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Seabird ecology in relation to fisheries

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Declaration

I declare that the work described in this thesis has been carried out by me, unless otherwise cited or acknowledged. It is entirely of my own composition and has not, in whole or in part, been submitted for any other degree.

Acknowledgements

Abstract

Previous research has hinted at changes in the migratory patterns of seabirds nesting in Scotland, including a decreasing number of Northern Gannets *Morus bassanus* wintering in the North Sea, and an increase in numbers of Northern Gannets and Great Skuas *Stercorarius skua* spending the winter off north-western Africa (NWA). Both species show increasing numbers of colonies in northern areas, including Norway and Russia. These seabird species move through the North Sea during autumn migration, and from there search for favourable wintering grounds mainly around Iberia, including the Atlantic coast of Portugal, the Bay of Biscay and the Gulf of Cadiz.

By means of historic ring recovery data, provided by the British Trust for Ornithology, it was possible to establish that the number of records of adults of both species are increasing in recent years from NWA coasts, despite having to attend their nests in the colonies and, as a result, having limited time to migrate south. Differences were observed in ring recovery locations between years and months. The number of ring recoveries by month coincides with records from observation points along the coast of Western Europe. However, ring recovery data are limited and potentially biased. Using data loggers, it was possible to establish that both species are diurnal in habits during the entire winter period, showing noticeable differences in the times spent flying during the migration months (September-October) and during the wintering and breeding months (January and March respectively), and to confirm the increasing tendency to winter off NWA in recent years.

Analyses of fishing landings, discard rates, and sea surface temperature data, show that food available to Northern Gannets and Great Skuas is increasing in NWA coasts where oceanographic conditions are stable; in contrast in the North Sea fisheries are decreasing and the sea surface is warming. Both species are apparently changing their migratory behaviour in order to face the constant changes in the abundance of food. Given the long life-span of Northern Gannets and Great Skuas, genetic changes can be ruled out of an explanation for the changes in migration behaviour, and the fact that the changes in winter distribution appear to be occurring within one generation of the birds. The winter distribution of Northern Gannets and Great Skuas may be due to an ideal free distribution over a wide range, in response to changes in the distribution of fish and the availability of discards.

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Chapter 1

General Introduction

Northern Gannet and Great Skua ecology

Several seabird species breed in Scotland, feeding mainly on pelagic fish species Sandeels *Ammodytes marinus*, as well as fisheries discards and offal, mainly from Haddock *Melanogrammus aeglefinus* and Whiting *Merlangius merlangus*. Among these seabird species are the Great Skua (*Stercorarius skua,* formerly *Catharacta skua;* see AOU, 2000) and the Northern Gannet *Morus bassanus*, whose populations migrate southwards during the winter.

The largest numbers of Scottish Great Skuas nest in the Shetland Islands (Furness and Ratcliffe, 2004). Many of the individuals breeding in the North-eastern Atlantic and in the North Sea were ringed at Foula (Furness, 2002). Skua numbers increased in the order of 84% between two censuses (1969-70 and 1985-88) in the Shetland Islands. However, the rate of increase was only 26% for the following years until 2002 (Furness and Ratcliffe, 2004). Smaller southern populations showed higher growth rates than Shetland, in the order of 148% and 26% for the same periods respectively (Furness and Ratcliffe, 2004). In both cases, growth rates were lower in recent years, maybe because these populations are close to carrying capacity (perhaps having already reached at in high density areas) in Scotland (Furness and Ratcliffe, 2004).

The increasing number of skuas in smaller populations, such as on Fair Isle (Shaw, 2007) as well of recent trends in growth rates, suggests that this seabird is experiencing ideal free distribution so dispersal movements could change owing to the search for new breeding areas. An example of this is the expansion of its geographical range as well the colonization of new areas, limited only by temperature (Furness and Ratcliffe, 2004). New colonies have been formed in Norway and Russia by individuals ringed at Shetland in recent years (Furness, 2002a) showing changes in migration patterns over several years.

Movements of Great Skuas from Orkney and Shetland into the North Sea, before migration southward to the Atlantic coast of Europe, could maybe drive differences in migration timing, as well in wintering area (Furness, 2002a). These changes in migration and emigration could be responsible for the changes in breeding numbers of Great Skuas at Foula during the mid-1980s (Ratcliffe *et al*. 2002, Furness and Ratcliffe, 2004).

From ringing recoveries, it is known that Great Skuas ringed in Shetland tend to be mainly recovered from Shetland during the summer, and Iberia and the North Sea during migrations and winter (Klomp and Furness, 1992). Whilst the majority of Great Skuas leave their breeding colonies during August, numbers of individuals begin to fall faster when feeding conditions are poor, even during July (Furness and Ratcliffe, 2004). Because there was a lack of records about adult Great Skuas wintering in Western Africa until 2006 (Furness *et al.* 2006), it is possible that Great Skuas are now moving to this region to feed on the pelagic fish in the area, or to take advantage of the fisheries developed there. It is important to stress that one of the most important factors affecting Great Skua populations is the change in food availability derived by fisheries (Furness and Ratcliffe, 2004).

On the other hand, the Northern Gannet breeds mainly in Britain and Ireland. The Bass Rock (in East Scotland) presents one of the biggest gannetries in the world, with about 39 000 AOS (apparently occupied sites) in 2001 (Nelson, 2002). Like the Great Skua, this species has formed new colonies in Norway since the 1940s (Brun, 1972), as well as in Russia (Wanless, 2002).

Northern Gannets have increased in numbers during the breeding season, but numbers wintering in the North Sea area have decreased during the last 20 years (ICES, 2007). Recently, at least 50% of the Northern Gannets in summer are moving out of the North Sea to winter in areas from the Celtic Sea to the Western coast of Africa (ICES, 2007). Ringing recoveries showed that 2-year old Northern Gannets migrate southward as far as Morocco, Senegal, and even Guinea-Bissau (Nelson, 2002). Additionally, many thousands of Gannets migrate into the Mediterranean Sea (Nelson, 2002). These changes may be related to food availability and the reductions in fish discards in the North Sea (ICES, 2007).

Scavenging seabirds tend to feed more on discards during winter, and more on natural foods during breeding (Furness, 2003). Because of this, changes of fisheries during the winter period could drive changes in the abundance and distribution of both migrating Gannets and Skuas. Analysis of fishing discards is very important due their impact on the ecology of seabirds. It is important to continue monitoring Great Skua diet, as well as breeding success, because of likely changes in the availability of discards in future years (Furness, 2003). In the case of gannets, the number of breeding pairs increased during the period between 1990 and 1999, in

part as a result of feeding on fish discards (ICES, 2001). Nevertheless, the role of fishing discards as complementary food affecting the survival of gannets during the period between fledging and recruiting to breeding is unclear (Wanless, 2002).

There is a gap in our knowledge of seabirds on land compared with that at sea, mainly because it is difficult to follow and observe them quantitatively at sea. Because of this, information about numbers, distribution and movements in relation to food is limited, but is necessary if the population trends in these birds are to be understood (Nelson, 2002). Data about migration patterns and wintering areas provide a baseline for future studies, especially those related to changes in the marine environment caused by global warming (Wanless, 2002) and changes in fishing activities.

New technologies provide an important source of information about seabird migration. As an example, the use of satellite tracking on the Short-tailed Albatross *Diomedea albatrus* determined post breeding distribution, and the relation between seabird movements and commercial fisheries in Alaska (Suryan *et al*. 2007). Satellite tracking devices and data loggers provide most of the information obout seabird migration nowadays (Weimerskirch *et al*. 1994, Furness *et al*. 2006, Shaffer *et al*. 2006, Suryan *et al*. 2007), allowing it to be related to oceanographic variables (Weimerskirch *et al*. 1995). These kinds of devices are used on both Northern Gannets (Hamer *et al*. 2001; Garthe *et al*. 2007) and Great Skuas (Furness *et al*. 2006).

The Northeast Atlantic

The Northeast Atlantic Ocean consists primarily of deep ocean basins, with the exception of the Celtic Sea and the continental shelf from the Iberian Peninsula north to the west of the British Isles. Its boundaries are between 36º N and 62º N parallels to the south and to the north respectively, 42º W longitude to the west, and the Atlantic coast of Europe up to the English Channel and further along the west coast of England and Scotland to the east (Johnsen *et al*. 2003).

The climate of the North Atlantic Ocean is strongly influenced by the Gulf Stream, or North Atlantic Drift (Frankignoul *et al*. 2001), with sea surface temperatures between 7-15º C

(Johnsen *et al*. 2003). The flow of oceanic water is mainly from west to east directed by the branches of the North Atlantic Drift (Johnsen *et al*. 2003), importing warm water from the South Atlantic (Schmitz and McCartney, 1993, Olsen and Schmith, 2007), with movements in the opposite direction for deep cool water (Schmitz and McCartney, 1993). The heat transport from equatorial waters to high latitudes is interrupted at the Iceland Basin, stopping the thermohaline circulation, and the surface layer flows to the Faeroese waters entering into the Norwegian Sea (Schmitz and McCartney, 1993) carrying warm water in a general north-eastward direction (van Aken, 1995). In the opposite direction, cold waters from the Nordic Sea sink to the bottom of the Iceland Basin as Iceland-Scotland Overflow Water across the sills in the Faeroe Bank Channel and on the Iceland-Faeroe Ridge (Schmitz and McCartney, 1993; van Aken, 1995).

The main currents in the area are the Gulf Stream-North Atlantic Drift, which carries water from the western edge of the ocean to northern Europe, and the North Equatorial Current that moves water in the opposite direction from Northern Africa to the Caribbean. Three main branches from the North Atlantic Drift flow into the Arctic, the Arctic Current, the Rennel Current and the Portugal Current. The Canaries Current drives water from Iberia to the Northwestern coasts off Africa (Fig. 1-1).
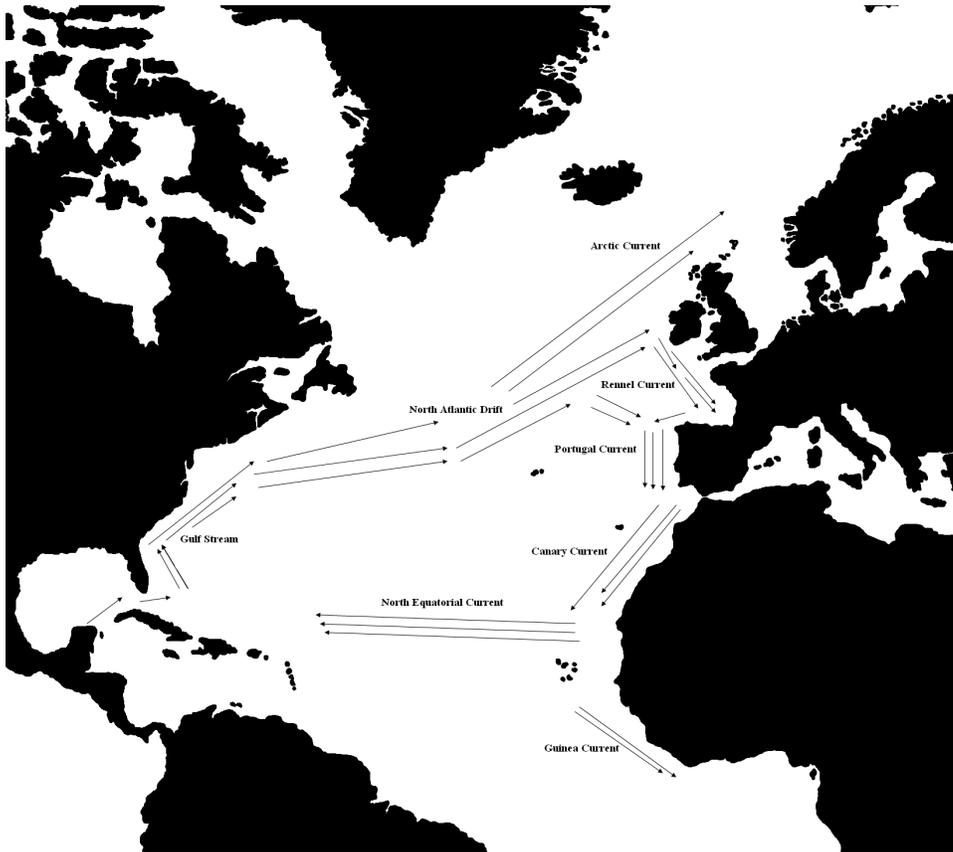
Figure 1-1. Main sea currents in the North Atlantic.

The Atlantic inflow of warm and saline Atlantic water, across the Greenland-Scotland Ridge into the Nordic Seas and the Arctic Ocean (fig. 1-2), is very important for the regional climate and for the global thermohaline circulation as well. This heat transport keeps the north of the Ridge free of ice (Hansen *et al*. 2003). This flux of Atlantic water presents three branches, Faroe-Shetland Current west of the Shetland Islands, the Faroe Current north of the Faeroes, and the North Icelandic Irminger Current around north Iceland (Steingrímur and Valdimarsson, 2005). The Greenland-Scotland Ridge separates the North Atlantic from the Nordic Seas and Arctic Ocean (Olsen and Schmith, 2007). The Iceland-Faroe Ridge connects directly the Iceland Basin with the Norwegian Sea, whilst the Faroe-Shetland Channel connects the Norwegian Sea with the Iceland Basin through the Faroe Bank Channel (van Aken and Eisma, 1987) being the deepest channel of the entire Greenland-Scotland Ridge (Duncan *et al*. 2003; Hansen and Østerhus, 2007).

Nutrients in the Northeast Atlantic Ocean are carried from the West Atlantic, just like heat. About 45% of the nitrogen and 70% of the phosphorus at the Atlantic coasts of America, Europe, and Northwest Africa, were discharged by large rivers in the western Atlantic (Nixon

et al. 1996). These nutrients are important to the survival of planktonic life. In the Northeast Atlantic Ocean and European seas, mapping of plankton associations have been possible because of the Continuous Plankton Recorder (Johnsen *et al.* 2003).
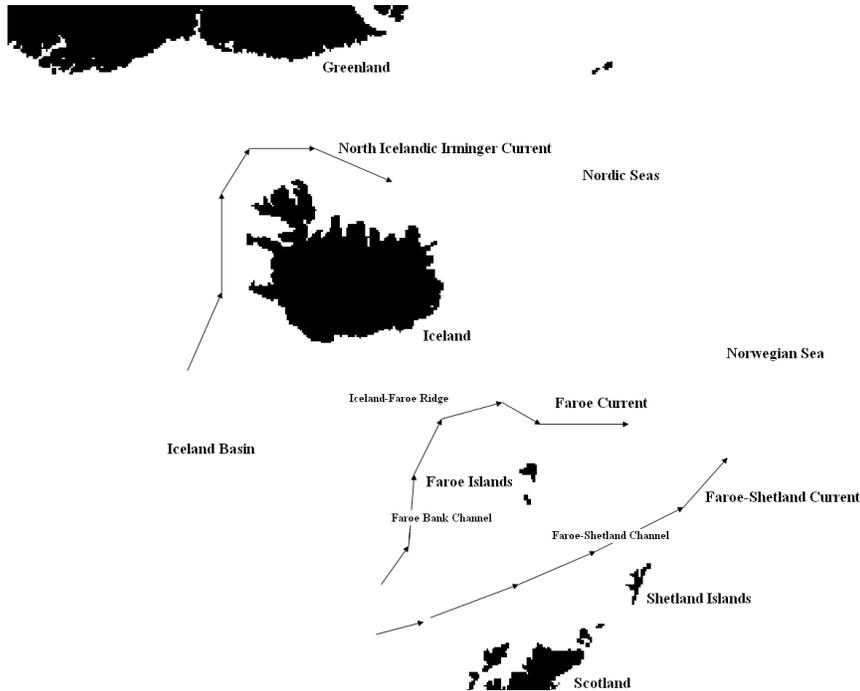
Figure 1-2. Sea currents in the Greenland-Scotland Ridge (from Hansen *et al.* 2003; Blindheim and Rey, 2004).

The OSPAR Convention (2000) divides the Northeast Atlantic into the following five divisions: I the Arctic Waters, II the greater North Sea, III the Celtic Seas, IV the Bay of Biscay and Iberian Seas, and V the wider Atlantic (fig. 1-3).
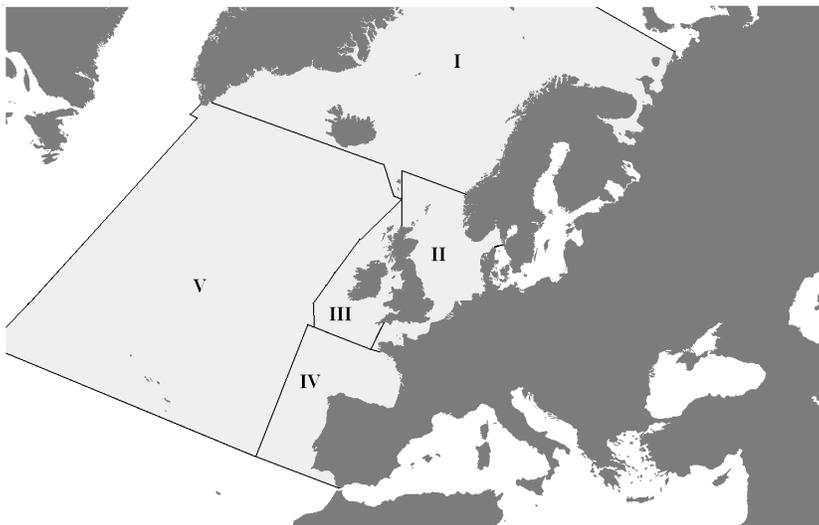
Figure 1-3. The Northeast Atlantic divisions (from OSPAR, 2000).

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Nearly 1100 fish species are known from the North Atlantic Ocean, 600 of them being pelagic forms. The most important species supporting fisheries include Anchovy *Engraulis encrasicholus*, Blue Whiting *Micromesistus poutassou*, Whiting *M. merlangius*, Megrim *Lepidorhombus boscii* and *L. whiffiagonis*, Plaice *Pleuronectes platessa*, Anglerfish *Lophius piscatorius*, Cod *Gadus morhua*, Haddock *M. aeglefinus* Hake *Merluccius merluccius*, Herring *Clupea harengus* Horse Mackerel *Trachurus trachurus* Mackerel *Scomber scombrus*, Saithe *Pollachius virens*, Sardine *Clupea pilchardus*, Sole *Solea solea* and elasmobranchs (Jonhsen *et al*. 2003). Other important commercial species at regional levels are Lesser Sandeel *A. marinus* (Frederiksen *et al*. 2007), Sprat *Sprattus sprattus* (Heath, 2005), Gurnard *Eutrigla gurnadus* (Floeter, 2005), Red Mullet *Mullus surmulletus* (Beare, 2005), and the crustacean Norway Lobster *Nephrops norvegicus* (Catchpole *et al*. 2006).

