, diluting any possible population effect. Studies around Wales (Thomas, 1992) and Scotland (Murray, 1993; Murray *et al*., 1994) found no evidence of widespread impact, with some "hot spots" where nets were set immediately beside colonies.

Other fisheries

Virtually all types of gear used in zones in which seabirds feed may catch birds. Common guillemots have been recorded in sandeel (*Ammodytes* spp.) trawls in the North Sea used in the feeding area of a colony (M. L. Tasker, personal observation). A minimum of 22 birds were caught in five hauls (others may have been missed due to bulk processing of the catch).

Direct impact: lost fishing gear

Birds may also become entangled in lost fishing gear (lines as well as nets), but few systematic studies have been conducted. Gannets and cormorants are notorious in picking up floating debris, including netting, from the sea surface to use as nesting material instead of seaweed. Camphuysen (1990a) reported that 92% of 465 checked gannet nests in Shetland contained some visible nylon, while 50% contained virtually nothing else. As a result, adults and chicks may become entangled and die from starvation (Montevecchi, 1991). Not surprisingly, the northern gannet and great cormorant (*Phalacrocorax carbo*) ranked highest among 90 species of stranded marine birds, of which 138 500 corpses were checked for entanglements as cause of death in the southern North Sea. Some 5% of all beached northern gannets checked (n = 1363) were entangled in ropes or fishing gear, while 2% of all great cormorants (n = 298) had suffered a similar fate (Camphuysen, 1990b, 1994). While the mortality associated with this type of pollution appears to be low, all indications are that the amount of debris consisting of fishing gear/number of incidences has increased substantially during the 1970s and 1980s (Montevecchi, 1991).

Harvesting for bait

Seabirds have probably acted directly as food for fishers for as long as boats have been put to sea. Archaeological sites in many parts of the world have revealed that coastal communities were often entirely reliant on seabirds and fish for their protein intake (e.g. Montevecchi and Tuck, 1987). Harvesting for food will not be reviewed here, although it is partially responsible for the extinction of the great auk (*Alca impennis*) in the North Atlantic, a little over 150 years ago. Harvesting by fishers still occurs in Indonesia (de Korte and Silvius, 1994) and elsewhere. The use of seabird islands by wandering fishers for temporary accommodation and for fish drying has led to the loss of colonies both through direct habitat disturbance and through the introduction of mammalian predators such as rats and cats.

Seabirds, primarily great shearwaters, were recorded as being harvested for bait in New England cod fisheries during the 19th century (Collins, 1884) and must have been used for this purpose in many fisheries for centuries. Audubon reported that Labrador fishermen annually visited Bird Rocks in the Gulf of St Lawrence to get flesh to bait their cod hooks. The scale of this harvest is likely to have reduced the local northern gannet population from over 100 000 pairs in the early 1800s to below 750 pairs by the turn of the century, when bird protection laws were enacted (Fisher and Lockley, 1954). In recent times, boobies have been used as bait in lobster traps off Brazil (Antas, 1991).

Culling

Fish-eating birds present in nearshore areas and capable of eating relatively large fish have long been blamed by fishers for declining catches or for damage to fish (Birt *et al*., 1987). This has led to mass killing or culls, many of which are licensed with no real evidence either to support the impact of the birds or to show that the birds exert any effect in reducing the fish populations concerned. In Europe, the prime victim of this prejudice is the great cormorant, while in North America it is the double-crested cormorant (*Phalacrocorax auritus*). Overall, there is no scientific evidence that a cull of any marine predator has enhanced a commercial fishery venture (Montevecchi, 1996).

Disturbance

Davidson and Rothwell (1993) reviewed the effects of disturbance to waterfowl in estuaries. Sustained, localized disturbance in feeding areas leads to shifts to alternative feeding sites. If the alternatives are of insufficient quality to meet energy requirements, and if intake rates fall below a critical threshold, the birds must emigrate or starve to death (Cayford, 1993). Bait diggers present typical examples of localized, sustained disturbance in estuaries, particularly because they have a tendency to work in quiet areas, away from the mainstreams of tourism and other human activities. Townshend and O'Connor (1993) described the effects of disturbance on wigeon (*Anas penelope*) at Lindisfarne National Nature Reserve (NE England). In the mid-1980s, large numbers of bait diggers operating in wildfowl refuge areas greatly reduced the extent of use by waterfowl, largely through the direct effects of disturbance.

In the southern North Sea, large concentrations of up to 160 000 common scoters along with smaller numbers of velvet scoters winter over banks holding stocks of the bivalve *Spisula subtruncata* within approximately 10 km of the coast. These seaducks are easily disturbed and the appearance of fishing vessels in the recently established *Spisula* fishery may have led to disturbance and possibly to local depletion of food stocks (Leopold, 1996).

