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Impacts of fisheries on seabird community stability

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Summary: Fisheries can change the structure of seabird communities. Fisheries may decrease numbers of some seabird species by reducing abundance of small prey-fish. They may increase numbers of others, by increasing prey-fish abundance through depletion of predatory fish stocks, or by provision of offal and discards. Fisheries can also change or trigger interactions between seabird species. Impacts of fisheries on seabirds are often difficult to measure against a background of many and varied environmental and human influences. Some impacts of fisheries are clearly evident. A few may have drastic effects on seabird community stability. I focus on examples of this last group. Long-line by-catch of albatrosses and petrels may soon lead to species extinctions if current trends are allowed to persist. Set-net by-catch has caused major reductions in certain seabird populations. Depletion of stocks of small lipid-rich fish can reduce food supply, and hence numbers, of seabirds, as documented in Peru, Norwegian Sea, and Barents Sea. However, reductions of predatory fish stocks in the North Sea appear to have more than compensated for the quantities of sandeels removed by the industrial fishery on that stock. If piscivorous fish stocks recover, reduced availability of sandeels to seabirds can be predicted to affect some species and not others. The influence of discards and offal discharged at sea on seabird communities is not widely appreciated. With dramatic increases in numbers of large, aggressive, scavenging seabirds, desirable changes in fisheries management to conserve stocks or reduce discarding can trigger diet-switching so that scavenging seabirds turn to killing smaller seabirds, with drastic consequences for community structure. Management of fisheries to reduce impacts on the wider environment needs to take this into account. The longer scavenging seabird populations are encouraged to increase as a result of discard provision, the more severe the impact on other seabirds is likely to be.

Introduction

Seabirds have two main requirements. They need safe places with suitable habitat in which to nest, and a suitable supply of food. In Europe, protection is afforded to many seabird breeding colonies through the EU Birds Directive and national conservation legislation. However, fisheries may have adverse effects on seabirds in several quite different ways. Fisheries may cause incidental mortality of adult seabirds through drowning birds that become caught in fishing gear. It has long been known that small numbers of seabirds, especially of inexperienced young birds, can be drowned in lobster pots, in set nets, trawls or seines. However there have been two developments that have greatly increased bycatch of seabirds. Development of monofilament nylon nets resulted in very large numbers of birds being drowned because these nets are almost invisible to birds swimming underwater. Development of long-line fisheries has resulted in large numbers of certain seabirds drowning as a result of their being attracted to long-line in order to steal baits from hooks as these are deployed; occasionally birds make an error and swallow the hook as well as the bait. In some parts of the world, seabirds are harvested by fishermen to use as bait, or as food for fishermen; this habit has tended to become less common as fisheries have become more sophisticated.

As well as causing direct mortality, fisheries can affect seabirds by changing the availability of food. Industrial fisheries, exploiting fish that are important natural foods of seabirds (mostly small pelagic schooling fish) may deplete stocks and so reduce food availability to some seabirds (Cairns 1987, Hamer et al. 1991, Furness & Camphuysen 1997, Hunt et al. 1999). Examples of impacts of industrial fishing on seabirds have been seen in Peru, Norway and the Barents Sea (Duffy 1983, Dunn 1994, 1995, Barrett & Krasnov 1996). A second kind of impact arises where fisheries make available to scavenging seabirds food that they could not naturally obtain for themselves. For example, fisheries catching benthic fish that are too deep for most seabirds to reach, and too large for those able to dive to the seabed to swallow, make these fish available to scavenging seabirds in the form of discards and offal (Hudson 1989, Hudson & Furness 1988, 1989, Camphuysen et al. 1995, Garthe et al. 1996, Moore & Jennings 2000). The quantities of fish discarded by fisheries are enormous. About 25-30 million tons of fish was estimated to have been discarded worldwide each year during the 1990s (Alverson et al. 1994, Furness 1999, Moore & Jennings 2000).

Global impacts of fishing were reviewed recently by Tasker et al. (2000), based on case studies from all around the world, and with particular focus on fisheries causing direct mortality of seabirds. In this paper I shall highlight fisheries management issues that will affect the future conservation status of vulnerable seabird populations, with particular emphasis on the situation in Europe where changes in seabird food supply caused by fisheries may result in alterations to seabird community structure, and affect predator-prey relationships within seabird communities.