Breeding seabirds in the Northeast Atlantic show the highest numbers of species (26 species) around the British Isles, with large abundances at several offshore islands (OSPAR, 2000). Iceland and Norway also have internationally important colonies of seabird species. According to the OSPAR Commission (2000), the seabird species in the region can be divided into northern species (Northern Fulmar *Fulmarus glacialis*, Lesser Black-backed Gull *Larus fuscus*, Great Black-backed Gull *L. marinus*, Iceland Gull *L. glaucoides*, Black-legged Kittiwake *Rissa tridactyla*, Little Auk *Alle alle*, Razorbill *Alca torda*, Common Guillemot *Uria aalge*, Black Guillemot *Cepphus grille*, and Puffin *Fratercula arctica*, among others); central species (Manx Shearwater *Puffinus puffinus*, British Storm Petrel *Hydrobates pelagicus*, Leach's Storm Petrel *Oceanodroma leucorhoa*, Northern Gannet, and Herring Gull *L. argentatus*, among others); and southern species (Cory's Shearwater *Calonectris diomedea*, Madeiran Storm Petrel *Oceanodroma castro*, Little Shearwater *P. assimilis*, Yellow-legged Gull *L. michahellis*, Red-billed Tropicbird *Phaeton aethereus*, and Roseate Tern *Sterna dougallii*, among others). On the other hand, several species are migrants into the North-east Atlantic (Red Phalarope *Phalaropus lobatus*, Pomarine Skua *Stercorarius pomarinus*, Great Skua, Arctic Skua *S. parasiticus*, Long-tailed Skua *S. longicaudatus*, Common Tern *S. hirundo*, Arctic Tern *S. paradisaea*, Great Shearwater *P. gravis*, and Sooty Shearwater *P. griseus* among others). In the North Atlantic, seabirds can also be classified as generalist species (like Northern Fulmar, Great Skua or Herring Gull) or specialists (Shag *Phalacrocorax aristotelis*, Black-legged Kittiwake, Common Guillemot, Razorbill and Atlantic Puffin) according to their diet (Hilton *et al*. 2000).

The number of cetacean species observed in the North Atlantic Ocean is 32 (OSPAR, 2000), many of them rare, and there are also several species of pinnipeds.

All this species richness is at risk as a result of human activities. Marine habitats and biodiversity in the Northeast Atlantic are threatened because of the absence of an adequate sustainable regulation of fisheries, pollution due to chemicals and waste products and as a result of oilspills (Johnsen *et al*. 2003). This part of the Atlantic Ocean is protected by the Convention for the Protection of the Marine Environment (known as the OSPAR Convention), which is primarily focused on coastal areas (Johnsen *et al*. 2003).

The highly variable climate in the North Atlantic has oscillated between warm and cool periods at decadal, centennial and millennial scales since the last Weichelian glaciation. Variations in the oceanic conditions of the North Atlantic and the overlying atmosphere control the climate of Western Europe, generally keeping its climate much milder than at similar latitudes elsewhere in the world (OSPAR, 2000). On the other hand, climate-induced increases in sea surface temperature have been recorded in the Northeast Atlantic (Hurrell and van Loon, 1997). This fact could impact on physiological processes on sea life, and affect several aspects of the biology of fishes, like reproduction, larval survival and reproduction. An example of this may be the unprecedented high numbers of juvenile Snake Pipefish *Entelurus aequoreus* in the Northeast Atlantic in several years following 2002, apparently related to the rise of sea temperature (Kirby *et al*. 2006).

The North Atlantic Oscillation and climate

Several ecological processes, like temporal and spatial distribution patterns of populations, and species abundance, are strongly influenced by climate. In addition, marine life is influenced by physical processes (Ottersen *et al*. 2004) such as winds and oceanic currents. An example of this is the dependence of the drift of larval Cod by the North Icelandic Irminger Current from the spawning grounds south of Iceland to the nursery grounds on the North Icelandic Shelf (Steingrímur and Valdimarsson, 2005).

Climate change affects marine ecosystems in both direct and indirect ways. Direct effects of temperature are the influences on metabolism and growth, while temperature indirectly affects species by changes in food availability, competitors or predators (Ådlandsvik, 2008). Climate

warming has a direct effect on plankton, and thereby affects indirectly the rest of the marine food web. Changes in sea surface temperature drive changes in the structure of the community of several groups in the sea. Ecosystems of the northeast North Atlantic have changed toward a warmer dynamical equilibrium, and these changes have been far faster and more profound than those seen in terrestrial ecosystems (Beaugrand *et al*. 2002a).

Another climatic event that affects the marine organisms is the North Atlantic Oscillation (NAO), and its effects have been receiving increasing attention in recent years (Arnott and Ruxton, 2002). The NAO is the dominant mode of climatic variability in the North Atlantic region (Alheit *et al*. 2005), and its variability influences regional temperatures, precipitation, wind speed and direction (Hurrell, 1995; Arnott and Ruxton, 2002). The NAO has consequences for regional climate in both Europe and Africa (Hurrell, 1995) and it is characterized by a north-south difference in pressure. A low-pressure region is located near Stykkisholmur (Iceland) and a high-pressure region in the Azores (Portugal). This contrast in the pressures drives the surface winds and winter storms across the North Atlantic to the east. When the pressure is lower than normal near Iceland, it tends to be higher than normal near the subtropics and vice versa; this relation defines the NAO index (Uppenbrink, 1999). This index is determined by subtracting the pressure results for Iceland from the Lisbon dataset (Reid *et al*. 2001). It is high when pressure is low over Iceland and high over the Azores, and is low when this difference is reduced or may even be reversed in sign (OSPAR, 2000).

The NAO is associated with changes in the surface westerlies across the Atlantic onto Europe and trade winds in Africa (fig. 1-4). Although it is evident throughout the year, it is more pronounced during winter (Hurrell and van Loon, 1997). High NAO index winters are associated with increased strength and frequency of westerly winds across the Atlantic, whilst low or negative NAO index winters are associated with storms tracks turning south-east across the Atlantic (Hurrell and van Loon, 1997; Frankignoul *et al.* 2001; Forchhammer *et al.* 2002). Positive winter indices (averaged over December to March) are correlated with strong winter storms crossing the Atlantic Ocean along northerly tracks. These storms result in warmer, windier and wetter winters in northeast Atlantic. Colder and drier winters are associated with negative indices (Hurrell, 1995).

Strong fluctuations in the NAO index have been recorded over long periods of time (even thousands of years), showing periods with high or low values (Hurrell and van Loon, 1997; Hurrell and Dickson, 2004; Olsen and Schmith, 2007). In the recent decades, extreme high positive values have persisted (Hurrell and van Loon, 1997; Hurrell *et al.* 2001; Hurrell and Dickson, 2004). Coincidently, the formation of Greenland Sea Deep Water slowed down considerably during the 1980s. Such a decrease could have significant impact on the properties of the waters flowing over the Scotland-Iceland-Greenland ridge system into the deep Atlantic (Schlosser *et al.* 1991), potentially resulting in severe changes of the sea life in the Northeast Atlantic.

The NAO impacts the atmosphere-ocean heat flux exchange, which controls the temperature of the upper mixed layer, affecting marine ecosystems (Alheit *et al.* 2005), especially plankton. Variations in the NAO have a wide range of effects on marine and terrestrial ecosystems, including the large-scale distribution and population size of fish and shellfish, and the production of zooplankton (Hurrell *et al.* 2001).
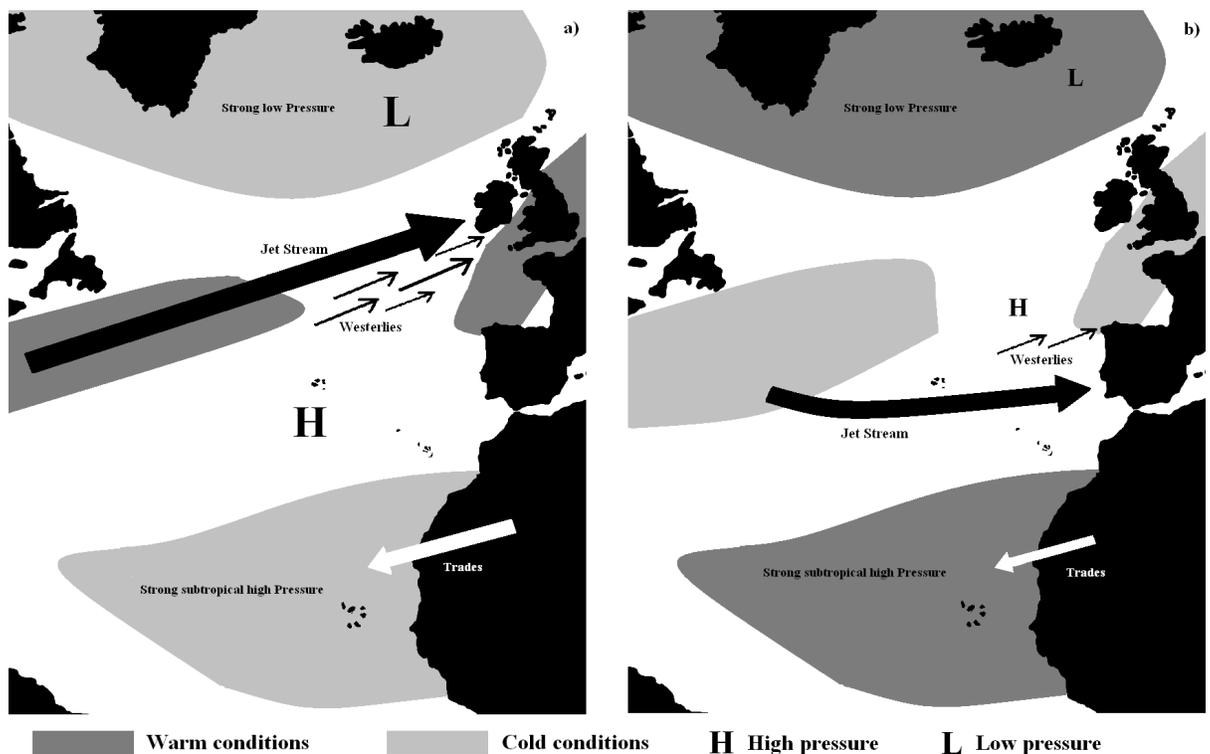
Figure 1-4. North Atlantic Oscillation conditions during a) the positive phase and the b) negative phase. The size of arrows and letters of pressures indicate the strength.

The effects of climate change and NAO on sea communities

Marine ecosystems change rapidly in response to perturbations that could be due to whaling, fishing, climate change, or a combination of these. Ecosystems are exposed to gradual changes in climate, because stochastic weather conditions are never constant. However, sudden shifts could interrupt the gentle changes, switching into a contrasting state (Scheffer *et al*. 2001). The term 'regime shift' has been used to describe large, usually decadal-sale switches in the abundance and composition of plankton and fish (Reid *et al.* 2001). This term means a catastrophic shift or abrupt shift from one dynamic regime to another (Beaugrand, 2004), involving fundamental changes in ecosystems (Caddy and Garibaldi, 2000), and resulting in an alternating state (Cury and Shannon, 2004).

Time series of abundances in biological communities show notorious leaps between stable conditions. These abrupt events of regime shifts are considered to be triggered mainly by physical events (Scheffer *et al*. 2001). More drastic changes between alternative stable states are driven by the coupled ocean-climate system (Rahmstorf, 1995). Changes in freshwater input are capable of triggering convective instability, inducing transitions between equilibrium states, and leading to substantial changes in regional climate (Rahmstorf, 1996).

Climate strongly influences changes in fish at individual, population and community level. The consequence of this is the fact that fish communities are affected by climate change. Temperature influences young fish directly by changing their rate of development (Henserson, 2007), or drives changes in fish distribution. An example of this is the shift in the spatial distribution of Cod in the North Sea, which may be caused by the warming of the sea (Beaugrand, 2003).

In addition, combined effects of the NAO and global warming could drive substantial changes in the biogeography and community structure of the plankton in the entire North Atlantic (Beaugrand *et al*. 2002b; Smayda *et al*. 2004). The use of the Continuous Plankton Recorder (CPR) has demonstrated that major shifts for all species assemblages have taken place since the early 1980s to the south-west of the British Isles (Johnsen *et al.* 2003).

Changes in physical conditions, caused by climatic variables such as the NAO, drive cascade-effects in the ocean, causing changes in phytoplankton productivity, which alters the

zooplankton community and, as a result, affects the abundance of fish species (Beaugrand and Reid, 2003; Beaugrand *et al*. 2003). This idea is supported by observations of the goby *Alphia minuta*, a planktonic fish species that responds strongly to changes in NAO conditions (Henderson, 2007).

But climatic fluctuations could be linked with changes in zooplankton distribution as well. Copepod species in the Northeast Atlantic have shifted northwards over the last 40 years, in relation to warming sea temperatures and changes in the NAO index (Beare *et al*. 2002; Heath, 2005). During periods of positive NAO index, the *Calanus finmarchicus* copepod stock is small in the North Sea, and large *C. finmarchicus* copepod stocks are associated with periods of negative NAO index (OSPAR, 2000; Hurrell and Dickson, 2004). Planktonic larvae of the benthic echinoderm *Echinocardium cordatum* are influenced by temperature. Although in recent years the larvae have been dominating the North Sea in summer (Lindley and Batten, 2002); reduced larval abundance in the summer of 1996 was driven by the previous winter being colder than usual as a result of a negative NAO index (Kirby *et al*. 2007).

In the late 1980s the sea around the British Isles was characterized by high temperatures and salinities, related to a high positive NAO index. This, with the increased inflow of warm Atlantic water into the North Sea (possibly via the Shelf Edge Current), caused an extremely warm oceanic climate during the late 1980s and early 1990's (Edwards *et al*. 2002). From 1988 onwards, the NAO index increased to the highest positive level observed in the century, and this has been interpreted as driving the migration of the Horse Mackerel **(**Reid *et al*. 2001) into northern latitudes.

The onset of a continued warm period in the North Atlantic Ocean has been related to fish species newly found in Iceland in the last decade. Among these fish Astthorsson and Palsson (2006) reported the Atlantic Bonito *Sarda sarda* and Blue Shark *Prionace glauca*. Other species previously rarely recorded are more frequent nowadays, like the Mackerel *S. scombrus* and Sea Lamprey *Petromyson marinus*, and others have extended their range from southern into northern Icelandic waters, like Snake Pipefish *E. aequoreus*. The fish species recorded for the first time at the southern coast of the UK, such as Sailfin Dory *Zenopsis conchifer*, Big-eyed Tunny *Thunnus obesus* and Barracuda *Sphyraena barracuda* have increased sharply since 1980 and this has been correlated with North Atlantic temperature data (Stebbing *et al*.

2002; Beare *et al*. 2005). These observed biogeographical shifts may have serious consequences for exploited resources in the North Sea, especially fisheries, leading maybe to substantial modifications in the abundance of native fish such as cod, which is already overfished **(**Beaugrand *et al.* 2002b).

Changes in community dynamics are related to competition and predation. It is therefore likely that fisheries can affect the entire food web, causing shifts in species abundance on various trophic levels (Reid *et al*. 2000). Also, those biotic interactions may affect sensitivity of a single keystone species, causing major shifts in community composition (Scheffer *et al*. 2001).

On the other hand, because fish appear to respond to warming by the northerly advance of the distributions of southern species, they may provide a useful index of the effects of warming in the North Atlantic (Stebbing *et al*. 2002).

The North Sea

Oceanography

The greater North Sea is a shallow basin (Corten, 2002) situated on the continental shelf of north-west Europe. It is partially open to the North Atlantic (Hutchance, 1997; Corten, 2002) with an extensive boundary to the north, and to a minor extent to the southwest via the English Channel (Hutchance, 1997; OSPAR, 2000), and it is connected to the Baltic Sea to the east although transfer of water between these two areas is restricted (OSPAR, 2000). The North Sea is divided into the shallow southern part, the central and the northern areas, the Norwegian Trench and the Skagerrak (OSPAR, 2000).

The North Sea is a remarkably heterogeneous sea with large regional variations in depth, temperature, salinity, topography of the coastline and type of sea bed (Daan *et al*. 1990). The Norwegian Trench is a conspicuous topographic feature that follows the coast of Norway, from the Norwegian Sea into the Skagerrak (Furnes *et al*. 1986). The greater North Sea has a surface area of about 750 000 km^2 (OSPAR, 2000), and it is surrounded by several countries (the UK, France, Germany, Belgium, Holland, Denmark and Norway).

North Sea currents are dominated by the Atlantic inflow, flowing into the North Sea by three main branches: the Fair Isle Current in the west, the Atlantic water entering to the east of Shetland, and the Norwegian Trench Current (fig. 1-5). To lesser extent, Channel water flows into the North Sea from the southwest. The overall pattern of sea currents in the North Sea is from west to east, from north to south along the east coast of Scotland and England, with some outflow northwards along the Danish and Norwegian coast.

The Norwegian Trench is the major link between the shallow North Sea and the deep Atlantic Ocean. The transition zone between the shelf and the deep sea is also a boundary of North Sea circulation (Klein *et al*. 1994). Because of the great open boundary with the North Atlantic Ocean, the North Sea is strongly affected by the inflowing Atlantic water (Corten, 2002). This water originates from a large current system flowing into the Norwegian Sea between the Faeroes and the Shetland Islands. Atlantic water also follows the western slope of the Norwegian Trench southward. This inflow (called the Shelf Edge Current) is the main source of Atlantic water into the North Sea (Furnes *et al*. 1986). Practically all the water entering the North Sea is directed into the trench and eventually flows out of the North Sea along the Norwegian coast (Furnes *et al*. 1986). As a result, the Norwegian Trench has a strong influence on the current system of the North Sea, followed by the Fair Isle Current and a third inflow offshore from Fair Isle (Turrell *et al*. 1992).

Figure 1-5. North Sea circulation patterns (from OSPAR, 2000).

A large portion of water is retroflected to the Atlantic from the Norwegian Trench, via topographic guidance, returning northwards along the Norwegian side without entering the main body of the North Sea (Furnes *et al*. 1986).