Indirect effects: increase in prey abundance

An effect of the reduction in stocks of large fish by fisheries has been to reduce competition for prey. Populations of diving seabirds in the North Sea and around the United Kingdom and Ireland increased substantially during the 20th century (Lloyd *et al*., 1991). This may have been partly a response to the cessation of seabird hunting at the end of the 19th century, but its duration indicates other causes. The larger proportion of small fish in the North Sea than on Faeroe Bank (Pope and Knights, 1982) and Georges Bank (Pope *et al*., 1988) was attributed to a possible direct consequence of more intense harvesting in the former. Sherman *et al*. (1981) considered that sandeel stocks had increased both in the

North Sea and in the Western Atlantic shelf seas as a response to reduced competition with herring and mackerel. Further north, Hamre (1988) suggested that capelin in the Barents Sea may have increased as a consequence of overfishing of cod, the main predator. However, there is no compelling evidence for such a relationship in the north-west Atlantic (Carscaden and Nakashima, 1997), perhaps due to the complexity of direct and indirect effects in marine food webs (Lavigne, 1996) or to oceanographic effects (Frank *et al*., 1996).

An increase has been observed also among penguin populations in the Antarctic, species that have not been hunted heavily in the past. Fraser *et al*. (1992) found it difficult to distinguish between the likely effects on penguins of the depletion of great whales (and some seals) and the recent retreat of sea ice due to global warming. The latter factor would make foraging near colonies easier for a greater part of the year than previously. Shaughnessy (1984) noted that an increase in African penguin (*Spheniscus demersus*) populations off South Africa coincided with a decrease in seal populations through hunting. It is obviously difficult to isolate cause and effect.

An opposite effect caused by the depletion of large fish by fisheries may be found among seabird species that prey on fish driven to the surface by large predatory fish – e.g. skipjack tuna (*Euthynnus pelamis*) – near Hawaii (Au and Pitman, 1988; Harrison, 1990). Depletion in the larger fish might reduce feeding opportunities in this case.

Indirect effects: target fisheries on forage fish

Western Norway

Nearly one million pairs of Atlantic puffins breed along the Norwegian coasts north of the main spawning areas of the Atlanto-Scandian herring stock. Herring was an important food for these birds in the 1950s (Vader *et al*., 1989). In the late 1960s, the stock collapsed completely, almost certainly as a result of overfishing (Jakobsson, 1985). In the absence of significant recruitment (with the exception of the 1983 and 1989 years classes), breeding success in puffins has been absent or very low in most years owing to chick starvation (Lid, 1981; Anker-Nilssen, 1987, 1992). Puffins, as most other seabirds, are long-lived and adapted to withstand years with poor feeding conditions. However, it is not surprising that decades of recruitment failure of herring have affected the numbers of breeding puffins. Numbers at Hernyken, a colony in Lofoten, have declined at 13.7% per annum (Anker-Nilssen and Røstad, 1993).

North Sea

Fisheries for fish meal and oil within the North Sea harvest sandeel (mostly *Ammodytes marinus*), sprat (*Sprattus sprattus*), and Norway pout (*Tristopterus minutus*), three main forage fish species. The first two are preferred prey species of a wide range of seabirds (Tasker and Furness, 1996). The sandeel fishery is the largest one, with annual catches of at least 500 000 t, occasionally exceeding 1 million tonnes in recent years. The scale of this industrial fishery has led to concerns about the impact on seabirds through competition for the same resource. It is important though to consider the spatial and temporal overlap between usage of sandeels by the fishery and by seabirds.

During the breeding season, seabirds in the North Sea feed predominantly close to their colonies in the north-west. If there is shortage of food in the immediate vicinity of the colony, some seabirds can feed at greater distance, but at a cost in terms of reproductive output and possibly in adult survival (Monaghan *et al*., 1992). After the breeding season, the birds are less constrained in terms of feeding location: some migrate out of the North Sea, while others move further offshore or even to the Skagerrak and Kattegat.

There are spatial differences in the exploitation of forage fish by the industrial fisheries. With the exception of a comparatively small catch near Shetland, sandeels are taken mostly offshore in the central North Sea with, in recent years, exploitation of banks off the east coast of Scotland. Jensen *et al*. (1994) studied the broad overlap between the distributions of sandeel and sprat, three auk species (common guillemot, razorbill, puffin) and the target fisheries. There were significant positive correlations between bird and fish distribution in the third quarter of the year, particularly in the north-western North Sea. There were some associations between birds and fisheries indicating that, at a large scale, some fisheries and some birds were exploiting the same species in the same place, but at different times of the year. For instance, sprat fisheries in the southern North Sea took place mostly in the autumn, but there was greater spatial overlap between birds and sprat fisheries in winter. This study illustrated also the difficulty of comparing data collected at different scales for different purposes, and therefore highlighted a problem in demonstrating the competitive impact of fisheries on seabirds. However, fishery impacts at these harvest levels could be cumulative, and potential effects on seabird populations might be lagged in time.

Wright and Begg (1997) examined the overlap among sandeels, the sandeel fishery, and common guillemots in the north-western North Sea at a much finer scale. Some areas were important for both guillemots and the fishery, but most birds were found in areas where sandeels were not exploited. However, the exact location of the sandeel fishery varies from year to year, probably in relation to the profitability at different potential locations. For example, the catch from the area off the Firth of Forth expanded rapidly in 1990 and this coincided with a decline in breeding performance of black-legged kittiwakes (*Rissa tridactyla*) on nearby coasts, a decline not reflected elsewhere. Research is under way to elucidate the feeding relationships in this area, as well as sandeel stock structure. If, as seems likely, the local sandeel population is relatively isolated and is relied upon by seabirds during the breeding season, fishing pressure may have a disproportionately large effect compared with elsewhere. Wanless *et al.* (1998) compared amounts of sandeel taken from this area by fisheries and by birds and concluded that fisheries were more likely to affect seabirds than vice versa.