Some theoretical considerations

Most seabirds share a set of demographic values characteristic of strongly 'K'-selected animals (Furness & Monaghan 1987): they have high adult survival rates (often >90% p.a.), deferred maturity (in many species not starting to breed until 5-10 years old), and low fecundity (typically less than 0.5 chicks reared per pair per year). As a result, seabird populations can only increase slowly even under highly favourable environmental conditions, and any factor increasing adult mortality rate will have a particularly strong negative influence on population dynamics. In contrast, changes to reproductive output may have a much smaller impact, and one that only becomes evident after a considerable time lag. Although seabird monitoring programmes tend to focus for practical reasons on breeding numbers and breeding success, impacts on adult survival rates are of particular significance for seabird conservation.

Long-line bycatch

A comprehensive and detailed review of the seabird long-line bycatch problem, and potential for mitigation measures, has been produced by Brothers et al. (1999), and so this topic will be described only briefly here. However, there is general agreement among seabird biologists that this is the most serious global seabird-fishery issue facing conservationists at present. Both pelagic long-line fisheries (mainly for tunas, swordfish and billfishes in temperate to tropical waters) and demersal long-line fisheries (for cod, hake, haddock, tusk, ling and wolf-fish in the North Atlantic, for cod, halibut, sablefish or walleye Pollock in the North Pacific, for hake, kingklip and Patagonian toothfish in South America, for kingklip, snapper and trevalla in Australia and for Patagonian toothfish in the Southern Ocean) take a by-catch of seabirds that accidentally swallow hooks when stealing baits as long-lines are deployed behind fishing vessels. Estimates of numbers of seabirds drowned by long-line fisheries are based on observations of small numbers of vessel-trips scaled up to the total number of hooks deployed by the fishery. These estimates involve multiplying a small number of birds recorded drowned by a very large number of hooks set; bird bycatch rates are generally less than 1 per 1000 hooks set. They are complicated by the fact that many factors influence seabird bycatch rate but these factors are not well known (Brothers et al. 1999, Weimerskirch et al. 2000). Data are not amenable to simple statistical analysis. Similarly, the effectiveness of mitigation measures is difficult to quantify given the multiplicity of factors affecting capture rate and the low capture rate per fishing vessel. Nevertheless, estimated bycatches of seabirds are large. For example, the northeastern Pacific longline fishery was estimated to drown over 13,000 seabirds per year from 1993-1996 (Brothers et al. 1999), most of which were northern fulmars. The South American Patagonian toothfish fishery was estimated to have drowned 2300 white-chinned petrels and 1150 albatrosses in 1990/91 Brothers et al. 1999), while the Southern Ocean Patagonian toothfish fishery may have drowned over a quarter of a million seabirds between 1996 and 1999 (Tasker et al. 2000). The Southern Ocean Japanese pelagic longline fishery was estimated to have drowned about 40,000 albatrosses per year during the 1980s (Brothers et al. 1999). Many of the birds drowned are from species with very large populations, such as the black-browed albatross (ca 500,000 breeding pairs) or white-chinned petrel (several million breeding pairs). Population sizes and trends for albatrosses are generally well documented and vary from a few tens of breeding pairs in some species to hundreds of thousands of pairs in others; for a few populations detailed demographic data exist showing which particular component of the population is subject to elevated mortality rates due to long-line fishery bycatch. Several albatross and petrel species are already listed as 'Critically Endangered', 'Endangered' or 'Vulnerable' by the World Conservation Union, and long-line fisheries are contributing to population declines in several of these species, with a clear risk of species extinctions if current trends are allowed to persist, since drowning of only one or two adults per year from a breeding population of only a few tens of breeding pairs will cause population decline (Croxall and Gales 1997). Mitigation measures are legally required in a number of regions and fisheries, but not all fisheries adopt these, and the efficacy of the many possible mitigation measures requires further study (Brothers et al. 1999, Weimerskirch et al. 1999), although there is no doubt that they can greatly reduce bycatch rates (see for example Murray et al. 1993).

Set-net bycatch

Monofilament gillnets represent a serious hazard for pursuit-diving seabirds (King 1984, Tasker et al. 2000). There are several examples where regional populations of seabirds have declined as a result of high mortality rates in monofilament nets, as in the eastern Canadian salmon fishery where an annual mortality of 20,000-30,000 common guillemots in Witless Bay, Newfoundland in the early 1970s removed 13-20% of the local breeding population per year (Piatt et al. 1984), or in northern Norway where during the mid-1960s to mid-1980s gillnets for cod and salmon drowned many tens of thousands of common and Brünnich's guillemots, and breeding numbers at local colonies declined dramatically, for example from 220,000 to 10,000 guillemots at Hjelmsøy between 1965 and 1985 (Vader et al. 1990).