The temperature pattern shows colder conditions in the southern North Sea during the winter, with an inversed relation for the rest of the year. This seasonal variation is due to the cold climate of continental Europe in winter, the warm climate of the continent in summer, and the shallow nature of the southern North Sea. In contrast, the North Sea shows much less seasonal variation in temperature in the northwest, where climate is less warm in summer, less cold in winter, and the inflow of Atlantic water in all seasons buffers water temperature. For the North Sea the inflow of Atlantic water is thus an important climate variable. There is a strong warm Atlantic inflow to the Norwegian Sea west of the Faeroe Islands, and low warming or cooling on the south side (Ådlandsvik, 2008). The shift in the Atlantic inflow is drive by a major change in the wind stress pattern, with decreased wind stress from north in the area (Ådlandsvik, 2008).

The North Sea is a varying mixture of North Atlantic water and freshwater run-off. The salinity and temperature in different areas are strongly influenced by heat exchange with the atmosphere and discharged freshwater. The deeper waters consist of relatively pure water of Atlantic origin, whereas shallow areas, especially in the southern North Sea, show a strong influence of seasonal inflows of freshwater from major rivers (OSPAR, 2000). The North Sea salinity presents values close to that of the ocean (Huthnance, 1997), and its variations follow those from the North Atlantic (Jones and Howarth, 1995).

The river inflows affect the salinity even in the central North Sea slightly. During 1988-1989, values were anomalously low, maybe as a result of lower rainfall and less than normal river flows (Jones *et al.* 1995). However, the Baltic Sea provides most of the fresh water input to the North Sea (Huthnance, 1997; Beare *et al.* 2002), forming a transition zone between the high saline North Sea and the low saline Baltic Sea (OSPAR, 2000; Lund-Hansen and Vang, 2003). The Atlantic Ocean, the rivers, the atmosphere and discharges from the coast, ships, platforms and dredged materials are all sources of nutrients into the North Sea (Brockmann, *et al.* 1990). The increase of nutrients in the North Sea, over recent decades, resulting from anthropogenic sources (Brion *et al.* 2004) has caused eutrophication, particularly in the shallow southeastern North Sea off Belgium, the Netherlands and Germany.

Marine Biology

The plankton in the North Sea increases surface concentrations of organic substances during spring blooms, and 40% of the biomass formed by primary production in summer directly goes to the food web (Brockmann *et al.* 1990). In autumn, a second bloom takes place. During winter, the highest concentration of nutrients is found at the northern boundary (Brockmann *et al.* 1990), due to the warm Atlantic inflow. Estimates of primary production in the North Sea areas range between 50 and 1350 kcal/m^{-2}yr^{-1}extremes, with higher values around Shetland as some upwelling and considerable mixing of currents occurs there (Furness, 1978).

Fishes of the North Sea include 224 species. Demersal species include gadoids, like Cod, Haddock, Whiting and Saithe; among the truly pelagic species are Herring and Mackerel; small and short-live species are Sandeel, Norway Pout and Sprat; and the two most important flatfish species are Sole and Plaice (Daan *et al.* 1990).

The fish fauna in the North Sea shows different ecological characteristics (Daan *et al*. 1990). For example, Cod occur at selected locations throughout the continental shelf, spatially controlled by environmental properties (O'Brien *et al*. 2000), whilst Haddock occupy a less extensive area, mainly occurring in northern and central regions (Hedger *et al*. 2004), and Saithe distribution is a result of active migration (Furness *et al*. 1986).

Because of the summer invasion of the North Sea by Scad, or Horse Mackerel, from the north via the shelf edge, and the south through the English Channel, and the presence of the western stock of Mackerel, the total biomass of fish in the North Sea is much higher in summer than in winter (Daan *et al*. 1990).

The Lesser Sandeel is one of the most abundant fish in the North Sea, showing highly variable recruitment dynamics (Pedersen *et al*. 1999; Arnott and Ruxton, 2002). Since the overfishing of Herring and Mackerel in the 1970s, sandeels have been until very recently the dominant mid-trophic pelagics in the North Sea (Frederiksen *et al*. 2007).

Most fish species in the North Sea are carnivores, rather generalists than specialists; Herring remains largely planktivorous even during the adult phase; and gadoids are opportunistic feeders (Daan *et al*. 1990). The ecology of fish in the North Sea has been influenced by exploitation by man, especially since 1945. The decline of the stocks of Herring and Mackerel was primarily the result of over-exploitation, and their reduction is thought to have driven changes in the entire ecosystem (Daan *et al*. 1990). Fish ecology is influenced by the climate as well. The North Sea is not an isolated area, and some fish move into the sea to feed or to spawn whereas others migrate to adjacent areas (Daan *et al*. 1990).

Fisheries

The North Sea is one of the most heavily fished regional seas in the world (Heath, 2005; Frederiksen *et al*. 2007), is one of the most biologically productive ecosystems in the world (Kirby *et al*. 2007), and is one of the most studied shelf seas (Heath, 2005).

The Lesser Sandeel is the most important prey fish to most breeding seabirds (Wanless *et al*. 1998; Furness, 2002b) like Fulmar, Gannet, Shag, Kittiwake, Puffin, Razorbill and Guillemot (Tasker and Furness, 1996). Also, sandeels are the prey of Herring (Last, 1989) and other

commercial fish species like Cod, Haddock, Whiting, Saithe and Mackerel (Tasker and Furness, 1996), and seals, dolphins, porpoises and whales (Pedersen *et al.* 1999) as well. The Lesser Sandeel is found from the mid-tide level down to around 30 m in inshore waters, with clean sandy bottoms where it can burrow. This fish feeds mainly on planktonic stages of fish, crustaceans, and other small invertebrates. As a result of this, changes in plankton drive changes in the sandeel populations. The sandeel population at Shetland was high in the 1970s, but it declined in the early 1980s (Corten, 2002). The decrease of herring during the 1970s in the North Sea affected positively the sandeel populations, with a massive boom of these species just like of the Sprat. This stock also depends for its recruitment on larvae that are retained in the area (Corten, 2002).

Grey Gurnard is a widely distributed demersal species in the North Sea, rated among the 10 dominant species. Since the late 1980s, Grey Gurnard catch rates showed a pronounced increase and it was included as an important predator in the North Sea, having a significant top-down effect on Whiting and potentially also on Cod recruitment (Floeter *et al.* 2005).

Overfishing in some areas of the North Sea, followed by a collapse in this activity, could drive rapid decrease of fish populations, or changes in species composition that affects seabirds. There is a decline for some seabird species in some places in the North Sea since the 1980s (Dunnet *et al.* 1990). In addition to the effects of overfishing, recruitment of some North Sea fish species was negatively affected by higher temperatures associated with the NAO since the late 1980s (Alheit *et al.* 2005).

Seabirds

Seabirds are abundant around the entire North Sea, with large colonies being present. Northern Britain is the most important area for seabirds in terms of both numbers and diversity of seabirds within the North Sea (Dunnet *et al.* 1990) and supports several breeding colonies (especially in the Shetland and Orkney Islands). Some breeding seabird populations around the North Sea mostly remain in the North Sea during the non-breeding period (Red-throated Diver *Gavia stellata*, Fulmar, Great Cormorant *Phalacrocorax carbo*, Shag, Black-headed Gull *Larus ribidindus*, Common Gull *Larus cannus*, Herring Gull, Great Black-backed Gull, Black-legged Kittiwake, Guillemot, Razorbill, Black Guillemot and Puffin), whereas others migrate to Iberia and the Bay of Biscay (Great Skua and Lesser Black-backed Gull), or to

Africa (Storm Petrel, Arctic Skua, Little Tern *Sterna albifrons*, Common Tern *S. hirundo*, Roseate Tern *S. dougallii*, and Sandwich Tern *S. sandivicensis*), or even moving so far as South America (Manx Shearwater), or the Arctic Tern, moving to the Southern Ocean (Dunnet *et al*. 1990). Numbers of seabirds breeding around the North Sea have increased during the 20th century, and this may be due to an increase in the stocks of small fish (Furness, 1982; Dunnet *et al*. 1990), caused by fishing activities (Furness, 1982).

Seabirds in the North Sea feed mainly on small fish, the Lesser Sandeel being their most important prey (Wanless *et al*. 1998; Furness, 2002a). Many seabirds feed in flocks on shoals of fish, because of the apparent reluctance of fish shoals to split or disintegrate when attacked by predators. This is particularly a feature of the behaviour of sandeels. Around Shetland, shoals of Sandeels at the sea surface attract flocks of Fulmars, Great Black-backed Gulls, Great Skuas and Gannets, with small numbers of Herring Gulls and Lesser Black-backed Gulls (Dunnet *et al*. 1990).

Other human impacts to seabirds in the North Sea are pollution (oil or chemicals), plastics, entanglement in discarded nets (Dunnet *et al*. 1990), shooting or disturbance.

Regime shift in the North Sea

A key challenge in marine biology research is to understand and predict the responses of marine ecosystems to climate warming (Beaugrand, 2003). Changes in wind intensity due to the NAO and oceanic inflow have been regarded as important factors in the ecology of the North Sea (Edwards *et al*. 1999; Reid *et al*. 2003; Beaugrand, 2004). A regime shift involves changes in ecosystems (Caddy and Garibaldi, 2000), being considered a sudden shift in the function and structure of a marine ecosystem resulting in an alternate state (Cury and Shannon, 2004).

Important inflows to the North Sea occurred in the region of the Fair Isle passage, between the Orkney and Shetland Isles in late 1980s and early 1990s (Stephens *et al*. 1998; Lindley and Batten, 2002). In the same way, sea surface temperatures showed an increase after 1987 in the North Sea, particularly in winter months (Edwards *et al*. 1999; Reid *et al*. 2001). Such rises in sea temperatures were correlated with biogeographical changes of plankton and fish.

Generally, warm-water species have increased, while colder-water species have decreased in the North Sea (Beaugrand, 2004).

A prolonged period with mild winters may have caused serious disturbances in the ecosystem (Beukema, 1992), including large changes in the macrobenthos community of the southern North Sea (Beukema, 1992; Edwards *et al*. 2002). Hypothetically, three main features linked to each other could be responsible for regime shifts in the North Sea:

1. A change in local hydro-meteorological forcing (Beaugrand, 2003). Winter flows in the northern North Sea are very dependent on westerly winds (Stephens *et al*. 1998). So, changes in winds could be responsible for changes in water flow.

2. A displacement of oceanographic biogeographical boundaries to the west of the European continental shelf (Beaugrand, 2003).

3. An increase in oceanic inflow to the North Sea (Reid *et al.* 2001).

The regime shift that occurred in the North Sea ecosystem in the late 1980s was linked with a positive NAO index, related with an increased inflow of warm oceanic water from the Atlantic Ocean (Reid *et al.* 2001; Alheit *et al.* 2005).

Temperature possibly was the key physical variable impacting phytoplankton, zooplankton, and fish species in the North Sea in late 1980s. Indirect effects appear to be triggered by increasing air and sea temperatures (Alheit *et al.* 2005). Anomalous conditions in ocean climate could be the cause of conspicuous ecosystem shifts rather than trends in atmospheric circulations or anthropogenic perturbations (Edwards *et al*. 2002).

Ecological changes in the North Sea include a number of new fish and invertebrate species reported. These changes appeared after several years of stability, and impact the feeding of top predators. As a result, prey species can be shown to have changed historically among high level carnivores. Using stable isotopes from skeletons of stranded Harbour Porpoises, during the period 1848-2002, temporal change in the diet were detected (Christensen and Richardson, 2008).

Plankton

There is strong evidence in the literature that ecosystem change is occurring in the North Sea. Patterns of primary production and species composition of phytoplankton are changing and this change permeates the entire food chain (Reid *et al.* 1998). Plankton from the central North Sea has changed from being numerically dominated by holoplanktonic calanoid copepod species, from 1958 to the late 1970s, to a dominance of the *pluteus* larvae of echinoid and ophiuroid echinoderms in the 1980s and early 1990s. There are many possible and hypothesised causes for such change. For example, changes in the benthos could influence the composition of the plankton, and may be related to the damage of benthos by beam trawling (Lindley *et al.* 1995).

Increased inflow of oceanic water from the North Atlantic is related to warming of oceanic conditions in the North Sea, and decreased inflows are related to colder conditions. Cold events carry boreal plankton from the Norwegian Sea, whilst warm events are consistent with higher oceanic inflows from the Slope Current that bring in water from Portuguese waters (Reid *et al.* 2003). The community structure of the plankton changed after 1987 with an increase in the abundance of the copepod of the genus *Corycaeus* (Reid *et al.* 2001).

The period in the late 1970s and early 1980s was anomalous in the North Sea, with reduced salinities and temperatures. During the late 1970s, there was an initial reduction in inflow of Atlantic water (Corten , 1990). This reduction may have been initiated by a decrease in flow by the North Atlantic Current, thus, allowing an opening for colder waters from the north to penetrate farther southward (Edwards *et al.* 2002).

From 1987, resident and cold water holoplanktonic species have declined in abundance in the North Sea, and meroplankton from warmer oceanic and mixed waters have increased, with an increase in species richness in the northern areas (Lindley and Batten, 2002). Evidence that changes in the circulation in the north-east Atlantic are bringing more southerly water into the north-east Atlantic derives from the presence of the copepod species *Euchaeta hebes* and *Rhincalanus nasutus*. In 1997, doliolids (identified as *Doliolum nationalis*) were first found in the North Sea in September (Edwards *et al.* 1999), and colonies of the ciliate *Zoothamnium pelagicum*, which is normally associated with oceanic water in the Bay of Biscay, were found

for the first time in the central North Sea. In January 1998, the oceanic tintinnid, *Dadayiella ganymedes* was also found for the first time in the southern North Sea (Edwards *et al*. 1999).

Copepods

Along the European continental shelf, severe biogeographical shifts in all copepod assemblages have occurred in recent years, with a northward extension of warm-water species' ranges and a decrease in the number of colder-water species (Beaugrand, 2004). The copepod *C. finmarchicus* is believed to have dominated copepod assemblages since the 1930s (Reid *et al*. 2003). Their abundance declined between 1958 and 1998 (Beare *et al*. 2002) and from 1968 to 1970 *C. helgolandicus* was more abundant than expected. At the same time *C. typicus* was close to the expected levels, and none of the environmental variables showed deviations that could explain this (Lindley and Reid, 2002).

In the last years the interannual abundance of the copepods *Centropages typicus* and *C. helgolandicus* in the North Sea are positively correlated with sea surface temperature (Lindley and Reid, 2002). With the increasing of warm conditions, *C. helgolandicus* has almost entirely replaced its boreal congener, *C. finmarchicus*, in the northern North Sea (Reid *et al.* 2003).

Other copepod species invading the North Sea, the mesozooplanktonic forms *Metridia lucens* and *Candacia armata*, are usually associated with inflow from the north, entering the North Sea via the Fair Isle Current and the East Shetland Atlantic inflow. These species are typical of Atlantic waters to the west of Scotland (Edwards *et al*. 1999).

Major fish stocks in the North Sea are affected by climate-mediated changes in copepod abundances described above (Alheit *et al.* 2005). The progressive substitution of *C. finmarchicus* by *C. helgolandicus* resulted in mismatch situations between larval cod and its *Calanus* prey as *C. helgolandicus* appears later in the year (Beaugrand *et al*. 2003; Alheit *et al.* 2005). Nevertheless, some aspects of the natural history of *C. helgolandicus* may make it a more suitable food for Anchovy and Sardine than *C. finmarchicus* (Beare *et al*. 2004).

Fish

A large ecosystem can respond in both a continuous and discrete manner to climate change. Discrete changes include the relative abundance of the permanent members of the community,

and the sudden alteration in the set of visiting species. These kinds of changes have been observed in the Bristol Channel, with a continuous increase in fish species richness related to increase in average sea temperature (Henderson, 2007). The fish records correlate significantly with temperature data from the North Atlantic (Stebbing *et al*. 2002).

In the same way, there is an increasing prevalence of unusual southern species (e.g. Sailfin Dory, Gig-eye Tunny, Saddled Seabream, Short-beaked Garfish, Blue-runner, and Barracuda) in the English Channel (Stebbing *et al.* 2002; Beare *et al*. 2004).

A noticeable warming of the northern North Atlantic Ocean took place during the 1920s and 1930s, with enhancing of Atlantic inflow in northern regions through to the 1950s and 1960s (Drinkwater, 2006). Further changes included mortality of Sole *S. vulgaris* in the winter of 1963-64, causing drastic declines in the level of spawning (Ottersen *et al*. 2004).

An increasing inflow after 1980 could be responsible for changes in fish stocks in the North Sea (Corten, 1990; Stephens *et al*. 1998), including an increasing abundance of southern species, such as Anchovy, Sardine, and Red Mullet (Heessen, 1996; Beare *et al*. 2005) in the southern North Sea. These changes are associated with the increasing of plankton production and are related to bottom-up processes (Drinkwater, 2006).

On the other hand, the reduction in the inflow of Atlantic water into the north western North Sea disrupts the transport of fish larvae from the hatching grounds in the northern North Sea to the nursery areas in the German Bight (Corten, 1990). The retention of water within the Fair Isle current may affect the survival and subsequent development of fish larvae, delaying the arrival of larvae tono the nursery grounds, and increasing predation (Turrell and Henderson, 1990). Recovery of recruitment in recent years has been a gradual process (Corten, 1990).

The climate, in combination with fishing activities, alters the functioning of the fish food web in the North Sea. Depletion of benthos-consuming fish, has shifted the structure of the secondary production demand towards zooplankton, and released the benthos from predation (Heath, 2005). Most of the information obtained on fish abundances is based on fisheries. However, it is important to notice, in using commercial fisheries-catch data to describe changes in ecosystems, that such data are influenced by the market economy and human

behaviour. As a result, changes in fish catches may not reflect real changes in ecosystem structure. Another problem is that records of commercial fish catch have only been maintained for a relatively short time period (Christensen and Richardson, 2008).

Small pelagic fish

Small pelagic fish (such as Sardine, Anchovy, Herring, Sprat and others) respond dramatically and immediately to changes in ocean conditions. They have short plankton-based food chains, including even phytoplankton (Ottersen *et al*. 2004). For example, the main components of the diet of Herring are the calanoid copepods (Last, 1989).

In the upper levels of the food chain, small pelagic fish provided food for larger fish, seabirds and marine mammals, and changes in their abundance may be accompanied by changes in ecosystem structure (Ottersen *et al*. 2004).

The landings records show that the fishery for small pelagic fish in the North Sea has remained relatively constant over time, because of the effect of competitive exclusion. As the landings of some species declined, others expanded to take their place. Sprat landings increased as Herring collapsed in the late 1970s, and declined again as the Herring fishery recovered. In the same way, Horse Mackerel partially replaced Mackerel in the pelagic piscivore guild during the 1990s (Heath, 2005).