The studies of Jensen *et al.* (1994) and Wright and Begg (1997) demonstrate that spatial scale is critical to understanding seabird–sandeel interactions and that it is essential to assess fish stocks accordingly. For many years, sandeel assessment has been based on the assumption that the stock could be split into a northern and a southern component, with a small isolated group near Shetland. Recent research has indicated that there may be many more unit stocks (Wright *et al.*, 1998).

In the most intensively studied case of seabird–sandeel interaction at Shetland, particularly Arctic terns (*Sterna paradisaea*) and black-legged kittiwakes suffered a series of years with very poor breeding in the 1980s. These birds are entirely reliant on sandeels during the breeding season and the decline coincided with an increase in sandeel catch from local grounds. Research, however, indicated that fisheries were unlikely to be the cause of the decline in sandeel abundance. Sandeel recruitment fluctuated considerably following a closure of the local fishery. A more likely cause was connected with recruitment mechanisms of sandeels in the area (Wright and Bailey, 1993; Wright, 1996). This case highlights the importance of fluctuations in year-class strength and of understanding the prey population structure in an area before any potential effects of fisheries can be understood.

Southern Africa

Competition with fisheries outside the breeding season has been implicated as the main cause of a decline in African penguins off southern Africa (Burger and Cooper, 1984). Competition during the breeding season was limited, as the fishery could not exploit the near-shore feeding grounds of adult birds. However, those immature penguins that spent their first year at sea in the same offshore areas as the fishery had a very low survival compared with those which spent the first year in a bay closed to the fishery (Duffy *et al.*, 1984).

Peru/Chile

The largest fluctuations in seabird numbers worldwide have been recorded along the upwelling system of the Humboldt Current to the west of South America, one of the most productive ecosystems in the world. The typical

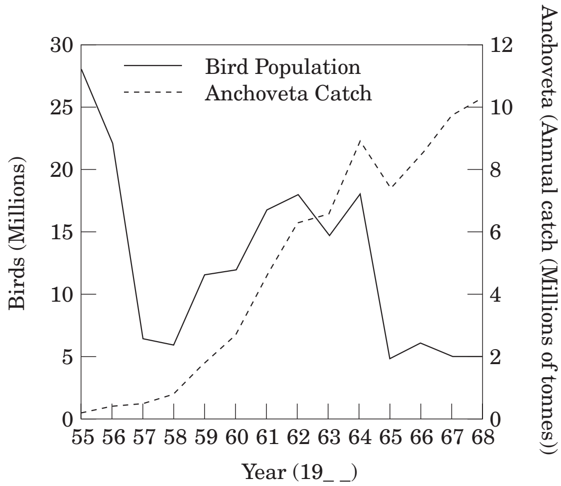

Figure 1. Changes in guano bird numbers and commercial landings of anchoveta and sardines in relation to El Niño events (based on Schaefer, 1970).

species of the area are the guano birds: the Peruvian booby, the guanay cormorant (*Phalacrocorax bougainvillii*) and the South American subspecies of the brown pelican (*Pelecanus occidentalis thagus*). These species are characterized by their ability to respond to large fluctuations in food availability brought about by El Niño. These events cause breeding failures and high mortality every few years among seabirds on a scale unknown anywhere else in the world (Furness and Monaghan, 1987). Anchovies (*Engraulis ringens*) and sardines (*Sardinops sagax*), along with some other fish species, are their food. These two species appear to fluctuate around an equilibrium, but fisheries have had a major impact on their abundance and their equilibrium. In previous decades, anchovies made up about 90% of the pelagic fish stocks in the Humboldt Current (Santander, 1981). The total population size of guano birds in Peru reached a maximum of 20 million in the 1950s, partly due to artificially increased nesting facilities (Jordan and Fuentes, 1966).

Fisheries became important in the 1950s when anchovies began to be processed into fish meal. The industry grew spectacularly (Fig. 1) until 1970 when catches in Peru reached 12.3 million tonnes. Overfishing and the El Niño of 1972/73 led to a dramatic reduction in catches and the record catch has never been even approached again. Instead, the fishery switched to sardines (Aguero, 1987). In Chile, the Peruvian horse mackerel (*Trachurus [symmetricus] murphyi*) is currently responsible for the highest landings (SERNAPESCA, 1997).

El Niño events have always had a negative influence on guano bird populations, but severe crashes have only been apparent since fishing activities intensified (Duffy *et al.*, 1984). Derived from crude estimates, adult mortality rates caused by the El Niño 1982/83 ranged as high as 66% in guanay cormorants (Tovar *et al.*, 1987). Population size has declined progressively. Furthermore, the dynamics of these seabird populations appear to have changed. Instead of rapidly increasing by raising large broods at least once per year, the guano birds failed to respond to the reduced competition brought about by their reduction in numbers. The reason seems to be that the anchovy fishery has taken up the superabundance of food on which the seabirds depended to cope with the recurring crashes induced by oceanographic perturbations (Furness and Monaghan, 1987).