The largest mortality of seabirds associated with gill nets was in the North Pacific high seas salmon and squid drift-net fisheries which were thought to have killed about 500,000 seabirds per year before the closure of these fisheries in 1992 (DeGange et al. 1993). These large numbers involved mostly shearwaters from populations that breed in enormous numbers in the southern hemisphere, and probably had very little impact on breeding numbers of those very abundant birds. More obvious impacts arise where gillnets are used in summer close to major breeding colonies, such that local breeding numbers can be noticeably reduced (Tasker et al. 2000).

Seabirds can also become entangled in lost or discarded fragments of fishing gear. In particular, gannets and various cormorant species will collect such materials to use in nest construction, which can lead to entanglement of adults and especially of chicks. Mortality rates resulting from this are low, but this form of pollution has increased considerably over recent decades (Montevecchi 1991).

Reduction in stocks of small lipid-rich shoaling fish

Although many oceanic or pelagic seabirds feed extensively on cephalopods or crustacea, most continental shelf and shallow seas seabirds feed predominantly on abundant, small, shoaling pelagic fish, at least during the breeding season (Furness and Monaghan 1987, Montevecchi 1993, Springer and Speckman 1997). Small shoaling fish species are often targets of industrial fisheries for production of fish meal and oils. The removal of large quantities of these fish by industrial fisheries might reduce food supply to seabirds. One frequently quoted example of this has been in Peru, where environmentally-driven dramatic decreases in numbers of guano seabirds occurred regularly during El Nino events but recovered between these to show cyclic fluctuations, but as the Peruvian anchovy fishery increased, seabird numbers began to fail to recover after El Nino driven crashes, such that the seabird population fell to only a small fraction of its earlier numbers (Duffy 1983).

Considered in abstract terms, industrial fishing could hypothetically affect seabird populations by a number of distinct processes. Fishing might reduce stock biomass, so that the prey density available to foraging seabirds, during the seasonal period of the fishery or subsequently, might fall below levels that would support high breeding success or survival. Such an effect would depend on whether seabirds require a certain minimum prey density to be available before foraging would be economic. Over a longer term, fishing might reduce the mean level, or increase variability, of recruitment into the fished stock. Such an effect would come about if fishing reduced spawning stock biomass and this reduction affected the level of recruitment of young fish. Thus the form of any relationship between spawning stock biomass and recruitment is of fundamental interest with regard to possible effects of such fisheries on seabird food supply. Finally, industrial fishing might alter food-web structure by affecting the competitive balance between fished and unfished, or between heavily fished and lightly fished stocks. For example, the relative abundance of two ecologically similar small planktivorous fish species might change such that species A decreased and species B increased over a period of heavy fishing on species A. If species A was the staple prey of seabirds while species B was unavailable to them or uneconomic, this change in community composition could have an adverse effect on seabirds, whereas if species B was the staple prey of seabirds, then a high fishing effort on species A might increase food availability to the seabirds and could result in an increase of seabird numbers as a result.

Seabirds are generally long-lived, mostly producing few fledglings that will only recruit if they survive to several years old (Furness and Monaghan 1987). In stark contrast, small pelagic fish exhibit short life spans, with early and highly variable recruitment. Their populations therefore tend to fluctuate rapidly, and rather unpredictably, in abundance. Seabird population sizes cannot track short-term changes in prey population abundance. Thus, seabirds have a variety of buffering mechanisms to cope with such natural variations in food supply. These vary among species in strength and form (Furness 1996, Phillips *et al.* 1996a). Theory predicts that the most vulnerable seabird species to reductions in pelagic food supplies would be small surface-feeding seabird species with specialised and energetically expensive foraging methods and little spare time to allow any increase in foraging effort (Furness and Ainley 1984) and this prediction is supported by empirical data (Furness & Tasker 2000). Arctic terns and kittiwakes in Shetland were particularly severely affected by the apparently oceanographically-driven (Wright 1996) reduction in sandeel stocks there in the late 1980s, whereas some of the larger seabirds continued to breed successfully despite the decline in sandeel abundance (Heubeck 1989, Furness and Barrett 1991, Furness & Tasker 2000). Theory also predicts that seabird species would maintain high adult survival rates even in the face of moderately reduced fish abundances, but that breeding success and time budgets would show responses to food supply (Cairns 1987). Some data support this (Hamer *et al*. 1991, 1993, Phillips *et al*. 1996b, Furness and Camphuysen 1997, Harris and Wanless 1997) but in several cases even adult survival may be affected by reductions in pelagic fish stocks (Vader *et al*. 1990, Hamer *et al*. 1991, Harris and Bailey 1992, Krasnov and Barrett 1995, Barrett and Krasnov 1996).