But independently of the fishing activities, changes of species composition could be a response of population changes. During the first half of the 1980s, a northward shift of mackerel was noticed along the west coast of Scotland and into the North Sea, preceded by an earlier shift in the opposite direction during the 1960s (Corten, 1990).

The delicate balance between populations may be altered by changes in oceanic conditions, or the water mass dynamics. Herring grows in the eastern North Sea, and recruits move to the northern and north-western North Sea to spawn. In the case of the Sprat, the larvae are transported to recruit probably in the eastern North Sea and thereby are lost from their parent population in the western area. A strong inflow from the Atlantic will transport both Herring and Sprat larvae to the eastern North Sea, which is advantageous for the Herring but not for

the Sprat. Conversely, a reduced inflow will reduce the number of Herring larvae reaching their nursery area, but increase the recruitment of the Sprat population (Corten, 2002).

One important component of the ecosystem, related to the distribution of pelagic fish, is the oceanic inflow, mainly because these species prefer warm conditions and the movement of their larvae is due to the sea drift. The increase of sea temperatures could indicate increased Atlantic inflow from the west, transporting eggs and larvae of Anchovy (Ré, 1996) and Sardine into the North Sea (Beare *et al*. 2004). During the mid-1990s, a sudden increase of Anchovies and Sardines was recorded off east Scotland, related to a penetration of relatively warm Atlantic water into the northern North Sea (Beare *et al*. 2004). A similar situation has been observed in Shetland waters, where Sardines and Anchovies began to appear in noticeable numbers in 1998 and increasing since then in along with rising sea temperatures (Beare, 2006). Finally, the invasion of the north-western North Sea by Anchovy and Sardine is a component of the marked ecological changes due to rising temperature and climate change (Beare *et al*. 2004).

The southward extension of Herring spawning in the northwestern North Sea since 1983 could be explained by an increased Atlantic inflow in this area, and in the same way, variations in Atlantic inflow could drive changes in the Mackerel stock in the North Sea because this species is closely associated with Atlantic water (Corten, 2002).

Cod

Though the relevant changes in Cod stocks in each regions in the east North Atlantic Ocean (from Greenland to the Barents Sea), can be related to changes in the large-scale Atlantic trade winds, responses could operate through changes in the interstock exchange of larvae by ocean currents (Dickinson and Brander, 1993).

Recoveries of depleted Cod stocks depend upon reducing fishing effort in the short term, but in the longer term climate change may have even greater effects on stock status (Kell *et al*. 2005). With climate change, Cod may respond in an unforeseen manner, moving their northern distribution northwards or changing their feeding ecology in the North Sea (Kell *et al*. 2005). In the North Sea this species is close to the southern limit of their distribution, which is likely to move northward with rising temperatures (Stebbing *et al*. 2002), maybe then

reaching the coasts of Greenland and Labrador, the Barents Sea, and may even extend onto some of the continental shelves of the Arctic Ocean (Drinkwater, 2005).

Modelled scenarios of climate change show increasing air temperatures, mainly in Arctic and Subarctic waters. Cod stocks in the Celtic and Irish Seas are expected to disappear, while those in the southern North Sea and Georges Bank will decline (Drinkwater, 2005).

Pipefish

Pipefish were not recorded around Scotland prior to the late 1990s. Between 1990 and 2002 the species was recorded consistently in the North Sea, increasing massively in numbers in the following years around Britain (Kirby *et al.* 2006; Harris *et al.* 2007). Norwegian surveys found considerable numbers of Pipefish in the northern North Sea in both 2004 and 2005 (Harris *et al.* 2007). Number of Snake Pipefish appeared suddenly in the deeper waters of the North Sea (van Damme, and Couperus, 2008) and this appeared to represent a very marked expansion of range into the central Norwegian Sea, further north to Bear Island and Spitzbergen and east into the Barents Sea basin from 2005 (Harris *et al.* 2007). In 2004-2005 pipefish were reported from seabird colonies over a broad geographic area including Great Britain, Norway, Iceland and the Faeroe islands, involving a wide range of seabird species (Harris *et al.* 2007), and they were also found in stomachs of fish and sea mammals (van Damme, and Couperus, 2008).

The cause of the population explosion of Snake Pipefish is unclear. The increasing sea surface temperature in the northern hemisphere, linked to global warming, was a possible cause of the increase in numbers of larval and juvenile Snake Pipefish west of the British Isles (Kirby *et al.* 2006; Harris *et al.* 2007). Another possible explanation is the fall in predation pressure associated with decreasing numbers of Mackerel and Short-beaked Common Dolphins (van Damme, and Couperus, 2008).

Because of the decrease in Sandeel numbers, novel fish species have become part of the seabirds' diet. The occurrence of pipefish (particularly Snake Pipefish) in seabird chick diet in 2004 and 2005 was unprecedented. In the same way, Great Shearwater, Northern Gannet, Northern Fulmar, Black-legged Kittiwake, Black-headed Gull, and Lesser black-Backed Gull, were seen feeding on large pipefish in the open ocean (Harris *et al.* 2007).

Because of the rigid bony structure of pipefish, they are extremely difficult to swallow, with a high risk of death by choking for seabirds preying on and feeding their chicks with this fish (Harris *et al*. 2006; 2007; van Damme, and Couperus, 2008).

Other fish species

The Red Mullet is a warm-water species common in the western coasts of the British Isles, the English Channel and also the southern North Sea. However there are some reports of red mullets caught around Scotland in recent years, coincidently with the increasing of the sea surface temperature (Beare *et al*. 2005). All the Red Mullet recorded in Scotland since 1990 were caught exclusively during winter months (January, February and March). During winter, the North Sea is warmer in the north than it is in the south due to the influence of the North Atlantic Current, and this could be the explanation why Red Mullet migrate into the northern North Sea from the southern North Sea (Beare *et al*. 2005).

Similar to the Red Mullet, Bluemouth (*Helicolenus dactylopterus*) abundance has increased over the last decade both in the west of Scotland and in the North Sea. Once it entered the North Sea the Bluemouth population survival depends on benign environmental conditions, such as stable sea temperature, and the relative absence of large predators such as Cod (Mamie *et al*. 2007).

There was an exceptional Atlantic inflow into the North Sea in 1991. This large water mass moving into the North Sea served as a highway to small individuals of the Bluemouth. After this influx Bluemouth were recorded all around the northern North Sea, but numbers have declined since 1997 and their distribution in the region has been constricted into some small areas (Mamie *et al*. 2007).

The demersal piscivore guild is more vulnerable to fishing than that of the planktivores, due to the apparent lack of capacity for species substitution (Heath, 2005). As a result, the biomass of the high-trophic level fish species in the North Atlantic is decreasing rapidly (Christensen *et al*. 2003). Unlike the bottom-up controls mediated by the pelagic side of the fish foodweb, the demersal component is apparently controlled by top-down processes, especially predation (Heath, 2005).

The Celtic Sea

The Celtic Sea is a shallow marine area (less than 200 m depth) in the south margin of Ireland (OSPAR, 2000). It is a connection area between the Bay of Biscay and the North-eastern Atlantic in the west, with the English Channel in the eastern boundary (fig. 1-6). The boundary between the Celtic Sea and the Bay of Biscay is formed by the margins of two shelves, the Celtic shelf and the Armorican shelf, a continuous formation from the oceanic waters in the south of Ireland to the coast off western France (Pingree and Le Cann, 1989). The dominant circulation pattern is from south to north, from the Armorican shelf northward across of the Channel, and a counter flow in the west, on the outer Celtic shelf (Pingree and Le Cann, 1989). Average sea surface temperatures to the west and south of Ireland oscillate from 8–10 °C in February-March to 14–17 °C in August (OSPAR, 2000). The Celtic Sea, as the Irish Sea, presents a seasonal thermal front with high levels of physical and biological activities, resulting in high concentrations of chlorophyll a (Savidge and Foster, 1978).

The biology of the Celtic Sea is interesting because this is a transition zone between cold waters from the north and warmer ones from the south, resulting in a transition zone for several species. Copepods are the most abundant group in the zooplankton, with *C. finmarchicus* and *C. helgolandicus* dominating the planktonic community, the first being a species from colder areas than the second (OSPAR, 2000). In the same way, clupeid fish from different environments coexist in this area. The Herring from arctic-boreal areas is more abundant in the Celtic Sea during colder years, whereas the Pilchard is more abundant during warmer years (Southward *et al*. 1988). The abundance of these fish species, just like abundance of copepods, varies between years. The Celtic Sea and English Channel are the southern limits of Cod, and present Sardines and Anchovies with northward penetration of warm waters (OSPAR, 2000).

Marine mammals are abundant in the Celtic and Irish Seas, mainly as visitors. Bottlenose Dolphin and Harbour Porpoise are common species, frequently found stranded on beaches. Seabirds and waterfowl are abundant with some species, like Shags, Guillemots and Arctic Terns increasing in numbers (by more than 100% between the end of the 1960's and mid 1980's), whereas numbers of several gulls and terns species are declining (OSPAR, 2000).

Figure 1-6. Marine areas in Western Europe.

The English Channel connects the Celtic Sea and Bay of Biscay with the North Sea. It is a transition area representing the boundary for many marine species. The fish species composition from the eastern English Channel is similar to the species assemblage in the southern North Sea, with many fish species migrating between the Channel and North Sea (Arnold and Metcalfe, 1996; Defra, 2005).

The Bay of Biscay and Iberia

The Iberian Peninsula is a projection in the west of the European continent, surrounded by the Bay of Biscay in the north, the North-eastern Atlantic in the west, and the Mediterranean Sea in the south. Western Iberia is part of the Eastern Boundary Current System of Western Europe and North Africa (Sanchez *et al.* 2007). The Bay of Biscay (fig. 1-6) is an open-ocean bay (Lazure *et al.* 2008) between the west of France and north of Spain. The continental shelf is wide in the northern area, and very narrow in the southern region, off the coast of Cantabria in Spain (OSPAR, 2000). The run-off of continental water from the southern area of France promotes a gradient in the density and salinity in the bay (Gil, 2008) with important implications for marine biodiversity.

Currents from the Azores govern the oceanographic and meteorological conditions off Iberia (Gil, 2008). Displacement of the Azores current to the south leaves Iberia under the influence from the strong south-westerly winds during winter, changing in the spring to soft winds in the opposite direction (Gil, 2008; Lazure *et al.* 2008).

Temperature gradient presents low sea surface temperatures in the Western Bay of Biscay (about 13 ºC), increasing to the east and south (to 15-16 ºC). The Western coast of Iberia, off Portugal, shows dramatically changing temperatures (from 15 ºC to 18 ºC). The South-west of Iberia, in the Gulf of Cadiz, has warm waters increasing up to 21 ºC in North-Western Africa (fig 1-7).
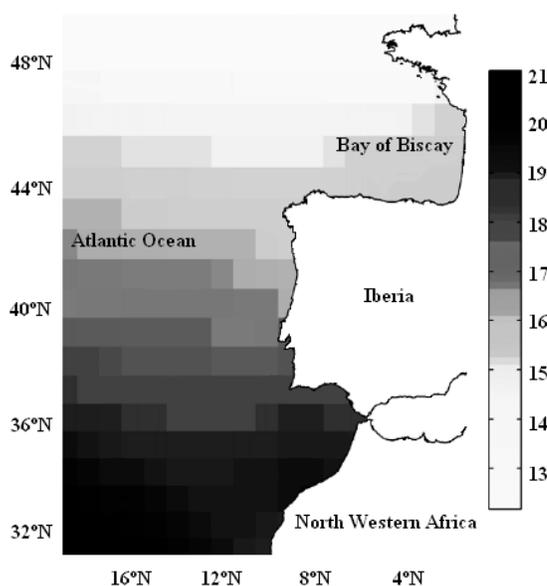
Figure 1-7. Mean sea surface temperature around Iberia and the North-Western Africa. Data from 1982-1998 (from Sanchez *et al.* 2007).

Transport of early fish life history stages, like eggs and larvae, is influenced by upwelling and offshore displacements due to Ekman transport, resulting in the concentration of fish in the narrow band of continental shelf in the Bay of Biscay (Gil, 2008) and their recruitment. Upwelling of water from North-central Atlantic and even North-eastern Atlantic is common around Iberia, especially in summer, resulting in an extraordinary primary production in the inner waters up to ten times that of offshore waters (OSPAR, 2000).

Copepods are the most important group in the plankton, and are present all year. Two species, *Centropages chierchiae* and *Temora stylifera* were seldom collected before 1998 in the Bay of Biscay and the Celtic Sea, but were found frequently from 2000, negatively correlated with the

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NAO (Lindley and Daykin, 2005). A similar situation has been observed in the fish community, with changes in the species composition due to climate change and the NAO (Poulard and Blanchard, 2005). Shifts in the environmental regime, in association with upwellings and the NAO, have also driven changes in the age maturity of the Hake (Dominguez-Petit *et al*. 2008).

The most diverse fish group in the Bay of Biscay is demersal. In terms of importance, the most remarkable fish species are Cod, Dab, *Echiodon drummondi*, Greater Sandeel, Haddock, Pipefish, Norway Pout, *Boops boops*, *Sarpa salpa*, seabass, Spanish Mackerel, Sea Bream, Boar Fish, Bib, Hake, Dogfish, Anglerfish, Whiting, Gurnard, Megrim, Mackerel, Horse Mackerel, Pilchard, Sprat and Anchovy. Important fisheries in the Bay of Biscay are related to pelagic species like Blue-fin Tuna, Anchovy, Mackerel and Albacore (OSPAR, 2000). In Portuguese waters, the main fish species are Snipefish *Macroramphosus scolopax*, Boarfish *Capros aper*, Blue Whiting, Horse Mackerel, Mackerel, Axillary Seabream *Pagellus acarne*, Hake, Jack Mackerel *T. picturatus*, Chub Mackerel *S. japonicus* and Dogfish (OSPAR, 2000).

Cetaceans are common in the region, mainly Sperm Whale *Physeter catodon*, the dolphins *Delphinus delphis* and *Tursiops truncatus*, and Harbour Porpoise *Phocoena phocoena*. Among whales *Balaenoptera physalus* is a common migrant. Right Whale *Eubalena glacialis* was very common before an extensive whaling fishery that began in the middle ages (OSPAR, 2000; RAM, 2007a).

The Bay of Biscay is a very important area for seabird species, many of them migrants. The community is dominated by the Yellow-legged Gull *L. cachinnans*. Seabirds are divided into pelagic species like Mediterranean Shearwater (*P. yelkouan*), Leach's Petrel *O. leucorhoa*, Northern Gannet and Razorbill, coastal species like Shag, Terns, Common Scoter *Melanitta nigra* and gulls (OSPAR 2000). The most common species by season are: during spring *M. bassanus*, *P. mauretanicus*, *L. ribidundus* and *C. diomedea* (RAM, 2007b); during summer the same species plus *S. sandvicensis* (RAM, 2007c); during autumn *L. ribidundus, C. diomedea* and *S. sandvicensis* (RAM, 2007a); and during winter *M. bassanus, P. mauretanicus, L. ribidundus, C. diomedea, Alca torda* and *M. nigra* (RAM, 2007d).

Oil spills are fairly common in the Bay of Biscay, due to the passage of oil tankers from the North-western African oil fields to Northern European countries. All the oil industries of Netherlands, Belgium, Germany, Norway, Sweden and part of France and the UK are dependent on ship passage through Biscay-Celtic Sea-Channel. The "Erika" oil spill at the end of 1999 caused a redistribution of seabird species in the Bay of Biscay, including the Northern Gannet and the Great Skua (Castege *et al*. 2004). The "Prestige" oil spill in 2002 affected severely the coast off Galicia, in the South-western Bay of Biscay. Seabird species most affected were juvenile Razorbills (winter visitors), adult Atlantic Puffins (winter visitors), adult European Shags (residents), adult Northern Gannets (passage migrants), and juvenile Common Guillemots (winter visitors) (Camphuysen, 2002)**.**

North-western Africa

The coast of North-western Africa (NWA) is the portion of the central-eastern Atlantic Ocean from Gibraltar (at about 35º N) to the Gulf of Guinea (at about 5º N), including Morocco, Western Sahara, Mauritania, Senegal, the Gambia, Guinea-Bissau, Guinea, Sierra Leone and Liberia in the mainland, and the islands grouped in the volcanic archipelagos of Madeira, Canary Islands and Cape Verde. The study area of the present project includes all these countries except Sierra Leone and Liberia (fig. 1-8).

Figure 1-8. Study area of the North-Western Africa, including political divisions.

The continental shelves off the coast of NWA extend about 50-150 km, being especially wide in the Guinea-Bissau area (Amorim *et al*. 2004) and the continental slope extends to 100 km approximately (Hagen, 2001). In the case of the archipelagos, all of them have very narrow continental shelves. The archipelago of Madeira and associated islands (about 32°N) is about 500 km from the African coast, in front of Morocco (Rusu *et al*. 2002), and belongs to Portugal. The two major islands are Madeira and Porto Santo.

The Canary Islands are located south of Madeira (at 28° N), in front of the coasts of southern Morocco and northern Western Sahara (Arístegui *et al*. 2004). The nearest island is located 110 km west of the continent (Juan *et al*. 2000). These Spanish islands include, among others, Tenerife, Gran Canaria, Isla de la Palma, Lanzarote and Fuerteventura.

The archipelago of the Republic of Cape Verde (about 15°N) is located approximately 500 km off the coast of Senegal (D' Olvera-Fonseca, 2000). It consists of ten main islands (D' Olvera-Fonseca, 2000; Évora and Amorim, 2002; Stobberup *et al*. 2002), the most important in terms of size and human population being Sal, Santa Luzia, Maio, and Boavista.

The most remarkable geographic areas in the continental coast of NWA are the Strait of Gibraltar, with its connection to the Mediterranean Sea; the wide and shallow Banc d' Arguin in Mauritania; the Senegal River, in the Senegal-Mauritania border region; the Gambia River in the Gambia; and the extensive fluvial area, in the coast of Guinea-Bissau, including the Bijagós Islands. One of the most studied areas of the coast is the Banc d'Arguin. It comprises a very wide area of shallow water and tidal flats, covered with dense seagrass beds and circular ponds, in the west of the Sahara (Wolff and Smit, 1990; Wolff *et al*. 1993; Schaffmeister *et al*. 2006), with a high diversity of marine environments (Sevrin-Reyssac, 1993), and abundant aquatic birds (Wolff *et al*. 1993).