Indirect impacts: depletion of shellfish stocks

Southern North Sea

In the early 1990s, the Dutch part of the Wadden Sea was cleared of old mussel banks and high-density cockle banks (Beukema and Cadée, 1996). Common eiders and oystercatches (*Haematopus ostralegus*) suffered extra mortality in 1991, which has been attributed to acute food shortages (Camphuysen, 1997). Wintering eiders have sought refuge in later years in coastal waters, mixing with common scoters and competing for food over *Spisula* banks (Leopold and Dankers, 1997).

United Kingdom

Studies of the interactions of shorebirds and shellfish stocks were made in south-west England and in South Wales (Goss-Custard *et al.*, 1995a, b). The study in south-west England was on a relatively enclosed estuary, and it seems likely that effects may have been more pronounced than in a wider embayment. Stillman *et al.* (1996) found that mussel fishers' presence, as well as depletion of the mussel stock affected oystercatchers. If oystercatchers could not get enough energy from mussel beds, they switched to feeding on earthworms in nearby fields. If the switch was unsuccessful, the birds died.

Indirect effects: discards

North Sea

Discards produced in commercial fisheries in the North Sea may be divided into different fractions (Table 1; Camphuysen *et al.*, 1995). Seabirds prefer the roundfish and offal fractions because these are easy to handle and have a relatively high calorific value. Benthic invertebrates are sometimes completely ignored by scavenging seabirds, but may be taken in substantial amounts when competition around fishing vessels is particularly intense, or following severe storms when feeding has been difficult. The amounts of discards and offal in offshore fisheries were estimated by Garthe *et al.* (1996) from published data and from unpublished statistics. In addition, Garthe *et al.* (1999) quantified discards in the coastal shrimp fisheries on the basis of calculations by Walter (1997). In total, about 1 million tonnes of biota is discarded every year by commercial fisheries in the North Sea (Table 1).

Table 1. Estimated quantities of discards (by major groupings) and offal in the North Sea in 1990. For assumptions and sources see Camphuysen *et al.*, 1995; Garthe *et al.*, 1996, 1999).

	Waste (t)
Roundfish	273 000
Flatfish	307 300
Elasmobranchs	15 000
Invertebrates	287 500
Offal	62 800
Total	945 600

Species of seabirds profiting most from discards and offal are northern fulmar, northern gannet, great skua (*Catharacta skua*), and several species of gull (Camphuysen *et al.*, 1995). Large feeding flocks follow fishing vessels, with spatial and temporal variations in species composition and a clear hierarchy among the scavenging seabirds attending (Camphuysen *et al.*, 1995). For example, fulmars are numerically the dominant species over wide areas, but particularly in spring and summer and in the north-western sectors. Large *Larus* gulls are important scavengers in the south-eastern part during most of the year. Several smaller species, such as black-headed gulls and common gull, are more numerous in inshore waters, notably in the Wadden Sea (Garthe, 1997).

Great black-backed gulls, great skuas, and northern gannets are socially dominant species and out-compete other seabirds when the trawl comes to the surface. The first two species obtain substantial amounts of prey by robbing other scavengers. Northern fulmars obtain significant proportions of the discards and (particularly) offal in areas where they are numerically dominant. Smaller species, such as black-legged kittiwakes, have developed a strategy of staying near the vessels, even when nothing is dumped, and of being fast and manoeuvrable when discards are actually discharged. The presence of certain large scavenging species around trawlers will often reduce the abundance of others, which simply avoid situations in which they are constantly out-competed (Garthe and Hüppop, 1998). These hierarchies can be used to predict the effect of changes in the amount of discards produced at sea (Furness, 1992). For instance, if competition behind fishing vessels increases, the smaller and less competitive species will suffer the earliest and greatest effects.

Baltic Sea

Studies on discards in the Baltic are sparse and deal only with a few fisheries in limited areas. Recent investigations in the otter trawl cod fishery in Kiel Bight revealed undersized cod and dab (*Limanda limanda*) being the most numerous discards (e.g. Friess, 1992). Fishing vessels in the Baltic are mainly attended by herring gulls (chiefly immatures during the breeding season, mainly adults outside the breeding season), great black-backed gulls, common gulls, and black-headed gulls (S. Garthe, unpublished data).

Mediterranean

The effects of discards in commercial fisheries on feeding and breeding biology have been clearly shown for the rare Audouin's gull (*Larus audounii*) in the western Mediterranean (e.g. Oro, 1996). A colony established in the Ebro delta in 1981 grew rapidly and now holds 70% of the world population (about 10 300 pairs in 1995). In this area, Audouin's gulls gain part of their food by following the trawling fleet and exploiting discards. Since 1991, a moratorium on trawling has been enforced in the provinces around the delta. Each year, the moratorium has affected different life history stages of the species. For example, in 1992 it overlapped with pre-laying and laying stages, and greatly affected egg production by delaying the start of egg laying and severely reducing clutch and egg sizes. The moratorium also caused significant changes in the species of fish taken (Oro *et al*., 1996).