Major industrial fisheries in Europe include the fisheries for capelin in the Barents Sea (Gjøsæter 1995, 1997) and for sandeels in the North Sea (Gislason and Kirkegaard 1996). These two fish species are extremely abundant lipid-rich fish that are a major part of the diet of many seabirds, so seabirds might be in direct competition with industrial fisheries for these resources (Furness and Barrett 1991, Monaghan 1992). The fact that these fisheries are well documented and that there are very detailed data on the numbers and breeding success of seabirds in these regions, means that these cases provide the best opportunity to detect effects of industrial fishing on seabird populations.

The Barents Sea capelin stock has a historical biomass of 6-10 million tonnes, and serves as a food supply for cod, whales, seals and seabirds (Gjøsæter 1997). It supported an industrial fishery taking 1-3 million tonnes of capelin between 1973 and 1984, but the capelin stock collapsed to 20,000 t in 1987, recovered rather rapidly until 1992 but then collapsed again in 1993-95 (Gjøsæter 1997). Although the industrial fishery contributed to the first collapse by removing fish from a rapidly declining stock, the main cause of the collapse was high predation levels from increased stocks of cod (Bogstad and Mehl 1997). Quantities of capelin taken by seabirds (Mehlum and Gabrielsen 1995) were very small by comparison to quantities taken by cod, marine mammals or the industrial fishery (Gjøsæter 1997), but the reduction in capelin abundance resulted in an 80% decrease in numbers of common guillemots in 1985-87, apparently as a result of starvation leading to mortality of young and adult birds in winter (Vader *et al*. 1990, Krasnov and Barrett 1995, Anker-Nilssen *et al*. 1997). However, some seabirds showed surprisingly little response to this huge decrease in capelin stock. For example, seabirds on Hørnøya, north Norway, continued to achieve high breeding success and fed predominantly on capelin during the period of minimum stock (Barrett and Furness 1990), possibly exploiting a local fjordic stock of capelin rather than the Barents Sea stock.

In the North Sea, many fish stocks are very heavily exploited. An industrial fishery developed during the 1950s, first harvesting young herring, then taking mackerel, and after these stocks collapsed, fishing mainly for Norway pout and sandeels.

The sandeel has become the main target of industrial fishing in the North Sea. Sandeel catch by the North Sea industrial fisheries increased from a low level in the late 1950s up to a peak of 1,039,000 t in 1989. By comparison, seabirds consume only about 200,000 t of sandeels per year, but predominantly from the northwest sector of the North Sea which is an area where industrial fishing for sandeels has contributed only a very small fraction of the total North Sea harvest (Furness and Tasker 1997). The extent to which seabirds might be affected by the fishery depends particularly on the stock-recruitment relationship. For the North Sea as a whole, abundance of 0-group sandeels on 1 June each year shows a negative correlation with total sandeel stock biomass in January (r_{11}=-0.61, p<0.05) and also a negative correlation with sandeel abundance estimated from catch-per-unit-effort data (Furness 1999). This suggests that there is a negative feedback operating, possibly through competition between young and older sandeels for shared food resources, that will tend to compensate for reduction in stock size by enhanced recruitment of young fish.

The kittiwake is one of the most abundant and widespread breeding seabirds in Europe, and it feeds very extensively on sandeels during the breeding season (Furness 1990, Harris and Wanless 1997). Many features of its biology suggest that it should be particularly vulnerable to reductions in food supply, such as its surface feeding habits, the fact that one adult is always present to protect the nest site, its relatively small size, high foraging costs (prolonged flapping flight) and specialised diet (Furness and Ainley 1984), and empirical data confirm that kittiwake breeding success is strongly affected by food abundance (Harris and Wanless 1990, 1997, Hamer *et al.* 1993, Rindorf et al. 2000). Thus the kittiwake is the most obvious seabird to study in relation to effects of industrial fishing for sandeels on seabirds in the North Sea.

From the mid-1970s the industrial fishery has been consistently caught more than 500,000 t but has increased very little, whereas before the mid-1970s the sandeel catch was below that level. The mean annual sandeel catch during 1986-95 was significantly higher than during 1975-85 (t_{19}=3.51, P<0.05). Thus any effects on kittiwake breeding numbers or breeding success might be expected to become most evident after 1986, on the east coast of England and southern Scotland where fishery catches have been larger than further north.