The most noticeable aspect of the oceanic conditions in the entire area is the presence of a well known upwelling system, which has been studied intensively (Cury and Fontana, 1988; Kostianoy and Zatsepin, 1996; Stevens and Johnson, 2003; Pastor *et al*. 2008). The description and characteristics of this upwelling are outlined below.

The climate in the NWA area is related to the tropical North Atlantic, and is controlled by trade winds, the Intertropical Convergence Zone, and the influence of high sea surface temperatures (Black *et al.* 1990). There is a gradient of vegetation, with dense areas in the southern part of the area, and dry areas with deserts in the north. As a result the Intertropical Convergence Zone is a climate boundary separating an arid area in the north, the Sahelian zone, with a humid area in the south, the Guinean to Congolian zone (Barusseau *et al*. 1988). The average annual temperatures are relatively high for the entire NWA, 18-23°C in the Banc d' Arguin (Wolff and Smit, 1990), and 24°C in Cape Verde (D' Olvera-Fonseca, 2000).

Trade winds are stable and strong in northern Mauritania (Sevrin-Reyssac, 1993). These winds flowing westwards are well developed in January in the southern NWA, between 10°N and 25°N, blowing offshore from the Sahara (Van Camp *et al*. 1991; Ratmeyer *et al*. 1999). These winds, called the Harmattan, carry dust from the desert to the ocean covering a belt of about 1500 km (Hagen, 2001). The resulting Saharan dust plume (fig. 1-9) is oriented in a south-eastern direction from Mauritania to the Gulf of Guinea, during winter, and parallel to the equator during summer (Longhurst, 1993). This dust influx to the ocean is a major source of nutrients and is one of the reasons for the lack of coral reefs on the western side of Africa (Barusseau *et al*. 1988).
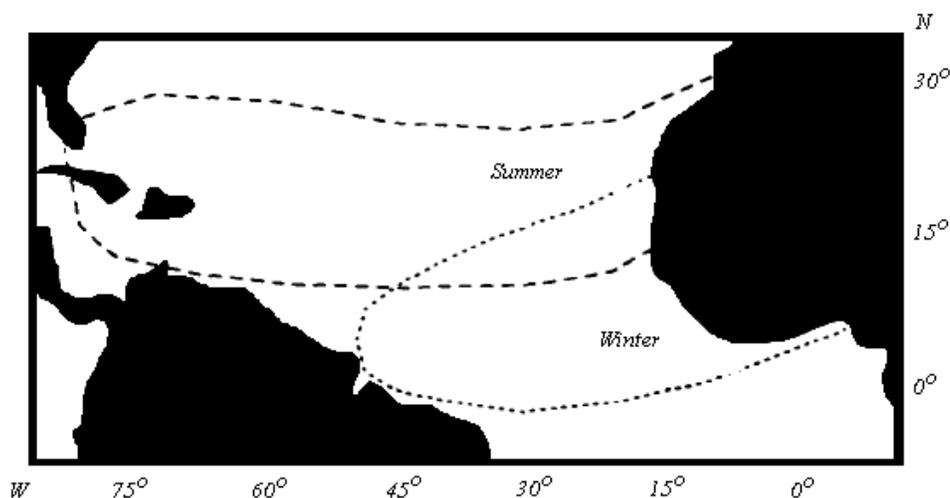
Figure 1-9. Saharan dust plume over the Atlantic Ocean, showing the seasonal changes related to changes in trade winds (from Longhurst, 1993).

The Canary archipelago is a wind and currents barrier, disrupting the currents from the Azores and Portugal areas, resulting in a centre of atmospheric and oceanic flow perturbation (Pelegrí *et al*. 2005). Finally, it is important to note that the NWA sub-continent and their seas, present very particular and dramatic characteristics, influenced mainly by the ocean currents, the trade wind, the presence of volcanic archipelagos, and the coastal shape, resulting in one of the most productive ecosystems in the world (Ould-Dedah *et al.* 1999).

Oceanography

Sea surface temperature is heterogeneous along the coast off NWA (fig. 1-7). Waters in the northern part of NWA are at fairly uniform temperature in winter, but show patchy temperature variation in time during spring depending on local upwelling and local currents (Mitrelstaedt, 1991). Temperatures oscillate between cold and warm in the coasts between Cap Blanc (Western Sahara) and Cape Verga (Guinea) during the year, again as a result of variable upwelling and prevailing currents (Sevrin-Reyssac, 1993).The Moroccan coast and around the Canary Islands, as well as in equatorial waters off Senegal, present generally warmer conditions than in the coasts off Western Sahara and Mauritania with less upwelling (Navarro-Pérez and Barton, 2001; Camphuysen and van der Meer, 2005). The shelf of Mauritania is a transition zone, and is a region of confluence between temperate and tropical regimes (Ould-Dedah *et al.* 1999).

The Azores Current flows eastward in the North Atlantic Ocean, and splits into several branches flowing southward. The easternmost branch moves towards the Canary Islands, forming the Canary Current (Pelegrí *et al*. 2005). This Canary Current system flows southwards 100–450 km from the coast, forming eddies connected with the continental coast (Brochier *et al*. 2008). The water is colder than expected for this latitude, and the fauna in the zone is quite similar to that off Iberia (Sevrin-Reyssac, 1993). In addition, the Canary Current is influenced by the Portugal Current (fig. 1-10). The sea surface circulation pattern in NWA presents four systems flowing independently: (1) the coastal currents over the shelf; (2) the Canary Current flowing in the north of the area; (3) the presence of a cyclonic gyre, between 15°N and 22°N; and (4) the current flowing in the south area of NWA (Mitrelstaedt, 1991).

Figure 1-10. General current pattern in the NWA. Light arrows show the summer current and dark arrows show the undercurrents (from Aristegui *et al*. 2004).

Undercurrents move below the currents described, in the opposite direction. Only the North Equatorial and their undercurrent are moving in the same direction (Arístegui *et al*. 2004), influenced by the Guinea Current. The Cape Verde islands are influenced by the Canary Current System, but there are changes between seasons. During July to November, the main currents in the area are southwestern, causing warmer conditions (Évora and Amorim, 2002). A remarkable characteristic of this area is the Cape Verde frontal zone, an unstable boundary between the waters from the North Atlantic and those from the South Atlantic Ocean (Vangriesheim *et al*. 2003). As a result, the oceanographic characteristic of the Cape Verde archipelago are determined by waters flowing from the north, the Canary Current, and from the south-east, the North Equatorial Current (fig. 1-11).
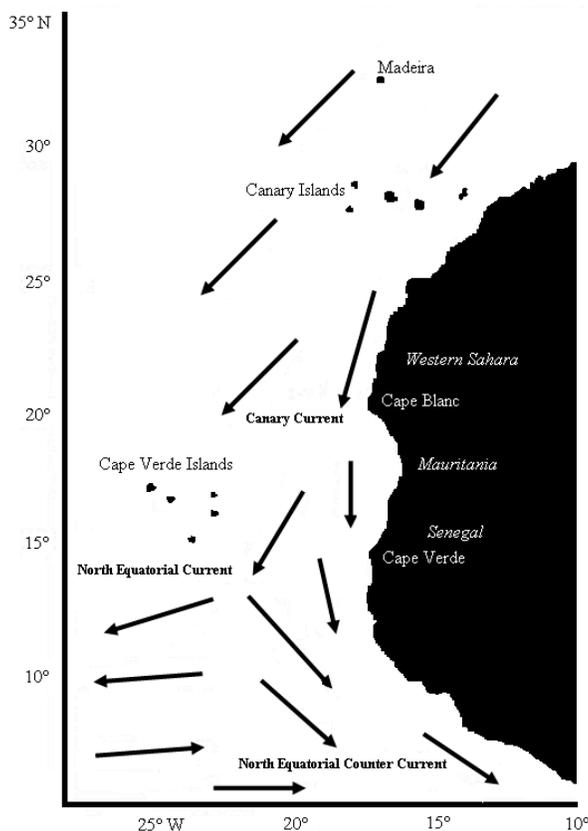
Figure 1-11. Detailed oceanic flow in the NWA, including the Cape Verde archipelagos (from Ratmeyer *et al.* 1999).

The presence of extreme climatic events, like those producing rainfall anomalies in the Sahel, is interconnected with the Southern Oscillation (Wolter, 1989). As a result, these are a central part of the ongoing oceanographic research in the area.

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Upwelling

The strong and stable trade winds in the north of Mauritania move the superficial water mass northwards. The sub-superficial cold water from the Canary Current flows upwards, bringing to the sea surface water from a depth between 60 and 200 m (Sevrin-Reyssac, 1993; Pelegrí *et al*. 2005). Due to an inflexion in the coastline of northern NWA, the presence of the upwelling, and the gyre of Mauritania (Van Camp *et al*. 1991) a water filament is formed. This quasi-permanent surface structure extends offshore, and is called the Ghir filament, named after Cape Ghir in Morocco (Pelegrí *et al*. 2005). Another quasi-permanent filament is formed off Cape Blanc (Brochier *et al.* 2008). Filaments are related to upwelling, and are therefore more frequent during the maximum upwelling season in summer. According to the changes in the upwelling conditions it is possible to classify three upwelling areas (fig. 1-12). Coastal upwelling occurs between Gibraltar and Cape Blanc all year long (Pastor *et al*. 2008). During the summer months the upwelling is strong in the north of the Canary Islands, north of the 25°N latitude, reaching the Iberian Peninsula (Pastor *et al*. 2008), but becoming weak in winter (Stanford *et al*. 2001). A second upwelling area is observed in the coast off Mauritania between 20°N and 25°N (Stanford *et al*. 2001). Here, the upwelling is permanent (Cury and Fontana, 1988).

The presence of canyons or submarine mountains affects the vertical transport of water, moving deep water from the oceanic currents upwards. In the Cape Timiris canyon, in Mauritania, the upwelling of deep water produces variations in the oceanographic parameters at the surface (Schulz *et al*. 1989). In the south side of NWA, in Cape Verde (Senegal), the North Equatorial Current and the North Equatorial Counter Current form another upwelling cell, moving cold water to the west. This upwelling is present mainly between November and February (Ratmeyer *et al*. 1999), with maximum effect on the continental shelf off Senegal during March and April (Mendy, 2004). As a result, the upwelling condition is permanent to the north of 20ºN latitude (Mauritania), whilst it is temporary to the south (Cury and Fontana, 1988). The influence of upwelling areas in NWA is very strong during winter and early spring, increasing the primary production (Évora and Amorim, 2002) due to the movement of cold water, rich in nutrients, to the surface. As a result of this, the sea in these areas is rich in fish and a cascade effect takes place, with the increase of commercial fish species, seabirds and marine mammals (Veen *et al.* 2003). Good examples of this are the rich fishing grounds of the Moroccan coast (Stanford *et al*. 2001), and the great amount of commercial demersal and

pelagic fish, associated with the productivity in Mauritanian waters resulting from the seasonal upwelling there (Stobberup *et al*. 2005a). The most productive area in the entire NWA is around Cape Blanc (Brown, 1979). However, the upwelling in the area is not the same every year. The North Atlantic Oscillation (NAO) causes variations in the upwelling index, at interannual and interdecadal levels (Pastor *et al*. 2008).

In the NWA coast, trade winds are cold and upwellings appear along the Iberian and Moroccan coasts during periods of positive NAO index. During periods of negative NAO index the western coast of Africa is warm with reduced upwelling (OSPAR, 2000; Hurrell and Dickson, 2004).
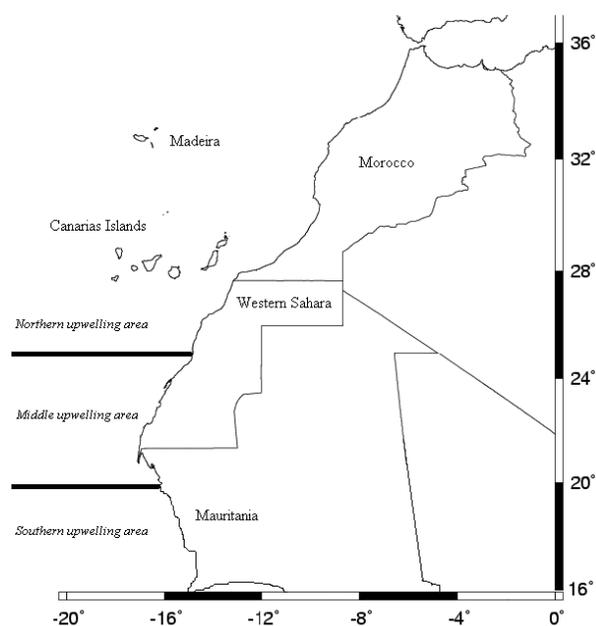
Figure 1-12. Upwelling areas in the NWA. The Northern area is from Gibraltar to Cape Blanc, Western Sahara. The middle upwelling area includes the coasts off southern Western Sahara and northern Mauritania. The Southern area is from Cape Timiris, Mauritania to Senegal.

Marine biology

The sea life in the entire NWA coasts and the associated Eastern Atlantic Ocean is diverse and abundant. The oceanic conditions, including currents and upwellings, allow the existence of temperate species in tropical latitudes. Thus, the entire area is a transition zone where marine species from different regions converge. An example of this is observed in the coast of Mauritania. Water temperature and salinity can reach extreme values in the Banc d'Arguin, due to the lack of fresh water from the continent. In addition, the northern subtropical

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hydrodynamic front produces large fluctuations in local oceanic conditions two times during the year. These extreme and changing conditions are reflected by variations in the abundance, composition, and migration of fish stocks; resulting in a fish fauna composed of temperate, sub tropical and tropical species (Jager, 1993). An example of that is the Horse Mackerel, forming a continuous chain of local stocks from the Celtic and North Seas to Cape Verde (Kompowski, 1975).

From Cape Blanc, north of the Banc d'Arguin, drastic faunistic changes are observed, like those in Cape Frio, Namibia, related with biogeographic barriers and thermal fronts. Between these capes lies a zone with tropical conditions (Le Loeuff and von Cosel, 1998). Indeed, the heterogeneity in habitats produces changes in the species composition between relatively close areas. An example of this is the difference in terms of ecosystem productivity and functioning between the Cape Verde archipelago and Guinea-Bissau. Productivity is relatively low in the Cape Verde ecosystem, linked to the open ocean, whilst the Guinea-Bissau coast is highly productive, because it is an area with an extensive continental shelf influenced by upwelling and river runoff (Stobberup *et al*. 2005a). In general, the marine animals in the islands are mostly pelagic, whilst those in the mainland are coastal species. On the other hand, the use of these different marine habitats could be different for several species according to their stage in the life cycle. Examples of that are the marine turtles *Chelonia mydas* and *Lepidochelys olivacea*, widely spread in the NWA, but with their nurseries in the Guinea-Bissau area, the Bissagós Archipelago in particular (Amorim *et al*. 2004).

Plankton

In the entire tropical Eastern Atlantic Ocean, pelagic algal blooms are mainly observed in three different areas, affecting the West African coast (fig. 1-13): over much of the Atlantic, from Angola to Brazil; in the North Equatorial Counter-current, from West Senegal to Demerara, Guyana; and in a coastal upwelling area in the northern Gulf of Guinea, off Ghana and Ivory Coast (Longhurst, 1993).
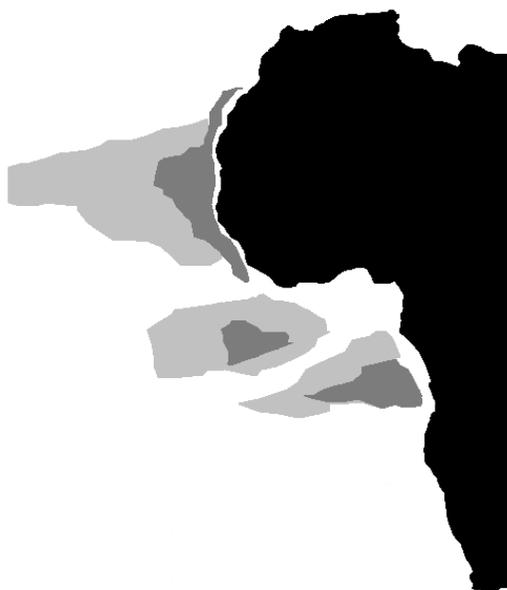
Figure 1-13. Main algal blooms areas in western Africa. Darker areas show the highest algal concentrations (from Longhurst, 1999).

The massive bloom in the NWA, near the coast off Senegal, is affected by the Canary and Azores currents, carrying cold water from the north. As a result, the phytoplankton composition presents characteristics more temperate than tropical, including cosmopolitan species (Margalef, 1961) in the Mauritanian and Senegalese waters. These very large phytoplankton stocks are partly wasted (Le Borgne, 1978), because of their great extension and failure of zooplankton to graze the phytoplankton down. Usually zooplankton increase is coupled with the maximum biomass of phytoplankton, but in NWA the increase in zooplankton growth and composition is mainly observed when the water mass is transported offshore (Pelegrí *et al*. 2005). The copepod *C. carinatus* is the most common species during the upwelling season, grazing the high diatom densities over the African shelf. Maximum abundance of *C. carinatus* is found near the centre of the upwelling, an area with high values of primary production. As the water masses are transported offshore this copepod species moves to deeper waters, and euphausiids migrate vertically and are observed offshore. *Euphausia khronii* is abundant north of Cape Blanc and the salp *Thalia democratica* forms high-density swarms over the slope waters (Pelegrí *et al*. 2005).

Zooplankton biomass varies with latitude and season, in relation to the wind intensity in the upwelling area, showing the highest annual values near Cape Blanc. Maximum values of zooplankton biomass are observed in northern NWA in summer and the minimum in winter, the opposite of the situation occurring south of Cape Blanc (Pelegrí *et al*. 2005). As a result of

this switch in the spatial and temporal peak of biomass values, zooplankton abundances are high through the entire year, when all NWA is considered as a single unit. In Mauritania, the high zooplankton biomass is explained either because of a lack of competition with other grazers (fish), or weak predation (Le Borgne, 1978). For this reason, the Banc d' Arguin is a very important area for wintering waders, and for zooplankton-feeding seabirds.

In the south side of NWA, the coast off Gambia should be anticipated to be an important area for plankton because of the influence of the nutrients discharged by the Gambia River and the upwelling in the Gulf of Guinea, but there is a lack of information, especially about zooplankton (Mendy, 2004).