Squid trawlers

In the 1980s, a major trawl fishery for squid (*Loligo gahi*) was developed off the Falkland Islands (South Atlantic), near very large colonies of black-browed albatross (*Diomedea melanophris*). The chicks were soon fed extensively on commercially exploited species, including squid and southern blue whiting (*Micromesistius australis*), a by-catch (Thompson, 1992). The discards fraction in the squid fisheries amounted to 5% of the reported catch (mean catch 55 000 t per season; mean waste: 1000 t of squid and 600 t of fish per season). Just over 50% of the waste is taken by black-browed albatrosses. The albatrosses also scavenged extensively behind finfish trawlers, as they also do off African coasts (Rodriguez, 1972; Abrams, 1983).

Grand Banks

Fisher (1953) and Tuck (1961) considered that discards from fisheries on the Grand Banks provided a significant amount of food for northern fulmars and black-legged kittiwakes, many of which were considered juveniles from colonies in the north-east Atlantic. Recent breeding range expansions by fulmars may be consequences of the enhanced food availability (Stenhouse and Montevecchi, in press a).

The eastern Canadian moratorium on groundfish since 1992 can be viewed as a large-scale experiment to study the effects on seabirds of taking away massive quantities of discards. Some indirect effects of predation by food-stressed scavenger gulls (great black-backed and herring gulls) on other seabirds have been profound and unexpected (Stenhouse and Montevecchi, in press b), partly because the changes observed were induced by complex and interactive environmental changes. For instance, unusual changes in water temperature in the early 1990s delayed the inshore movement of spawning capelin by about 4 weeks and put a significant stress by shortage of food on much of the seabird community (Chapdelaine and Rail, 1997).

Tropical Australia

As at northern latitudes, recent research in Australia suggests that discards from commercial fisheries in the tropics may affect the feeding ecology and population sizes of some seabirds (Table 2). The coupling of food availability, and the timing and success of reproduction may be very tight in tropical seabirds (Harris, 1977). Hence, if food availability changes significantly as a result of discards, fluctuations in population sizes and success of reproduction may relate to changes in commercial fishing effort and location. Demersal trawling for penaeid prawns, the largest and most widespread fishery, has a by-catch-to-prawn ratio of up to 14:1 (Pender *et al*., 1992). The by-catch, mainly small fish, is discarded and available to scavenging birds (Blaber and Wassenberg, 1989).

Seabirds are a conspicuous component of the northern Great Barrier Reef, which, as a protected area, has a global significance in terms of its large seabird populations and numerous breeding sites. In a study of the effects of fishing in two areas of the reef, Blaber *et al*. (1995) investigated the diets of 12 species with particular reference to the effects of discarded by-catch on diets and reproduction. Species (scientific names in Table 2) whose diets included at least 20% discard taxa were crested and roseate terns and perhaps bridled tern. There was a marked contrast in crested tern diet in closed and open trawling seasons: in the closed season, only 5% of the prey were benthic species normally unavailable to the birds, whereas in the open season they made up about 70% of the diet.

There is no evidence that the availability of discards has resulted in the birds taking larger specimens of their normal prey (Blaber and Wassenberg, 1989). However, it may have affected feeding strategies. The greater availability of discards may have led to greater dietary overlap. Ashmole and Ashmole (1967) stated that "competition is reduced mainly by differences in feeding methods"; this important paradigm may be less significant where a superabundance of food of a limited range of taxa is provided artificially through discards. Also, although discarding may not have greatly affected the sizes of prey taken owing to constraints associated with prey weight and size and with bill morphology

Table 2. Summary of information on behaviour (S: follow ships?; D: Feed on discards?) of, and population effects (P.E.; nn: none noted) on, tropical seabirds in northern Australia in relation to discards from trawling (from Blaber *et al.*, 1995, 1998).

Species	S?	D?	P.E.?
Crested tern (*Sterna bergii*)	Yes	Yes	Increases
Lesser crested tern (*Sterna bengalensis*)	Yes	Yes	nn
Black-naped tern (*Sterna sumatrana*)	No	Yes	nn
Bridled tern (*Sterna anaetheta*)	No	Possibly	nn
Roseate tern (*Sterna dougalli*)	No	Yes	Possible decreases
Caspian tern (*Sterna caspia*)	No	Possibly	nn
Sooty tern (*Sterna fuscata*)	No	No	nn
Common noddy (*Anous stolidus*)	Yes	Yes	nn
Black noddy (*Anous minutus*)	No	No	nn
Brown booby (*Sula leucogaster*)	Yes	Yes	Increases
Masked booby (*Sula dactylatra*)	No	No	nn
Red-footed booby (*Sula sula*)	No	No	nn
Lesser frigatebird (*Fregata ariel*)	Yes	Yes	Possible increases
Greater frigatebird (*Fregata minor*)	Yes	Yes	nn
Pied cormorant (*Phalacrocorax varius*)	Yes	Yes	Increases
Red-tailed tropicbird (*Phaeton rubricauda*)	No	No	nn

(Hulsman, 1988), it may have changed the mix of prey species and could have affected feeding behaviour. For example, crested terns now feed behind trawlers at night, taking advantage of the powerful spotlights (Blaber and Wassenberg, 1989), and lesser frigatebirds, instead of pirating from other species, pick up prey directly from the surface. Hence, as in the Northern Hemisphere (Furness *et al.*, 1988), the availability and quantity of discards in tropical waters may cause major changes in the feeding ecology of some species, changes that can be facilitated by the essential "dynamism of their niches" (Hulsman, 1987).