Kittiwake breeding numbers have increased since the turn of the century in all areas of the British Isles. Between national censuses in 1969 and 1987, the increase in kittiwake breeding numbers was high on the east coasts of England (+167%) and Scotland (+44%), but low in Shetland, Orkney and much of western Britain and Ireland (Lloyd *et al*. 1991). Between 1986 and 1995, rate of annual change in breeding kittiwake numbers at selected monitoring colonies (Thompson *et al*. 1997) showed no significant difference between regions on the North Sea coast, which are potentially affected by the North Sea sandeel fishery (mean rate of increase 2.12% p.a., s.d. 2.57) and regions to the west of the British Isles, where sandeel fishing is negligible or nonexistent (mean rate of increase 1.2% p.a., s.d. 1.74), but kittiwake numbers have been decreasing at Shetland (-6.9% p.a.) which is a faster decline than seen in any other region, consistent with the collapse of the Shetland sandeel stock during the late 1980s.

Kittiwake productivity monitoring data for the years 1986-96 show that the mean breeding productivity in Shetland (mean 0.53 chicks per nest, s.d. 0.28) was significantly lower than in other regions (mean 0.84 chicks per nest, s.d. 0.29) of the British Isles (t_{64}=3.27, P<0.05). However, excluding Shetland, breeding success was significantly higher at colonies adjacent to the North Sea sandeel fishery (mean 0.97 chicks per nest, s.d. 0.28) than in colonies in western parts of the British Isles (mean 0.65 chicks per nest, s.d. 0.20) (t_{53}=4.57, P<0.05).

Breeding productivity of kittiwakes monitored in Shetland (1986-96) showed a significant correlation with the (log transformed) number of 1-group sandeels caught at Shetland per 30 minute survey tow (r_9=0.72, P<0.05), and with the (log transformed) total of 1- plus 2- plus 3-group sandeels caught per 30 minute tow (r_9=0.70, P<0.05) (Furness 1999).

Over the period 1986-95, breeding productivity of kittiwakes in Orkney showed a significant correlation with VPA estimated numbers of 1-group and older sandeels in the North Sea (r_8=0.61, P<0.05), as did breeding productivity of kittiwakes in east Scotland (r_8=0.41), and in east England (r_8=0.58, P<0.05). However, there were no significant correlations between VPA estimated numbers of 1-group sandeels in the North Sea and breeding productivity of kittiwakes in southwest Britain and southeast Ireland (r_8=0.09, n.s.) or in west Scotland and northern Ireland (r_8=0.01, n.s.). Kittiwake productivity at Orkney colonies also correlated with sandeel CPUE throughout the whole North Sea fishery (Furness 1999), indicating that good years for the fishery tended also to be good years for kittiwake breeding.

The ICES Multispecies Assessment Working Group (ICES 1997) estimated that over the last three decades, mackerel, whiting, haddock, gurnards and the industrial fishery were the largest consumers of sandeels in the North Sea, but the amounts taken by these consumers varied considerably over years, primarily as a result of changes in predator population sizes. In particular, the North Sea stock of mackerel collapsed in the early 1970s and has failed to recover since, so that the mass of sandeels consumed by North Sea mackerel has fallen dramatically, from almost two million tonnes in 1974 to less than 100,000 t each year from 1986-93. In addition, the Atlantic stock ‘western mackerel’ migrates into the northern North Sea to a variable extent from year to year and consumes North Sea sandeels. Consumption by this stock is variable across years as a result. Consumption of sandeels by other predators is estimated to be much less than by mackerel. However, there has been a downward trend in consumption by whiting and by haddock as these stocks have decreased from the 1970s to the 1990s. During this period, however, the industrial catch of sandeels has grown. Adding together the industrial catch with the consumption by mackerel (North Sea and western stocks when in the North Sea), whiting, haddock and seabirds, the summed consumption of sandeels shows virtually no overall change from 1976 to 1995 (Furness 1999).

Discharge of offal and discards

Although it is clear from recent research that discards and offal can be a very important food for certain seabirds in many different parts of the world (Abrams 1983, Dändliker & Mülhauser 1988, Hudson & Furness 1988, 1989, Ryan & Moloney 1988, Blaber & Wassenberg 1989, Berghahn & Rosner 1992, Furness et al. 1992, Thompson 1992, Camphuysen 1994, Evans et al. 1994, Garthe & Hüppop 1994, Walter & Becker 1994, 1997, Blaber et al. 1995, Camphuysen et al. 1995, Thompson & Riddy 1995, Arcos & Oro 1996, Garthe et al. 1996, 1999, Tasker & Furness 1996, Chapdelaine & Rail 1997, Freeman 1997, Walter 1997, Oro & Ruiz 1997, Walter & Becker 1998, Freeman & Smith 1998), the extent to which this supplementary food supply affects breeding success and population trends of scavenging seabirds is less clear (Howes and Montevecchi 1992, Noordhuis and Spaans 1992, Oro 1996, Oro et al. 1995, 1996a,b, Furness 1999, Tasker et al. 1999). There is evidence to indicate large increases of scavenging seabird populations where large quantities of discards have been generated (Furness 1992, 1999, Chapdelaine and Rail 1997, Garthe et al. 1999), and evidence suggesting that reductions in discard rates adversely affect scavenging seabird breeding and population size (Hamer et al. 1991, Paterson et al. 1992, Oro 1996, Oro et al. 1995, 1996a,b, 1999, Oro and Pradel 1999, 2000).