Benthos

Benthic biota is different between localities, mainly because of the presence of different kinds of substrates. The islands have a volcanic origin, and present rocky formations, whilst almost the entire coast of the mainland consists of sandy beaches. In the Banc d' Arguin, the presence of submerged vegetation promotes the existence of several micro-habitats suitable for a very high diversity of benthic forms and micro-invertebrates including annelids, molluscs and arthropods. On the other hand, the lack of coral reefs is a remarkable characteristic in NWA, and there is a very low diversity of corals for a marine region at this latitude. Most of the information about benthic organisms in NWA is restricted to commercial species, especially the cephalopod species *Octopus vulgaris* and *Sepia officinalis*, and *Penaeus notialis* shrimps in The Gambia (Mendy, 2004), and the Palinuridea lobsters in the Cape Verde Islands (Lindley *et al.* 2004).

Fish

As a result of the presence of both cold and tropical waters, the list of fish species in NWA is large and diverse. In northern NWA and around the archipelagos, fish species are mainly pelagic, influenced by the upwelling system. In southern NWA, fish assemblages are associated with, and enhanced by, the flow of nutrient from rivers. The clearest example of this is the Gambia waters, very rich in terms of fish abundance and diversity due to the effect of the Gambia River, which forms a large and productive estuary (Mendy, 2004).

Surveys, mainly from Morocco, show that this group includes demersal species like Sergeant Major *Abudelduf scratalis*; Damselfish *Charis charis*; the Gobies *Aphia minuta*, *Gobius paganellus* and *G. niger*; Cardinal Fish *Apogon imberbis*; the Wrasses *Symphodus mediterraneus, S. melops* and *Ctenolabrus rupestris*; Big-scale Sand Smelt *Atherina boyeri*; Scaldfish *Arnoglossus laterna*; Snipefish *Macrorhamphosus scolopax*; Rockfish *Scorpaena loppei* and *S. maderensis*; Bogue *Dentex maroccanus*; sea breams *Diplodus vulgaris, D. sargus*, *D. cervinus*, *D. bellotti* and *Oblada melanura;* Pandoras *Pagellus acarne*, *P. erythrinus*, and *P. bellottii*; Gurnards *Lepidotrigla dieuzeidei* and *Chelidonichthys obscurus*; Scorpionfish *Scorpaena notata*; Narrow-head Grey Mullet *Mugil capurrii*; Parrot Seaperch *Callanthias rubber*; Brill *Scophthalmus rhombus*; Common Guitarfish *Rhinobatos rhinobatos*; Forkbeard *Phycis phycis*; Red Bandfish *Cepola macrophthalma,* Canary Drum *Umbrina canariensis*, Grey Gurnard *Chelidonichthys gurnardus*, False Scad *Caranx rhonchus*, Hakes *Merluccius senegalensis* and *M. merluccius,* Common Dentex *Dentex dentex* and *D. macrophthalmus*, Brown Meagre *Sciaena umbra*, Splendid Alfonsino *Beryx splendens*, Seabreams *Pagellus bogaraveo*, *Sparus aurata* and *Agrus caeruleostictus,* John Dory *Eus faber* Red Porgy *Agrus pagrus* European Seabass *Icentrarchus labrax* Longneck Croaker *Seudotolithus typus* Greater Forkbeard *Phycis phycis*, Bluefish *Pomatomus saltatrix*, Groupers *Epinephelus marginatus* and *Epinephelus costae*, Silver Scabbardfish *Lepidopus caudatus*, Meagre *Argyrosomus regius*, Largehead Hairtail *Trichiurus lepturus*, Greater Amberjack *Seriola dumerili*, European Eel *Anguilla anguilla,* Orange Roughy *Hoplostethus atlanticus,* Blue Ling *Molva dypterygia*, Oilfish *Ruvettus pretiosus*, Smalltooth Sawfish *Pristis pectinata* and Mediterranean Moray *Muraena helena* (Stanford *et al*. 2001).

Demersal fish assemblages on the Cape Verde and Mauritanian shelves are dominated by subtropical species, especially sparids, whereas tropical species are more dominant in Guinean waters, specifically sciaenids (Stobberup *et al* 2005b). Other species recorded in Cape Verde archipelago are tuna *Katsuwonus pelamis* and *Thunnus albacares,* the Wahoo *Acanthocybium solandri,* and the small pelagic species *Spicara melanurus, Selar crumenophthalmus* and *Decapterus macarellus* (Stobberup and Erzini, 2006).

Large deep-water benthic fish in NWA include the Alfonsino *Beryx decadactylus*, Wreckfish *Polyprion americanus*, European Conger Eel *Conger conger*, Anglerfish from the family Lophiidae, and the Anglers *Lophius budegassa* and *L. piscatorius* (Stanford *et al*. 2001).

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Sharks are diverse and abundant off the Gambia, mainly Carcharinidae (Mendy, 2004). Another miscellaneous group of fish species is the groupers of the genus *Epinephelus*, mullids like *Pseudopeneus prayensis,* flatfishes, and species from the families Sciaenidae, Pomadasysidae, Sparidae and Scorpaenidae (Mendy, 2004).

The non-commercial species reported in the area are, among others, the Wrasses *Coris julis, Labrus bergylta, Symphodus tinca* and *Labrus bimaculatus*, Broadnosed Pipefish *Syngnathus typhle*, Dragonet *Callionymus lyeara*, Painted Comber *Serranus scriba*, Poor Cod *Trisopterus minutus*, Fourspotted Megrim *Lepidorhombus boscii*, European Flounder *Platichthys flesus*, Lesser African Threadfin *Galeoides decadactylus*, Blotched Picarel *Spicara maena*, the Grenadiers *Nezumia aequalis* and *Caelorinchus caelorhincus;* Slender Rockfish *Scorpaena elongate*; and the Weevers *Trachinus vipera* and *T. draco* (Stanford *et al.* 2001).

Pelagic fish includes the Derbio *Trachinotus ovatus,* Pilotfish *Naucrates doctor,* African Threadfish *Alectis alexandrinus*, Atlantic Saury *Scomberesox saurus*, Mediterranean Flyingfish *Cheilopogon heterurus*, Cornish Blackfish *Schedophilus medusophagus*, Slender Sunfish *Ranzania laevis*, Driftfish *Cubiceps gracilis*, mackerels *T. trachurus, T. mediterraneus, S. colias, S. scombrus, S. japonicus* and *Scomberomorus tritor*, Crevalle Jack *Caranx hippos*, shads *Alosa alosa* and *A. fallax*, Spotted Seabass *D. punctatus*, Agujon Needlefish *Tylosurus acus acus,* Leerfish *Lichia amia,* Common Dolphinfish *Coryphaena hippurus*, European Sprat *S. sprattus*, the Sardine or European Pilchard *S. pilchardus*, the Sardinella *S. aurita* and *S. maderensis*, and the European Anchovy *E. encrasicolus* (Stanford *et al.* 2001).

But the most studied, and commercially important species are the small pelagics, mainly sardines and sardinellas. The Round Sardinella *S. aurita* is a species very common along the NWA coasts from West Sahara to Angola (Krzeptowski, 1981). The Canary Current System, in northern NWA, sustains a large number of sardines, *S. pilchardus* and *Sardinella* spp*,* and the Anchovy *E. encrasicolus* (Brochier *et al.* 2008). *S. pilchardus* is dominant in the Canary Current system, from northern Iberia to Morocco, in contrast to the dominance of Anchovies in most upwelling systems (Humboldt, Benguela, California). Further south, in the coast off Mauritania and Senegal, *S. aurita* and *S. maderensis* dominate (Cury and Fontana, 1988, Brochier *et al.* 2008).

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A large stock of *S. aurita* along the Mauritania and Senegal coasts, follows movements north-south between the Canary Current and Guinea (fig. 1-14a), forming different small local stocks (Brainerd, 1991). Another stock, off the Sahara and Morocco, is confined within the Canary Current upwelling area (Kompowski, 1975). Migration starts off Senegal in May, reaching Mauritanian waters in August and until December. In early winter, movements to south take place (ter Hofstede *et al.* 2007). The amplitude of these migrations is different between years (fig. 1-14b) as a function of the thermal regime (Samb and Pauly, 2000). This species enters Mauritanian and Moroccan waters from the south during spring, and returns south after the summer (Tjoe-Awie *et al.* 2006; ter Hofstede *et al.* 2007), delaying the return to Senegal during summer and autumn depending on the sea surface temperature. A shift in ocean climate during 1995 marked sudden Sardinella abundance off Mauritania (Tjoe-Awie *et al.* 2006). These environmental changes could cause changes in the distribution and abundance of colder water species such as Sardines *S. pilchardus*.
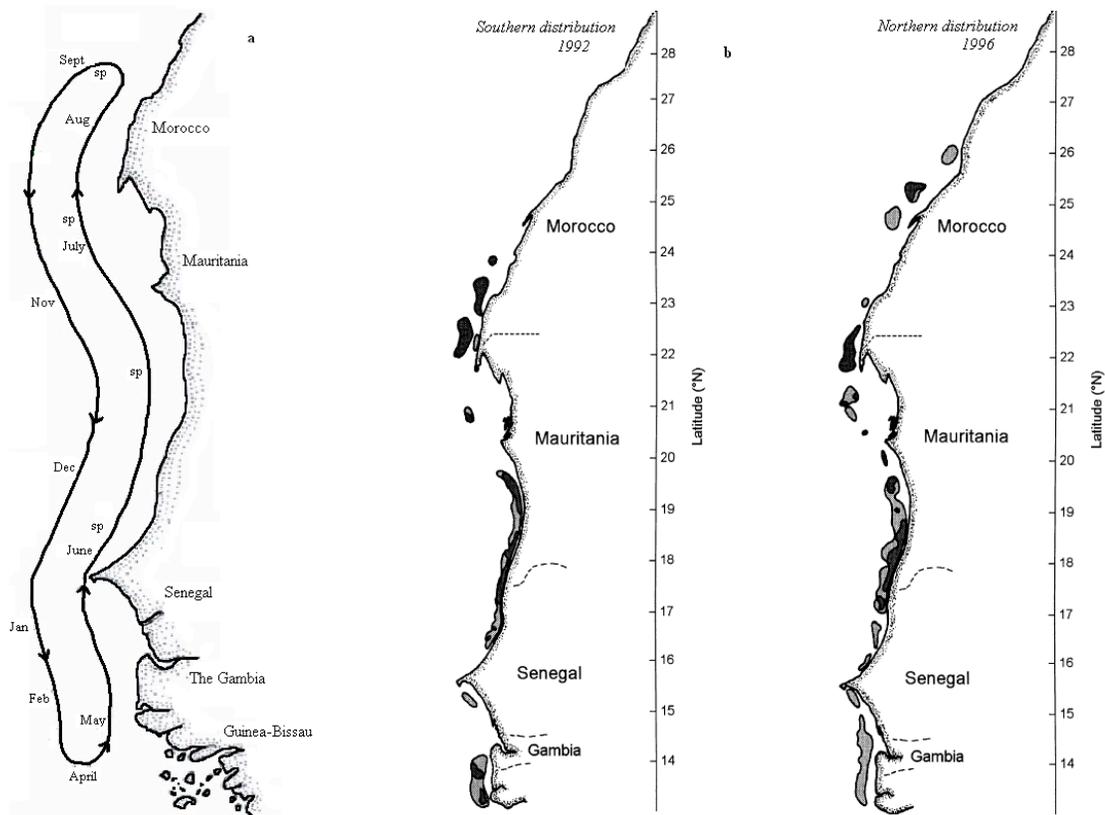
Figure 1-14. Migration and Distribution of *Sardinella* spp stocks showing (a) spawning areas along the NWA and (b) differences between years (from Samb and Pauly (2000) and ter Hofstede *et al.* (2007)).

Movements of sardinellas are also from the coast to offshore waters, mainly because of changes in salinity. An example of that is the displacement of sardinellas from the coast to offshore, as a result of the low salinities caused by the discharge of the rivers in Sierra Leone (Ettahiri *et al*. 2003).

In the northern range of NWA, important spawning areas for both Anchovy and Sardine during winter are Cape Draa and Cape Juby in Morocco (Brochier *et al*. 2008). In the case of the Sardine, main spawning areas in the Western Sahara are Cap Bojador and off Villa Cisneros during three periods: March-April, August-September, and November-December (Krzeptowski, 1983). In the case of sardines, winter is the maximum spawning season (Ettahiri *et al*. 2003).

The sardinellas use the same food during their growth (Medina-Gaertner, 1988), with a diet composed mainly of zooplankton and phytoplankton (Mendy, 2004). The calanoid copepods have been recognized as the main prey for *S. maderensis* and *S. aurita* in Senegal (Medina-Gaertner, 1988). Finally, other small pelagic fish in NWA are the carangids *Trachurus trachurus, T. trecae* and *Caranx rhonchus* (Mendy, 2004).

Marine mammals

The cetaceans observed in the NWA area are the Sei Whale *B. borealis*, Fin Whale *B. physalus*, Bryde's Whale *B. edeni*, Minke Whales *B. acutorostrata*, and Humpback Whale *Megaptera novaeangliae* (Stanford *et al*. 2001). According to reports from Morocco and Guinea-Bissau, the odontocetes include the Sperm Whale *P. macrocephalus*, Short-finned Pilot Whale *Globicephala macrorhynchus*, Common Dolphin *D. delphis*, the Spinning Dolphin *Stenella coeruleoalba* and *S. frontalis*, Cuvier's Beaked Whale *Ziphius cavirostris*, Risso's Dolphin *Grampus griseus*, Bottlenose Dolphin *T. truncatus*, Harbour Porpoise *P. phocoena*, False Killer Whale *Pseudorca crassidens*, Killer Whale *Orcinus orca*, and the Atlantic Hump-back Dolphin *Sousa teutzii* (Stanford *et al*. 2001; Amorim *et al*. 2004). The Manatee *Trichechus senegalensis* is the only sirenian species in the zone (Amorim *et al*. 2004).

Seabirds

It is difficult to establish the total diversity of seabird species in NWA because either there is little information available about them, or they are only found in a specific area for a very short time each year (Stanford *et al*. 2001). The central-eastern Atlantic Ocean in NWA has received little attention from ornithologists, especially in comparison with other tropical areas like the central-eastern Pacific Ocean. Maybe the most studied location is the Banc d' Arguin, where bird density is high (Wolff *et al*. 1993) with especially large numbers of waders. One feature of the NWA region is a scarcity of breeding seabirds due to shortage of predator-free nesting habitat. The lack of breeding seabirds contrasts with the high abundance of suitable food due to the upwelling and high primary production of many of these areas.

According to some published reports, the seabirds observed in Morocco, Senegal, Mauritania, Cape Verde, Guinea-Bissau, and Gulf of Guinea are: the shearwaters (*P. gravis*, *P. assimilis*, *P. griseus*, *P. mauretanicus*, *P. puffinus, C. diomedea* and *C. borealis*), petrels (*O. leucorhoa, O. castro, Bulweria bulwerii*, *H. pelagicus* and *Oceanites oceanicus*), Northern Gannet, Brown Booby *Sula leucogaster*, Great Cormorant, Shag, Pink-backed Pelican *Pelecanus rufescens,* skuas (*S. pomarinus, S. parasiticus, S. longicaudus,* and *S. skua*), Terns (*Sterna hirundo*, *S. dougallii*, *S. paradisaea*, *S. sandvicensis*, *S. maxima, S. caspia*, *S. fuscata*, *S. anaethetus*, *S. maxima, Sterna bergii*, *S. balaenarum, Anous stolidus, Gelochelidon nilotica*, and *Chlidonias niger*), gulls (*Larus minutus*, *L. argentatus*, *L. sabini*, *L. audouinii, L. ridibundus, L. fuscus, L. michahellis, L. cirrocephalus,* and *L. genei),* the main waders include *Calidris ferruginea,* Bar-tailed Godwit *Limosa lapponica,* Common Sandpiper *Actitis hypoleucos,* Grey Plover *Pluvialis squatarola,* Whimbrel *Numenius phaeopus,* Grey Phalarope, *P. fulicaria* and Greater Flamingo *Phoenicopterus ruber* (Wallace, 1973; Brown, 1979; Marr *et al*. 1988; Leopold, 1993; Stanford *et al*. 2001; Burton and Camphuysen, 2003; Amorim *et al*. 2004; Camphuysen and van der Meer, 2005).

The main breeding areas for seabirds in the NWA are Mauritania, Senegal, the Gambia, and Cape Verde archipelago (Burton and Camphuysen, 2003). The breeding colonies there show strong differences between years, as a result of differences in the food supply (Veen *et al*. 2003). The most remarkable breeding seabirds are some tern species, moving for winter to Guinea-Bissau, Bonaire and Sierra Leone (Brenninkmeijer *et al*. 2002). Although breeding seabirds are scarce in NWA, this area is very important for migrating seabirds (Leopold,

1993), for example being one of the most important wintering areas for the Pomarine Skua in the world (Furness, 1987). In the Mauritanian coast, around the Banc d' Arguin, a high number of migrating seabirds have been reported (Leopold, 1993; Wolff *et al*. 1993; Burton and Camphuysen, 2003).

The Mauritanian shelf slope area has been reported as an important area for seabirds in NWA. This area supports local breeders and migrating seabirds (e.g. skuas, terns and Sabine's Gull), including immature and sub-adults individuals like Gannet (Burton and Camphuysen, 2003). This area has been increasingly targeted by commercial fisheries and is of prime importance for seabirds (Camphuysen and van der Meer, 2005).

Pelagic fish, mainly scombrids and other medium-sized fish are available to large seabirds like Northern Gannet, and possibly also to the Skuas. These seabird species can feed either fishing for themselves, by scavenging or by piracy (Brown, 1979).

Morus bassanus *in North-western Africa*

It is well known that large numbers of Northern Gannets utilize NWA waters during the non-breeding season although it has been thought that most of these birds are juveniles and immatures (Nelson, 2002; Wanless, 2002), and some two-year old individuals are known to spend the summer in the region (Nelson, 1978). In fact, some individuals have been observed during August in Senegal (Baillon and Dubois, 1991). This species is nowadays widespread throughout NWA at low densities, apparently more abundant near the coast (Burton and Camphuysen, 2003).

Northern Gannets have been observed in association with fishing vessels and pods of cetaceans (Burton and Camphuysen, 2003). During daytime, 40% of the all seabirds observed in Mauritanian shelf break waters were associated with fishing vessels, with more than 88% of Gannets in association with fishing boats (Camphuysen and van der Meer, 2005).

The age class proportion of Northern Gannets observed in Mauritania changes according with the month. The proportion of adults was about 50% during January 2000, and less than 20% during March 2003. In the opposite direction, proportion of first year individuals was about 30% during January 2000 and about 50% during March 2003 (Camphuysen, 2003; Burton and

Camphuysen, 2003). Most of the individuals observed in Senegal during April were immatures (Gaston, 1970). Observed differences could be due to the fact that adults should migrate to breeding areas northward towards the end of the winter, or perhaps to an increase in the numbers of young birds in recent years (Burton and Camphuysen, 2003).