Discussion

Features of seabird biology

Most marine birds are relatively long lived in comparison with land birds. Those that forage far from the coast tend to have low reproductive rates, lay small clutches (usually one or two eggs), delay breeding for 5–10 years, have slow chick growth (thus long chick rearing period), and may desert their breeding attempt if conditions deteriorate. Wandering albatrosses, for instance, do not breed until about 10 years old, lay one egg every 2 years (if successful in the previous attempt), and rear their chick for more than 270 days. The average annual survival rate of adults, once they are breeding, exceeds 90% if there is no human interference. Nearshore species have a different life strategy: common scoters have an annual adult mortality of 23%, but produce around 7 eggs per clutch each year. Most species, especially gulls and shorebirds, have intermediate strategies.

As a consequence, populations of offshore species are particularly sensitive to any increases in adult mortality, but relatively insensitive to raised immature mortality. The magnitude of negative effects of fisheries on seabird populations is thus partly dependent on the age spectrum of the birds being affected. Increased adult mortality of albatrosses and mollymawks in long-line fisheries will have a considerably more severe effect than high immature auk mortality in gillnets. Conversely, the positive effects of fisheries, through provision of discards and offal, or possibly the increased availability of small fish, are likely to operate through increased survival of immature birds. The likely overall effect of fishing on a scavenging offshore seabird population is to reduce its average age, similar to exploited fish stocks (although through different processes).

An overall assessment

Negative and positive impacts of fisheries on seabirds can occur at multiple spatial and temporal scales. Commonly, effects on population abundance are hard to demonstrate, even if they are likely to exist. Direct effects due to increased mortality may be masked if the by-catch consists predominantly of immatures; in these circumstances, trends in recruitment would have to be studied in detail in relation to by-catch. To make things more complicated, a single fishery can potentially have simultaneous positive and negative impacts on a species. Long-line fisheries could have positive effects on the survival and fitness of individual seabirds if baits are taken without the bird being hooked itself. Whether a population suffers or benefits from such a fishery depends largely on the balance between numbers surviving and drowning. The examples discussed, however, suggest strongly that the mortality in long-line fisheries

Table 3. Overall assessment of the impact (− negative; + positive) of different types of effects of fisheries on seabirds by taxon (or group) and geographical region (S.H., N.H.: Southern and Northern Hemisphere, respectively).

Effect type	Region	Taxon	Impact on population Great	Moderate	Low
By-catch/long-lines	S.H.	Albatrosses	−		
	Global	Petrels		−	
	Global	Shearwaters		−	
	Regional	Other seabirds			−
By-catch/gillnets	N.H.	Divers		−	
	Regional	Grebes			−
	Pacific	Shearwaters	− [a]		
	Global	Cormorants		−	
	N.H.	Seaduck			−
	N.H.	Auks	− [a]		
By-catch/fish traps	Regional	Divers			−
	Regional	Grebes			−
	Global	Cormorants		−	
	Regional	Gannets			−
	N.H.	Seaduck		−	
	N.H.	Auks		−	
Lost fishing gear	N.H.	Gannets		−	
	Regional	Cormorants		−	
	Regional	Gulls			−
	N.H.	Auks			−
Harvest for bait	Brazil	Boobies			−
Culling	Global	Cormorants	− [b]		
	N.H.	Gulls	− [b]		
Disturbance	Regional	Divers			−
	N.H.	Seaduck			−
	N.H.	Other wildfowl		−	
	Global	Shorebirds		−	
	Global	Terns		−	
Fish farming	Regional	Cormorants			−
	Regional	Eider		−	
Prey stock depletion overfishing[d]	North Sea	Piscivores	+ [c]		
Discards and offal	S.H.	Albatrosses		+	
	Global	Petrels	+		
	Global	Shearwaters		+	
	Global	Gannets and boobies		+	
	Gobal	Cormorants			+
	Global	Skuas			+
	Global	Gulls	+		

[a]Recent past.
[b]Culling mostly relaxed, resumed in certain areas.
[c]Effect and scale of impact expected, but details largely unknown.
[d]Of large predatory fish species.

(without mitigation measures) can have a highly negative impact on the populations of many species, and result in the drowning of many thousands of birds. The expected impact on the populations of Southern Hemisphere albatrosses is therefore ranked as highly negative, although these fisheries in themselves may be attractive as a source of food.