Seabird utilisation of discards has been studied in most detail in the North Sea and in the western Mediterranean. Fisheries in the North Sea generate very large quantities of discards. Estimates vary, partly as a result of low sampling intensity (Stratoudakis et al. 1998); the Scottish gadoid fishery is especially well studied but only 0.1-0.2% of trips is sampled (Stratoudakis et al. 1999), but recent annual discards have been estimated to amount to around 60,000 t of offal and 500,000 t of fish per year (Alverson et al. 1994, Evans et al. 1994, Garthe et al. 1996, 1999, Walter 1997, ICES 1998, Stratoudakis et al. 1998, 1999, Tasker et al. 1999, Reeves and Furness 2000). Fisheries for demersal fish in the western Mediterranean also generate large quantities of discards, although there are less data on discard volumes here than for the North Sea (Oro & Ruiz 1997). In recent years reductions in discarding by these fisheries (Reeves and Furness 2000) appear to be having serious impacts on entire seabird communities rather than just on the scavenging species themselves. Large scavenging seabirds unable to find sufficient discards have been turning to predation on smaller seabirds to supply their food needs (Regehr and Montevecchi 1996, Russell and Montevecchi 1996, Furness 1997,1999, Phillips et al. 1997, 1999). A 50% drop in numbers of kittiwakes in Shetland in the last 10 years can be attributed partly to increased killing by great skuas (Heubeck et al. 1997, 1999, Oro & Furness in prep.), which had previously been able to feed on sandeels and discards without needing to kill many other seabirds. These trends also suggest further ecological problems for the future, since it is both general policy to reduce the quantities of discards and offal discharged at sea (FAO 1995) and current changes in technical measures in the northern North Sea demersal fisheries are anticipated to cause a further reduction in quantities discarded over the next few years (Reeves and Furness 2000). Similarly, yellow-legged gulls in Mediterranean colonies cause breeding failures and increased mortality of other seabirds due to increased predation and kleptoparasitism during periods when the local trawl fishery is closed so no longer generating discards (Oro & Martinez-Vilalta 1994, Oro et al. 1999).

Discussion

North Sea sandeel fishing and seabirds

The decline in breeding numbers of kittiwakes at Shetland since 1986 contrasts with the general increasing trend in most other areas of the British Isles. This decline has been attributed to predation of both kittiwake chicks and adults by great skuas (Heubeck *et al.* 1997) as a result of reduced sandeel abundance combined with declining quantities of discards in the late 1980s. Thus low stocks of sandeels can impact kittiwakes both directly by reducing breeding success through food shortage (Hamer *et al.* 1993, Harris and Wanless 1997), but also through the indirect effect of increased predator impact (see also Regehr and Montevecchi 1996). The decrease in sandeel abundance at Shetland had little or no effect on the breeding success of common guillemots, but did affect their population during winter (Heubeck *et al.* 1991), so the timings and mechanisms of effects of low food abundance can vary from species to species.

In contrast to the clear effect of reduced sandeel abundance on kittiwakes in Shetland, kittiwakes breeding on the east of Britain, which might be expected to display responses to changes in sandeel stocks through the rest of the North Sea, showed no difference in mean population growth rate from kittiwakes monitored at colonies on the west of Britain and in Ireland. Furthermore, sustained high catches of sandeels since 1986 occurred as kittiwake numbers at the monitoring colonies continued to increase on the North Sea coast. Breeding success of kittiwakes on the North Sea coast was significantly higher than on the west of Britain and Ireland, suggesting that food supply to kittiwakes in the North Sea was at least as good as elsewhere despite the industrial fishery. One possible reason for this result may be the fact that the quantity of sandeels removed by the industrial fishery is less than the quantity that used to be removed by major fish predators. Since the stocks of these major fish predators have fallen, the total consumption of sandeels has remained almost constant since 1976. Given that the mackerel stocks were much higher during the late 1960s and early 1970s, it seems that sandeel consumption by fish predators would have been much higher before 1976, so that the industrial fishery appears to have filled a niche vacated by North Sea mackerel when their stock collapsed. These data suggest that the mackerel is a keystone predator in the North Sea pelagic food web, and that reduction of the mackerel stock has improved the food supply to seabirds. Whether recovery of mackerel stocks in the North Sea would be compatible with a sustained industrial fishery and continued historically high populations of seabirds is unknown, but seems unlikely.