Stercorarius skua *in North-western Africa*

The Great Skua has been reported in NWA waters during the winter months, regularly observed near fishing vessels (Leopold, 1993), with a few records during autumn (Baillon and Dubois, 1991). In spite of this species presenting lower abundances than Northern Gannet off African coasts, it has been observed from Mauritania (Camphuysen and van der Meer, 2005) and Senegal (Marr *et al* 1988) to Nigeria (Wallace, 1973).

Age determination by plumage is difficult in Great Skuas, but both adults and immatures have been reported migrating near the Banc d' Arguin (Leopold, 1993). In Mauritania, during January, Gannets were most abundant in the north, with colder waters, whilst skuas were most abundant in southern areas (Camphuysen and van der Meer, 2005).

Chapter 2

Great Skua ring recovery

Abstract

By means of ring recovery data from the BTO migration of the Great Skua was observed between age classes. Analyses were made considering the entire year, the non-breeding period and only wintering months. Mean finding latitudes were high between the 1970s and 1990s decades, decreasing in recent years, with the southernmost recoveries observed prior to the 1970s. Typical annual trend is observed with individuals spending the spring and part of the summer in northern latitudes, moving to the south during autumn and staying in southern latitudes during the winter months. Adult skuas tend to stay close the breeding areas, being the young birds the individuals migrating far south. However, the number of records from young individuals migrating to North Western Africa decreased in the last 17 years. Despite the overall increment in the number of skuas wintering in Africa in the last years, records from this area could present bias because the lack in the ring recovery culture.

Introduction

Migration of Great Skuas is well documented, and represents travel from the colonies in Scotland, Iceland, the Faeroes, Greenland, and recently Russia and Norway (Furness and Ratcliffe, 2004), to southern latitudes off Iberia and north western coasts of Africa (Furness, 2002a). Adult Great Skuas migrate to winter off the coasts of southern Europe (especially Iberia), and return in spring to their colonies, usually to the same breeding territory. Because of their philopatry, the offspring normally try to establish a territory within a few hundred meters of their birthplace (Klomp and Furness, 1992).

Radar has been used to track migrating birds, especially by night, but new technologies, like satellite tracking devices and data loggers, provide much more detailed information related to seabird migration nowadays (Weimerskirch *et al*. 1994, Furness *et al*. 2006, Shaffer *et al*. 2006, Suryan *et al*. 2007). Recorded movements can thus be related to oceanographic variables (Weimerskirch *et al*. 1995). The use of remote sensing enables researchers to obtain information about movements and location automatically at any time (Marchant, 2002). As an example, the use of satellite tracking on Short-tailed Albatross determined post breeding distribution, and the relation between seabird movements and commercial fisheries in Alaska (Suryan *et al*. 2007). Unfortunately, satellite tracking devices are expensive, heavy, and the

risk of losing of them is high (especially when individuals die at remote places, or when the apparatus is not deployed correctly). On the other hand, data loggers must be recovered to obtain the information recorded, and this requires the capture of the bird two times.

The use of rings provides useful information related to migration, because the marking of known individuals permits their movements between sites to be recorded (Marchant, 2002). Ringed animals can be followed for the entire life of their rings, unlike the use of electronic devices (satellite tracking or data loggers) which is limited by the duration of batteries. But effectiveness of ringing depends on systematic surveys to ring and recover individuals. The BTO (British Trust for Ornithology) ringing scheme represents an important effort to organize and co-ordinate a great number of trained and licensed volunteers throughout the United Kingdom.

Ring recoveries are reports of ringed birds found dead, and include reports from volunteer and professional ornithologists, and members of the public. The BTO ring recovery data include information of recoveries from many parts of the world (Clark *et al.* 2007; 2009).

Ringing of birds is a powerful tool used in several ecological studies. Using data from BTO ringed birds, migratory movements of several species at risk can be followed; for example the White-fronted Goose *Anser albifrons* (Coiffait *et al.* 2008). Also, ringing recoveries has been used in order to establish the effects of the winter weather on shorebird mortality (Clark, 2004).

The largest numbers of Great Skuas in Europe nest in Shetland with the densest colony on Foula (Furness and Ratcliffe, 2004). As a result of this, most ringing of Great Skuas has been undertaken with chicks at Foula (Furness, 2002a), although there has been ringing at many other Scottish colonies, and to a lesser extent in Iceland, Faeroes and Norway.

The ringing scheme from the BTO provides important information needed to understand changes in Great Skua populations, by monitoring their survival rates, productivity and dispersal. From ring recoveries it is possible to determine individual movements, related to age class, year and month.

Many recoveries are reported simply as "found dead" but Great Skuas deliberately or accidentally killed by humans, including those drowned in fishing nets or caught on baited lines, are a major cause of ring recoveries. Because reports from dead individuals are infrequent in some countries, a picture of Great Skua distribution may be biased (Furness, 2002a). In spite of this, bird movements have been tracked through analyses of ring recoveries, as described in the "*Atlas of Bird Migration for Birds of Britain and Ireland*" (Wernham *et al.* 2002). The existing ring recovery data arte thus useful in detailed analyses related to long-term changes in Great Skua migration patterns.

Ring recovery data include information related to the date of ringing, age and status. The age of the bird at ringing is known in the case of those individuals ringed as chicks. Furthermore, the date of recovery and number of days between ringing and recovering helps to determine the age of such animals when they died.

According to the BTO, from each 50 ringed birds that died only one is recovered on average. In spite of the low recovery rate, the total number of recoveries is very large, as a result of the sustained effort to ring individuals of this species, especially during the breeding season in the nesting colonies, mainly in Great Britain (including Orkney, Shetland and the Western Isles) and Iceland as well.

In this chapter I have analysed the BTO Great Skua ring recovery database to assess whether these data provide any useful information on changes in the wintering latitudes of Great Skuas over recent years or decades.

Materials and Methods

Data were obtained from the BTO ringing and recovery scheme. Each record consists of individualized detailed information from every single individual ringed and recovered. These records include dates, places and geographical locations from ringing and recovery. In addition, information related to the distance and time between ringing and recovery is included.

The main breeding colonies, where most of Great Skuas were ringed are located in the United Kingdom. In order to establish a relationship between breeding colonies and finding zones, the UK was divided into several areas: Shetland Islands (including Foula), Orkney Islands, Fair Isle (all these at northern Scotland), Western Isles (in the Hebrides), and UK (rest of the Great Britain). Additionally, Iceland was added as a BTO breeding-ringing area.

In some cases, the ring was found several days after the death of the animal, or the ringing was reported long after. Because of that, the BTO ring recovery scheme included information about the accuracy of the recovery date. The minimal period of time used during the data analyses was one month; as a result of this, finding and ringing inaccuracies greater than 30 days were excluded.

Similarly, an estimation of the age is provided when the individual was not ringed as a chick. Fortunatelly, almost all ringing has been on chicks (Furness, 2002a). In the case of individuals not ringed as chicks, the age of recovery was estimated according to the age codes from the BTO.

Using the BTO ring recovery database between 1938 and 2007, several analyses were made. In all analyses where data were examined by calendar year, individual years were included only when there were more than three records, because years with fewer records tend to produce wide standard deviations. In analyses of months and mapping of recoveries related to main colonies, all data were considered.

Finding latitudes are expressed in minutes, and all positive values correspond to North latitude. In the case of latitude in the southern hemisphere, the value appears as a negative number. As a reference, Foula is located at 3608 min. Differences in latitudes were calculated (ringing - finding latitudes).

Individuals ringed in southern latitudes (with negative values) were excluded because these records correspond to South Polar Skuas (*C. maccormicki*) ringed by British Antarctic Survey using BTO rings. The number of ringed skuas by year, and their survival to the first year, were calculated as well as the recovery areas of individuals from the main colonies.

Data were analyzed in three groups: all year (including data from the 12 months of the year), the non-breeding period (including the months from September to May; Furness, 2002a), and winter (including the months from December to March). All-year months analyses represent the annual trend and the following groups (non-breeding and winter) were considered in order to accurate the analyses during the migration period. Analysis included comparisons of finding latitudes between years, months and age classes, using graphs to look for trends.

Ages of individuals were grouped in three age classes: age class 1 (fledged up to one year old), age class 2 (individuals between 1 and 3 years old), and age class 3 (individuals more than 3 years old). Age class 3 includes immature (three to eight years old) and adults (Furness, 2002a), and age class 1 includes juveniles in their first migration journey.

In order to test for differences, ANOVA analyses were made. In cases of non-normal distributions of residuals, in spite of transformations of data, Kruskal-Wallis test were employed.

Results

The number of ringed birds (including only those ringed as chicks), and those recovered during their first year are presented in table 2-I. The ringing numbers show a clear difference in the numbers between years, with the highest values during the 1970's (fig. 2-1). The number of records by year for all year, and for the three age classes for non-breeding or wintering months as well, is presented in Table 2-II.

Between 1985 and 2003 years, the percentage recovered more than one year after ringing showed marked periods with high values, followed by lesser values. But percentages are decreasing in the more recent years, 2000-2003 (fig. 2-2).

The numbers of ring recoveries by country, and by ringing area, are presented in the Table 2-III, with detailed description of finding areas in maps (fig 2-3a-f).
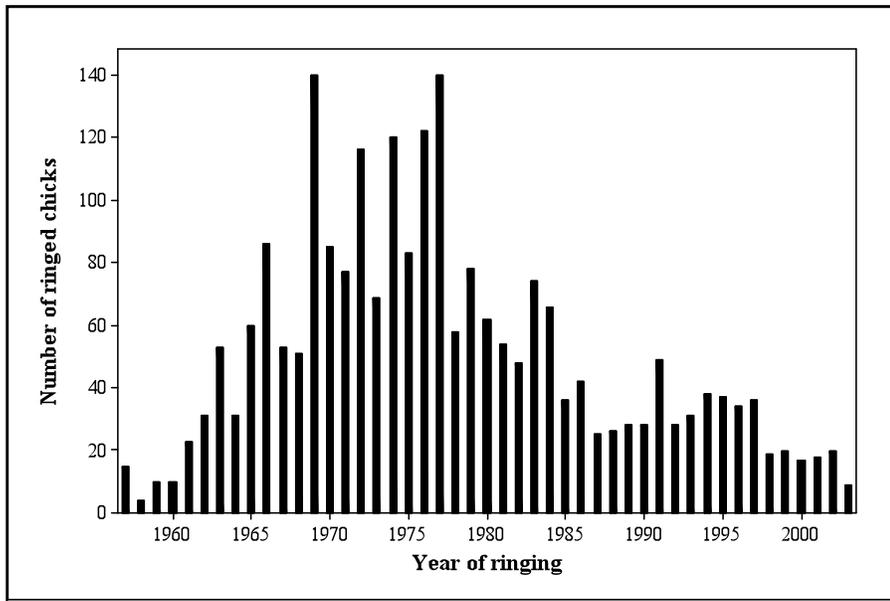
Figure 2-1. Number of Great Skua recoveries of chicks ringed by year.
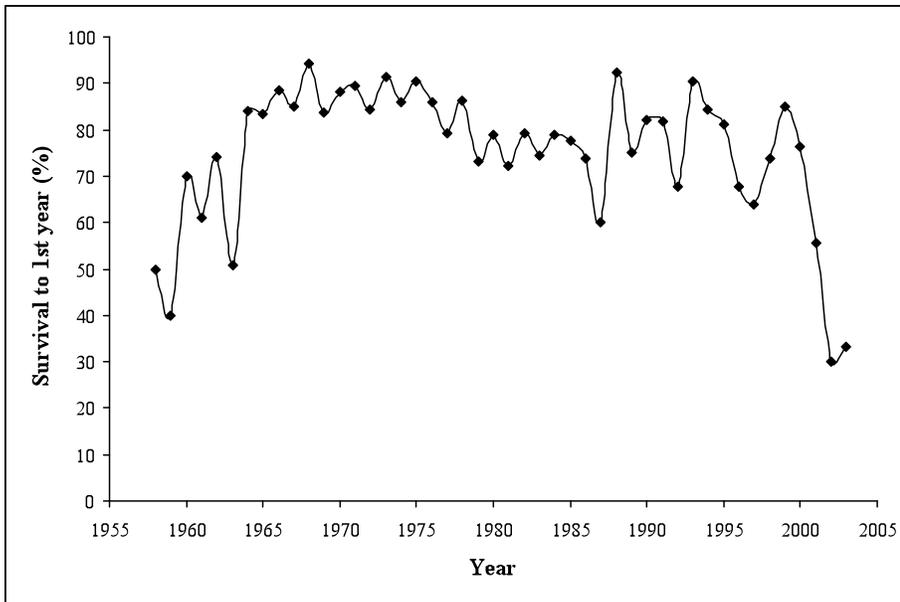
Figure 2-2. Percentage of Great Skua chick recoveries that were after the first year in each year during the period 1958-2003.

Table 2-I. Number of ringed birds and chicks by year, number of birds recovered the same year and survival.

Year of ringing	Number of ringed birds recovered	Number of ringed chicks recovered	Number of ringed chicks recovered the same year	Percent recovered after 1st year
1939	15	15	13	13.3
1958	4	4	2	50.0
1959	10	10	6	40.0
1960	10	10	3	70.0
1961	23	23	9	60.9
1962	31	31	8	74.2
1963	53	53	26	50.9
1964	31	31	5	83.9
1965	61	60	10	83.3
1966	86	86	10	88.4
1967	53	53	8	84.9
1968	51	51	3	94.1
1969	141	140	23	83.6
1970	85	85	10	88.2
1971	77	77	8	89.6
1972	117	116	18	84.5
1973	69	69	6	91.3
1974	124	120	17	85.8
1975	83	83	8	90.4
1976	122	122	17	86.1
1977	140	140	29	79.3
1978	58	58	8	86.2
1979	78	78	21	73.1
1980	62	62	13	79.0
1981	54	54	15	72.2
1982	48	48	10	79.2
1983	74	74	19	74.3
1984	66	66	14	78.8
1985	36	36	8	77.8
1986	42	42	11	73.8
1987	25	25	10	60.0
1988	32	26	2	92.3
1989	34	28	7	75.0
1990	34	28	5	82.1
1991	49	49	9	81.6
1992	31	28	9	67.9
1993	31	31	3	90.3
1994	39	38	6	84.2
1995	38	37	7	81.1
1996	38	34	11	67.6
1997	37	36	13	63.9
1998	19	19	5	73.7
1999	21	20	3	85.0
2000	19	17	4	76.5
2001	19	18	8	55.6
2002	21	20	14	30.0
2003	9	9	6	33.3

Table 2-II. Number of records by year, for years with all months included, by age class.

Year	All year	Age Class 1		Age Class 2		Age Class 3	
		Winter	Non-breeding	Winter	Non-breeding	Winter	Non-breeding
1939	13*		13				
1959	5	2	4				
1960	4		2	1	2		
1961	8	3	7				
1962	11	2	9	1	1		
1963	35	5	26	1	4		
1964	10	1	6	1	1		
1965	23	3	7	3	6	2	4
1966	17	3	11		2		1
1967	23	5	12		4		2
1968	20	1	3	1	4		3
1969	35	4	21	2	3	2	4
1970	37	13	21	2	3	1	5
1971	39	5	12	4	7	1	6
1972	55	5	18	1	3	1	9
1973	44	3	7		4	3	8
1974	63	7	18	2	6	8	18
1975	53	4	9	2	7	3	11
1976	98	6	15	2	5	3	29
1977	88	9	29	5	8	3	17
1978	63	5	11	2	10	6	20
1979	86	2	12	3	8	5	29
1980	89	4	8		2	2	32
1981	66	6	12	2	4	8	20
1982	43	3	8	1	4	6	19
1983	85	2	16	2	7	5	22
1984	73	3	14		2	5	26
1985	75	2	9		3	3	25
1986	68	2	8	2	3	6	19
1987	59	2	6		1	2	18
1988	51		1		1	4	22
1989	34	1	6	2	5	7	12
1990	52	3	6	2	8	11	25
1991	35		3	2	3	3	10
1992	32	1	10	1	2		8
1993	26	2	5	1	2		10
1994	30	1	4	1	3	5	9
1995	39	2	10	1	2	7	15
1996	39	3	7		2	3	14
1997	52	2	14	1	3	5	17
1998	51	4	8	5	6	5	13
1999	24	1	3	1	1	8	16
2000	48	4	7	2	3	13	22
2001	37		9			6	15
2002	48	3	11	2	3	7	16
2003	41		2	1	1	4	13
2004	35	1	1			2	16
2005	21				1	2	8
2006	27		4			2	12
2007	12	2	2			1	2

For the period between 1959 and 2007 one trend graph of the annual mean finding latitude was made, including all data recorded (fig. 2-4). Great Skua individuals tended to be recovered in higher latitudes during the period between 1970's and 1990's. In previous years ring recoveries were made at low latitudes, with the lowest values for the entire period analyzed during the 1960's. In recent years, there is a tendency to recoveries at low latitudes.

Table 2-III. Number of ring recoveries by country for each breeding area, including all the data for the entire period.

Finding country	Breeding colonies					
	Shetland	Great Britain	Orkney	Fair Isle	Western Isles	Iceland
Algeria	10	2	1	1	1	
Azores	2					
Austria	1					
Belgium	13	3	1			
Brazil		4				
Canada	2	1				
Cape Verde		2				
Caribbean	1					
Ceuta	1					
Channel Islands	2					
Denmark	41	33	4	4		
Faeroe Islands	38	25	2	1		
Fair Isle	20	3	1	61	1	
France	189	93	11	9	1	
Germany	57	28	15	4		
Gibraltar	1					
Great Britain	109	299	27	7	17	16
Greenland	17	17		1		
Iceland	8	4				
Ireland	5	11		2		
Italy	4	2		1		
Ivory Coast		1				
Madeira		2				
Malta	4	3				
Mauritania		1				
Morocco	27	18	1		1	
Norway	36	20	2	1		
Orkney	35	1	64	6		1
Poland	1	1	1			
Portugal	25	35				
Russia	2					
Senegal	2	1				
Shetland	486	20	4	5		1
Sierra Leone					1	
South America		3				
Spain	62	47	9	3		
Sweden	12	2	1	1		
Switzerland	1	1				
The Netherlands	98	36	8	1	1	
Tunisia	2	4	1			
United States	2	1				
Western Isles	14			1		1
Western Sahara	1	2				

Ringed at Shetland Islands
1277 records

Figure 2-3a. Number of rings recovered of Great Skua individuals, ringed at Shetland Islands, in different areas of the Atlantic Ocean. White numbers correspond to areas with the biggest numbers.