In our view (Table 3), by-catches of albatrosses, petrels, and shearwaters in long-line fisheries (Robertson and Gales, 1998), as well as the massive catches of shearwaters and auks in gillnets in the recent past (Piatt *et al.*, 1984; DeGange *et al.*, 1993), are the greatest threats to seabirds worldwide. Mortality in lost (ghost) fishing nets, fish traps, or through entanglement in debris may be substantial locally or regionally. The potential effects of shifts in age and size-structure of fish as a result of overfishing large predatory fish are very difficult to quantify, but are likely to have been substantial in some areas. Discards and offal as an extra source of food probably have had significant positive effects on birds like the northern fulmar and several species of gulls. Finally, populations of cormorants and

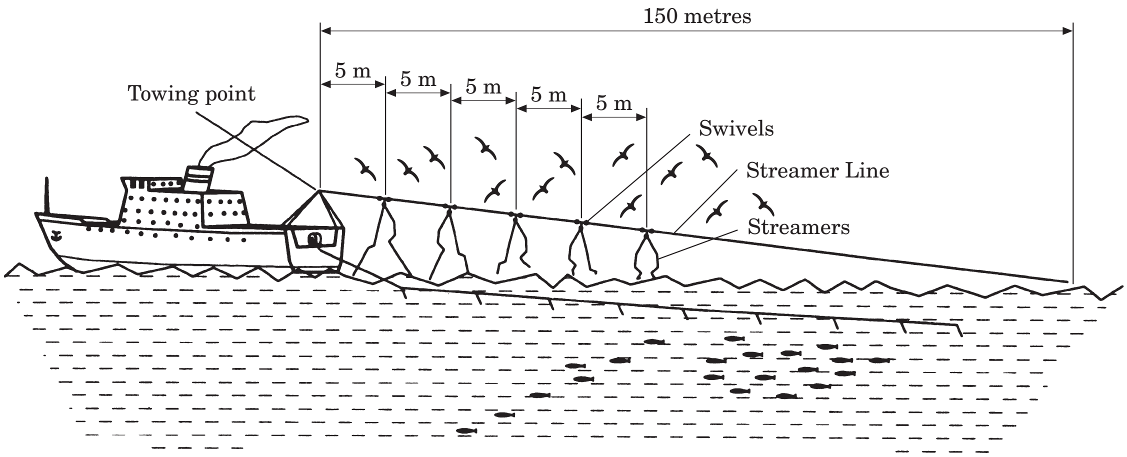

Figure 2. Ideal deployment of a "tori pole" behind a long-line vessel while baited hooks are being set (from Brothers *et al.*, 1999).

several species of gulls have been kept low by culling in many parts of the world. Although most culling activities have relaxed during the last decades, new programmes are starting up to 'protect' some fisheries. Culling programmes on adult birds have had dramatic effects on their populations and these effects are therefore labelled as "greatly negative". As far as we can tell, culls have had no benefit on any commercial fishery.

Mitigation measures

Changes in fishing practice can have a great effect on seabird populations. Fisheries management is aimed primarily at safeguarding commercial fish yield. Only rarely are the likely effects of fisheries on other aspects of the marine ecosystems assessed (by for instance Environment Impact Assessment) before they are developed. Usually, such effects are not addressed until after a problem has been identified, and by then, irreversible damage may have occurred. The visibility of, and considerable public interest in, birds has led to a number of high-profile cases of impacts being deemed unacceptable. As a consequence, high-seas drift nets were placed under a moratorium. Currently, the greatest impact appears to be from long-lines on albatrosses. In this case, mitigation measures have been developed, and are now being implemented, but not at the rate necessary to avoid further unacceptable losses to albatross populations.

Observer programmes have shown that most seabirds are hooked when long-lines are set during daylight hours. Therefore, switching to setting by night is an effective mitigation measure. However, in high latitudes the few hours of darkness during summer deem this method insufficient by itself. The use of lines with streamers trailed behind the vessel ("tori poles") deters birds from approaching baited hooks as they exit the vessel (Fig. 2). Putting extra weight on the lines to take the hooks rapidly out of reach of seabirds may also be an effective measure, and this possibility is currently being assessed in several fisheries. Lastly, Norway and New Zealand are developing devices that are designed to set lines underwater beyond the reach of birds. Field tests appear promising. These and other mitigation measures tested and adopted are described in detail by Brothers *et al.* (1999).

Development of efficient mitigation measures is insufficient and has to be accompanied by implementation and enforcement. This requires a combination of efforts, including regulation at both national and international level, raising public awareness to increase the political will to act, and exploring whether product certification (e.g., 'albatross friendly' canned tuna) is feasible. Examples include: the activities of scientific committees and working groups of CCAMLR and CCSBT; the adoption by FAO's Committee on Fisheries in February 1999 of an International Plan of Action to Reduce the Incidental Catch of Seabirds by Long-line Fisheries; ongoing efforts under the Bonn Convention on the Conservation of Migratory Species of Wild Animals to develop an Albatross Range State Agreement, and the data-collection and advocacy efforts of BirdLife International's Seabird Conservation Programme. Product certification is being explored by both the non-governmental Marine Stewardship Council and the FAO.