Environmental changes can affect seabird populations through ‘bottom-up’ effects on foodwebs (Ainley *et al*. 1995). Aebischer *et al.* (1990) showed that kittiwakes, as well as marine organisms at other trophic levels, responded to long term variations in environmental conditions in the North Sea. Changes in sandeel abundance in Shetland during the late 1980s are thought to have been driven by changes in oceanographic patterns affecting recruitment of sandeels at Shetland, and not by the industrial fishery for Shetland sandeels (Wright 1996). There is evidence that seabird distribution at sea can be a response to sandeel distribution (Wright and Begg 1997), but over recent decades, the industrial fishery for sandeels in the North Sea has tended to harvest predominantly from areas of the North Sea where seabird foraging densities are low (Wright *et al*. 1997). This comes about because most feeding on sandeels by seabirds occurs during the breeding season, when seabirds are constrained to forage in the vicinity of their colonies, and the majority of seabirds breeding in the North Sea are found in the northwestern sector, where industrial fishing for sandeels has traditionally been very slight.

The fact that breeding performance of kittiwakes in Orkney, in east Scotland and in east England each show significant correlation with VPA estimated numbers of 1-group sandeels in the North Sea is noteworthy. Firstly, the kittiwakes in Orkney will not be foraging in the southern North Sea while breeding; they will only be sampling sandeels from relatively close to Orkney (data from Shetland and the Isle of May suggest that kittiwakes generally forage within 50 km at most from colonies while rearing chicks). Although traditionally the North Sea sandeel stock is treated as a single stock, it is likely that there are separate stocks in different parts of the North Sea. The broad correlations between kittiwake performance and aggregated sandeel data for all the North Sea suggest that sandeel stock dynamics are fairly coherent across years from Orkney to east England at least.

It appears that the sandeel fishery in the North Sea has had very little, if any, influence on the numbers of seabirds breeding on North Sea coasts until recently. Whether it is now affecting breeding numbers is uncertain; there is evidence suggesting that it has had slight effects on breeding success of some species at colonies on the southeast coast of Scotland in the early 1990s (Rindorf et al. 2000). Continued monitoring of breeding performance, together with complete censuses of seabird breeding populations on the coasts of Britain in 2000 may shed further light on this. The broad picture developing from the analyses presented here suggests that interspecies interactions involving stocks of mackerel and piscivorous gadoids will be the most influential factor affecting future availability of sandeels to seabirds. Given the very high consumption of sandeels by the large stocks of mackerel and gadoids present before the 1970s, it seems unlikely that the high current numbers of seabirds could flourish alongside both an industrial fishery and increased stocks of mackerel and gadoids if those stocks were to recover to previous levels when there was no sandeel fishery and seabird numbers were lower. Furness and Tasker (2000) showed that the species of seabirds likely to be affected by reductions in sandeel abundance can be predicted with considerable confidence, so that the changes to seabird community composition that would result from reduced sandeel abundance can be anticipated.

Reductions in discharge of discards and offal at sea

The FAO Code of Conduct for Responsible Fisheries (FAO 1995), section 7.2.2 states 'measures should provide that discards and impacts on associated or dependent species are minimized'. This creates a dilemma. Over recent decades, many populations of large scavenging seabirds have increased enormously in size. Several factors may influence these population increases, including the protected status of birds that many decades ago were subject to persecution or harvesting. However, the circumstantial evidence that discards and offal have encouraged population increases is strong (Lloyd et al. 1991, Furness 1992, Garthe et al. 1996). Given the current trend for reduction in discarding of haddock and whiting, the main discard species in the northern North Sea taken by scavenging seabirds, and predictions of further reductions as a consequence of technical measures and reduced fishing effort currently coming into effect (Reeves and Furness 2000), we can anticipate that the supply of discards to some scavenging seabirds may cause conservation problems over coming years.

It would seem logical to look for effects of changes in discarding rates on seabirds by correlating changes in breeding numbers of scavenging seabirds in the northern North Sea with changes in amounts of fish discarded over the last 20 years or so. Unfortunately, such a simple approach is not appropriate. Firstly, the last complete census of breeding seabird numbers was in 1985-87. Trends in breeding seabird numbers since 1987 are not clear as for most species only some sample counts are available and these are not necessarily representative of the population as a whole. Secondly, seabird breeding numbers do not necessarily reflect seabird total population size. Nonbreeders may fill vacancies that arise in the breeding component, such that breeding numbers remain relatively stable even during a period of rapid decrease in total population numbers. An example of such buffering is provided by great skuas in Foula during the 1980s, when numbers of nonbreeders decreased rapidly due to adverse feeding conditions but breeding numbers changed little (Klomp and Furness 1992). Thirdly, responses of seabird populations will tend to lag behind changes in environmental conditions because seabirds show delayed maturity. Any effect mediated through breeding production will not become evident until several years later, when altered numbers of young birds recruit into the breeding population. If reductions in discarding were to affect breeding numbers, then we must bear in mind that most seabird populations in the North Sea have been increasing. To reverse an increase is like changing the course of a supertanker. It takes time. The cohorts of young birds about to recruit into the population may have to be used up before a decline in breeding numbers can begin. In the case of great skuas, some birds do not start to breed until more than 12 years old. The importance of this becomes more obvious when it is appreciated that in a typical scavenging seabird population the breeding adults represent less than 50% of the fully grown birds; in other words the typical population contains more prebreeding (immature) birds that cannot be censused than breeding birds that are counted. The pool of potential recruits may continue to maintain or even increase breeding numbers for many years after the demographics have shifted to values that in the long term will result in a declining breeding population. It is possible that breeding success of scavenging seabirds might be more clearly and immediately responsive to reductions in discard rates, but the fact that scavenging seabirds feed more on natural foods while breeding and feed more on discards in winter suggests that breeding success may not be very responsive to discard rates and may more often be affected by variations in the abundances of the preferred natural foods. Possibly immature survival through the winter might be the most useful parameter to relate to discard rates, but immature survival rates are difficult to measure and this approach would not be practical at present. Also, this could mean that effects of reduced discarding in the northern North Sea may eventually be seen in terms of breeding numbers in other geographical areas. For example, great black-backed gulls wintering in the northern North Sea include birds that breed in Arctic Norway and Russia.

Reductions in quantities of offal are not predicted to be severe (Reeves and Furness 2000), and the most pronounced change will be in the amounts of small discards produced by the fishery. These small discards are particularly important for great skuas, herring gulls and lesser black-backed gulls, and it may be these species that will show the most pronounced changes. The highest catches of haddock, whiting, cod and saithe in the North Sea are from areas close to Orkney and Shetland. It is therefore likely that impacts of reduced discarding will be most evident in Orkney and Shetland scavenging seabird populations. Given the likely impact of prey switching by great skuas to killing other seabirds (Furness 1997, 1999) there is a need to monitor great skua breeding and diet as a consequence of changes in discarding over the coming years. If other feeding opportunities remained unchanged, reductions in discarding might result in reductions in numbers of great skuas, herring gulls and lesser black-backed gulls while having little direct negative effect on populations of fulmars, gannets or great black-backed gulls. However, increased predation by great skuas as a consequence of diet switching when discard supplies are low might impact a number of other seabird species on which great skuas may feed, including kittiwakes, puffins, storm petrels, Leach’s petrels, red-throated divers, eiders, and even great black-backed gulls, although variation in sandeel abundance may be a greater influence than variation in discard availability for predation rates of great skuas on other seabirds. Probably bird killing by great skuas will be a function of both sandeel and discard abundance.

It seems almost inevitable that quantities of fish discarded will reduce further in the North Sea in future. Reducing discarding is a major objective of the FAO’s policy for Responsible Fisheries, and is recognised to be a management objective by ICES and the EC as well as national fisheries managements and governments. However, it is not easy to see how best to manage interactions that will arise as a consequence of reductions in discarding. It would be foolish to suggest that rates of discarding should be maintained at current levels ‘for the sake of seabirds’. That would not be a practical proposition and even if it could be achieved, it would only serve to perpetuate the imbalance in seabird community composition that now exists in the North Sea as a consequence of many decades of intensive discarding. There may be a case for suggesting that a complete cessation of discarding would be the best strategy to minimize longer term impacts on seabird communities, as this would probably bring seabird populations to a new sustainable equilibrium very much faster than if discarding is slowly reduced over decades. The larger the populations of large scavenging seabirds become as a consequence of continued feeding on discards, the greater the secondary impacts of prey switching by great skuas and the large Larus gulls is likely to be on their prey seabirds. Given that culling would not be an attractive proposition, there is clearly a need for further research into interactions between scavenging seabirds and other wildlife, particularly with regard to consequences of low discarding rates.

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