Virtually all fishers find it burdensome and economically disadvantageous to deal with non-target avian and mammalian by-catch in their gear. Hence, they are well motivated to seek means to reduce such by-catch, while not reducing catches of target fish species. A potential strategy to help minimize seabird by-catch in gillnets would be to exclude their use in the immediate vicinity of seabird colonies. At least one fishing community in Newfoundland (Petty Harbour) has elected, for other reasons than non-selective catches, to ban the use of gillnets on their fishing grounds (Bryant and Martin, 1996). Fishers may be encouraged to use other gear types, if these are economically feasible. Gear designs might be modified to enhance catch rates of target species and to minimize the capture of non-target species (Lien *et al*., 1988). To date, some acoustical devices have helped in reducing marine mammal captures in gillnets; seabirds have not received as much attention or fared so well.

Interactions with other factors

Fisheries are not the only factor affecting seabird populations. Other factors, of both natural and anthropogenic origin, frequently make it difficult to fully understand the effects of fisheries, particularly in respect of indirect effects.

Changes in stock abundance of the fish (or other prey) have certainly affected seabirds. The effect of El Niño/Southern Oscillations and unregulated fisheries on the anchoveta stock of western South America has been well documented, as has the parallel collapse in seabird populations. The effects of the collapse in sandeel recruitment around Shetland were described above. A collapse in the North Sea sprat stock in the early 1980s was considered to be partly responsible for a mass mortality of auks in spring 1983 (Blake, 1984). Harris and Bailey (1992) found that winter survival rates of auks were correlated with the abundance of sprat. It has not been possible to isolate the contribution of fishing to these collapses, and in most cases recruitment failure appears to have been the most important factor. Short-lived pelagic species are particularly at risk from recruitment failures as the stock biomass is composed typically of only one or two year classes. Failures have occurred in the absence of any fishery (e.g. Southward *et al*., 1988). However, fisheries may increase the frequency, duration or extent of a stock collapse and depress locally important fish stocks.

Most *Larus* gulls frequently scavenge around fishing vessels in the North Sea. Until recently, most species have increased markedly in numbers and have expanded their breeding range on all coasts. These trends have often been attributed to improved food resources, partly as a result of production of fishery waste (Lloyd *et al*., 1991). Camphuysen and Garthe (in press) evaluated the increase of (scavenging) North Sea seabirds over the last centuries in the light of these improved food supplies. Although there is mounting evidence that discards and offal may be at least an important additional source of food, the reproductive output of seabirds that rely greatly on fishery waste is not necessarily very high (Hamer *et al*., 1991). Some authors consider the increase

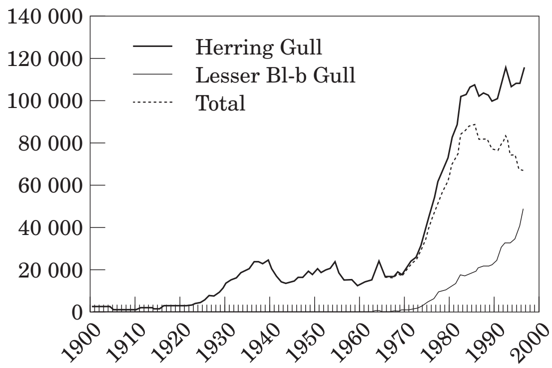

Figure 3. Changes in gull populations in the Dutch Wadden Sea, 1900–1997 (from Spaans, 1998a, b).

simply to be a consequence of the cessation of exploitation and persecution of seabirds just prior to the 20th century. Spaans (1998a, b) concluded that the relaxation of persecution must have been an important force driving the spectacular increase of both herring and lesser black-backed gull populations in The Netherlands (Fig. 3). When the breeding colonies were protected in the 1930s, the population of herring gulls increased. The increase stopped when culling was introduced to control their numbers for the protection of other birds, but when full protection measures were taken in the 1970s, populations of both species increased further.

Owing to the overfishing of large (predatory) fish, stocks of small fish species as well as the number of juveniles of many species exploited for human consumption in the North Sea are generally believed to be at an historically high level (Daan *et al*., 1990). Congruent shifts in sandeel abundance in the western and eastern North Atlantic ecosystems were explained by the relative scarcity of large predatory fish as a result of overfishing (Sherman *et al*., 1981). The increase in the amount of small fish intuitively must have resulted in a larger food resource for piscivorous seabirds. Although shifts in age structure, species composition, and length distribution of North Sea fish are beyond doubt, the conclusion that seabirds benefited from this larger food resource remains largely untested and would be difficult to prove.

Further indirect effects of fisheries caused by changes in food supply appear to have occurred in Shetland. Prior to the collapse of the sandeel stock in the 1980s, great skuas used to feed primarily on sandeels with an addition of discarded fish. During the collapse, great skuas started to feed directly on other seabirds. In 1996 (well after the end of the worst years for the sandeel stock), some great skuas were still specializing in hunting seabirds, but most of the diet consisted of discarded fish (Furness, 1997). The numbers of birds being killed was estimated at 200 000 per year. It seems likely that the recently observed decline in numbers of black-legged kittiwakes breeding in Shetland can be at least partly attributed to the change in diet of the great skua population. Any further reductions in discards around Shetland would presumably lead to greater pressure on the seabirds. Similar effects with gull predators and kittiwakes have been documented in the north-west Atlantic (Regehr and Montevecchi, 1996).

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