Most of the recoveries from individuals ringed at Shetland were at the same Shetland Islands, followed by recoveries from elsewhere in Great Britain and from France (fig. 2-3a). Great Skuas were recovered in an extremely wide area across the Atlantic Ocean (from the North Sea to Greenland and North Canada, and from the Western coast of Africa to the Caribbean) and the Mediterranean Sea (fig. 2-3a).

61

Ringed at United Kingdom
Not including Shetland, Orkney, Fair Isle, and the Western Isles
676 records

Figure 2-3b. Number of rings recovered of Great Skua individuals, ringed in the rest of the United Kingdom, in different areas of the Atlantic Ocean. White numbers correspond to areas with the biggest numbers.

Great Skua individuals ringed in the United Kingdom were recovered at the same breeding areas, and France as well (fig. 2-3b). Just like birds ringed at Shetland, they were recovered over a wide area of the Atlantic Ocean, including remote areas in South America, Cape Verde and Ivory Coast (fig. 2-3b).

Ringed at Orkney
153 records

Figure 2-3c. Number of rings recovered of Great Skua individuals, ringed at Orkney, in different areas of the Atlantic Ocean. White numbers correspond to areas with the biggest numbers.

Individuals ringed at Orkney were mainly recovered at the same Orkney Islands and in France, as well as showing dispersal from the Faeroes Islands to Northern Africa (fig. 2-3c).

63

Figure 2-3d. Number of rings recovered of Great Skua individuals, ringed at Fair Isle, in different areas of the Atlantic Ocean. White numbers correspond to areas with the biggest numbers.

Like individuals ringed at Orkney, those ringed at Fair Isle were recovered at the same Island (fig. 2-3d), showing similar dispersal from the Faeroes Islands to Northern Africa (fig. 2-3d).

64

Ringed at the Western Isles
22 records

*The Great Britain records include
those from the Western Ilses*

Figure 2-3e. Number of rings recovered of Great Skua individuals, ringed in the Western Isles, in different areas of the Atlantic Ocean. White numbers correspond to areas with the biggest numbers.

Great Skuas ringed at the Western Isles showed a limited dispersion, with a few extreme records in the North and Western Africa, including one in Mauritania (fig. 2-3e).

Figure 2-3f. Number of rings recovered of Great Skua individuals, ringed at Iceland, in different areas of the Atlantic Ocean (presenting data held by the BTO ringing scheme and not all Icelandic data). White numbers correspond to areas with the biggest numbers.

Individuals ringed at Iceland showed a very limited dispersion pattern, with most of the recoveries at the Great Britain, but this represents a biased sample as it only includes data held by the BTO (fig. 2-3f).
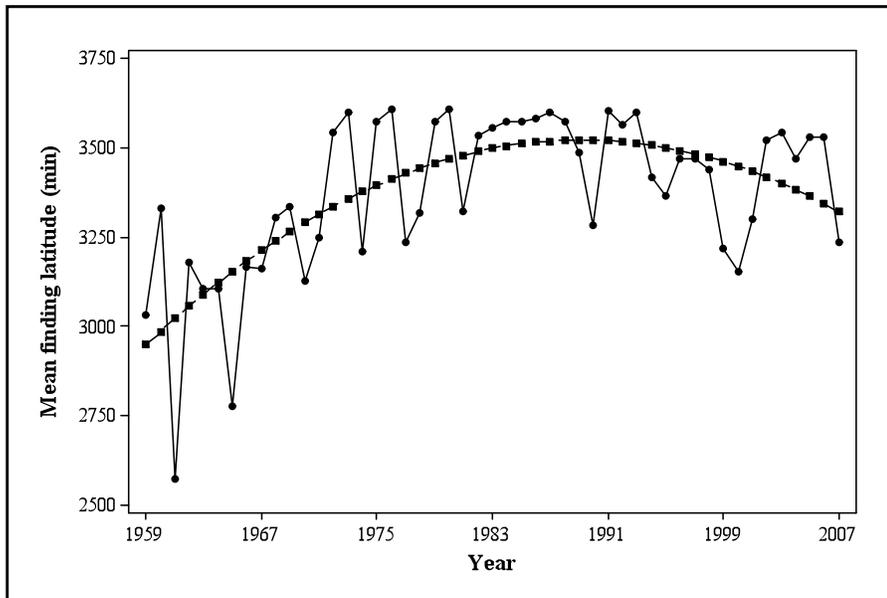
Figure 2-4. Time series analysis and quadratic trend curve, for the mean finding latitude by year, for all recoveries of Great Skuas ringed in UK colonies.

All year analyses

Analyses comparing differences between ringing and finding latitudes, among years and months showed marked differences between months (Kruskal-Wallis; H = 950.82, DF = 11, p < 0.001) and years (Kruskal-Wallis; H = 159.81, DF = 49, p < 0.001).

In case of the months, three groups are clearly noticeable (fig. 2-5); one of them with the higher differences through the period between January and April, a second one, with the lowest differences, during the period May-August. The last group corresponds to the autumn migration months (September through December).

In the case of years, mean differences showed a pattern that tends to be smaller in recent years (fig. 2-6). Nevertheless during the second half of the 1990's decade, mean differences in latitudes between ringing and recovery were higher than those in the previous and following years although less than in 1960's (fig. 2-6).
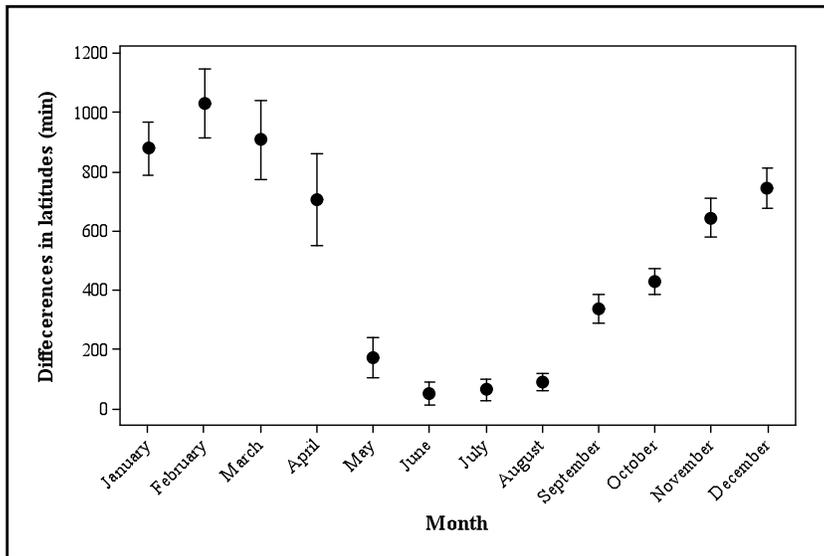
Figure 2-5. Mean differences between ringing and finding latitudes for the all months of the year.

Differences in latitudes are related directly to the age class (Kruskal-Wallis; H = 200.45, DF = 2, p < 0.001), with major differences in the age class 1 followed by age class 2 and finally age class 3 (fig. 2-7). Age was calculated from the ring recovery database, and represents the time recorded between the ringing date (for birds ringed as chicks) and the finding date.
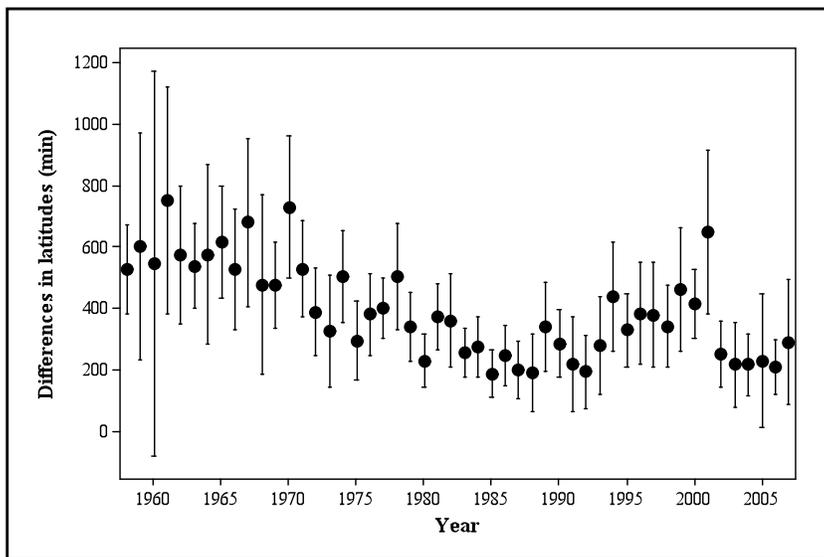
Figure 2-6. Mean differences between ringing and finding latitudes for the years through the period 1959-2007.
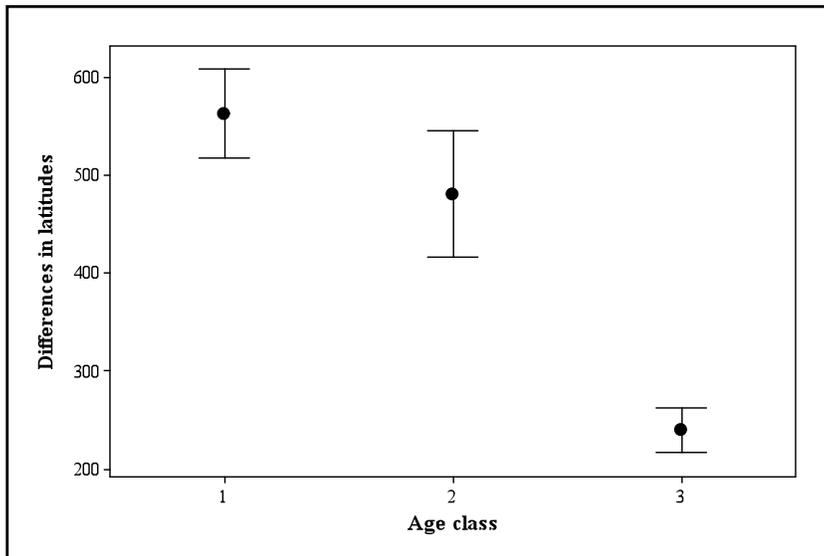
Figure 2-7. Mean differences between ringing and finding latitudes among age classes for the all months of the year.

Non-breeding period (September to May)

At the extreme months of the period (September and May) finding latitudes were higher. This is due to the movements to the north during the breeding period. On the other hand, winter months presented lower latitudes, showing the migration to the south to winter. These differences between months are statistically significant (Kruskal-Wallis; H = 451.14, DF = 8, p < 0.001; fig. 2-8).
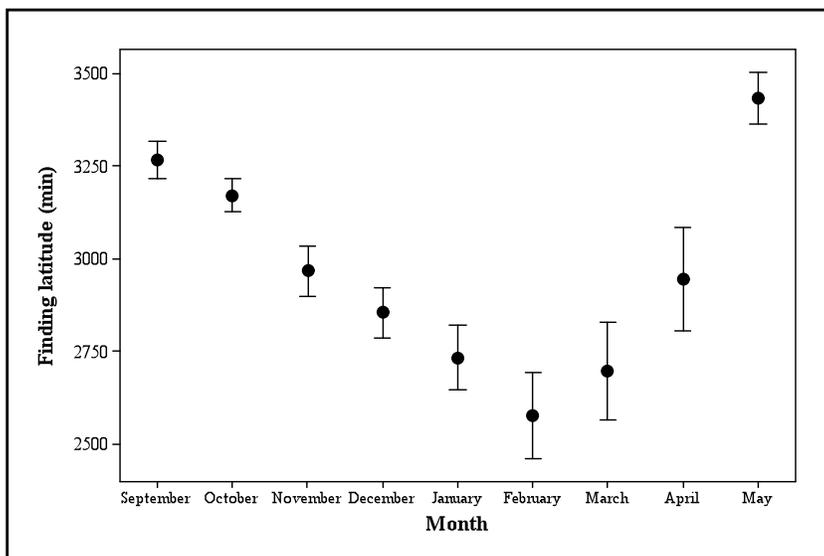
Figure 2-8. Monthly mean finding latitudes through the non-breeding period.

During the period between 1959 and 2007, a noticeable variation in finding latitudes was found (fig. 2-9). During the second part of the 1980's, as well as in the last years, finding latitudes were higher. For the rest of the period, especially during the 1960's and 1970's and between 1995 and 2000 as well, the graph shows a marked tendency for birds to migrate to southernmost areas. Observed differences are statistically significant (Kruskal-Wallis; H = 131.82, DF = 49, p < 0.001). These differences could be due to changes in migration behaviour or to changes in proportions of birds of different age classes in the ringed population. So the following analyses were made on different age classes.

During this non-breeding period of time marked differences in finding latitudes by age class were observed. Juveniles and immature individuals were found at lower latitudes (fig. 2-10), maybe because they do not breed and do not have to attend nests. Differences in finding latitudes between age classes are statistically significant (Kruskal-Wallis; H = 84.88, DF = 2, p < 0.001).
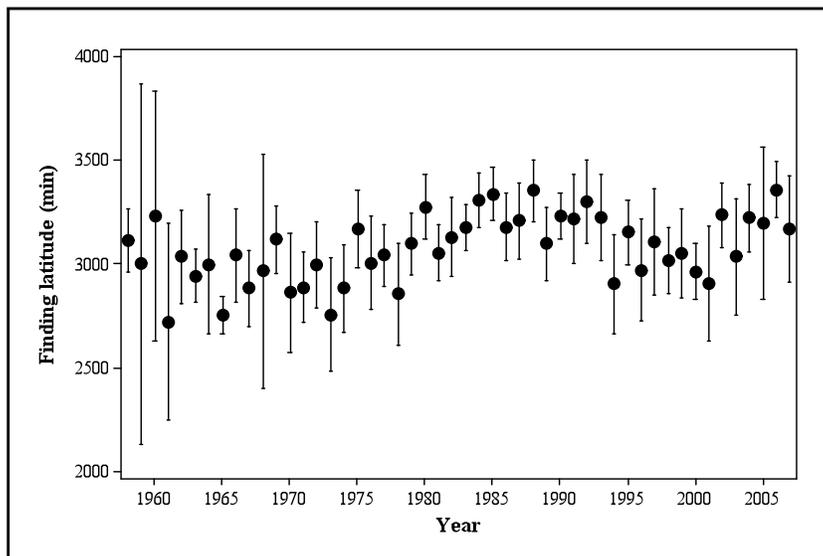
Figure 2-9. Mean finding latitudes by year. Data within years include only the non-breeding months.
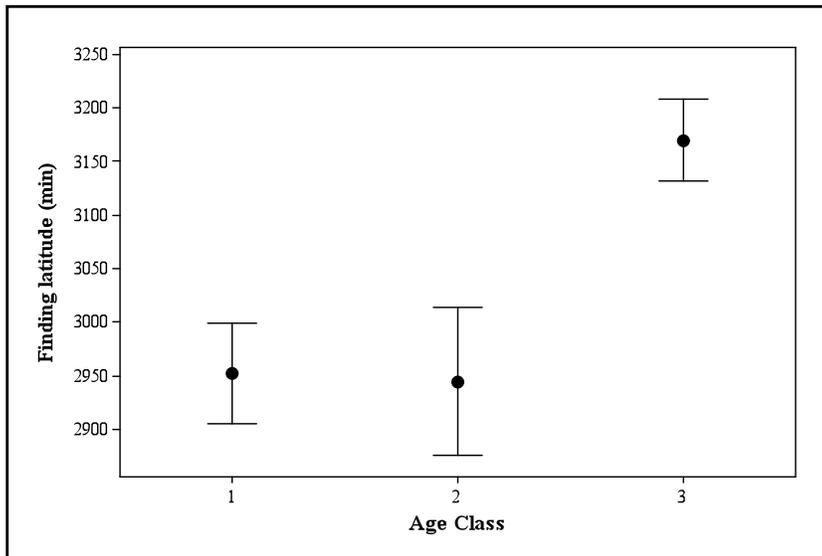
Figure 2-10. Mean finding latitude by age class, through the non-breeding period.

In case of age class 1 (fledged up to one year old), months with lowest latitudes were January, February and March, and months with higher latitudes were September and October (fig. 2-11). These tendencies among months showed marked differences (Kruskal-Wallis; H = 111.04, DF = 8, p < 0.001). In spite of this tendency being similar for all individuals (fig. 2-8), in age class 1 the highest mean values were observed during September and October, whereas May showed the highest value for all individuals.
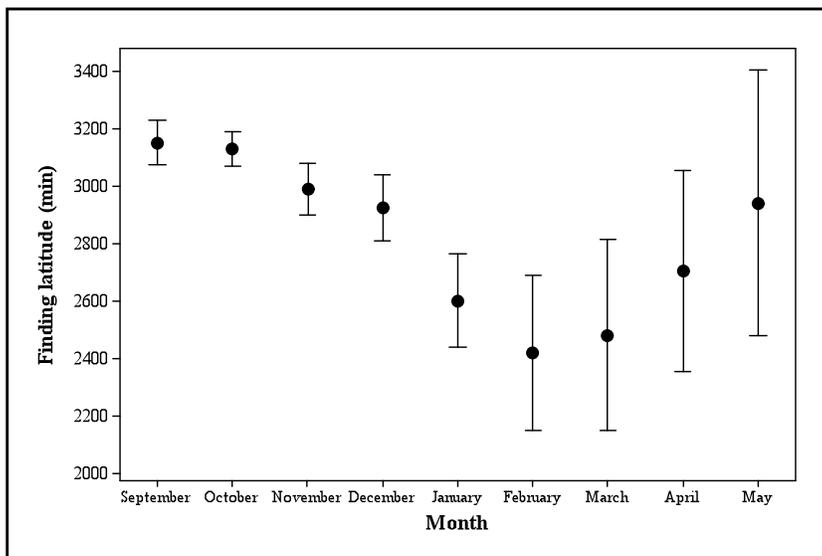
Figure 2-11. Mean finding latitude between non-breeding months for age class 1 individuals.

Variation in the mean finding latitudes through the non-breeding period among years, between all individuals and those of the class 1, were similar. Age class 1 Great Skuas migrated furthest south during some years in the 1970's decade, whilst shorter migrations were found at the beginning of the 1990's (fig. 2-12). These tendencies among years showed marked differences (Kruskal-Wallis; H = 76.97, DF = 41, p = 0.001). Nevertheless, in recent years large standard deviations were observed; maybe due to some individuals of this age class migrating to low latitudes, and to small sample sizes.
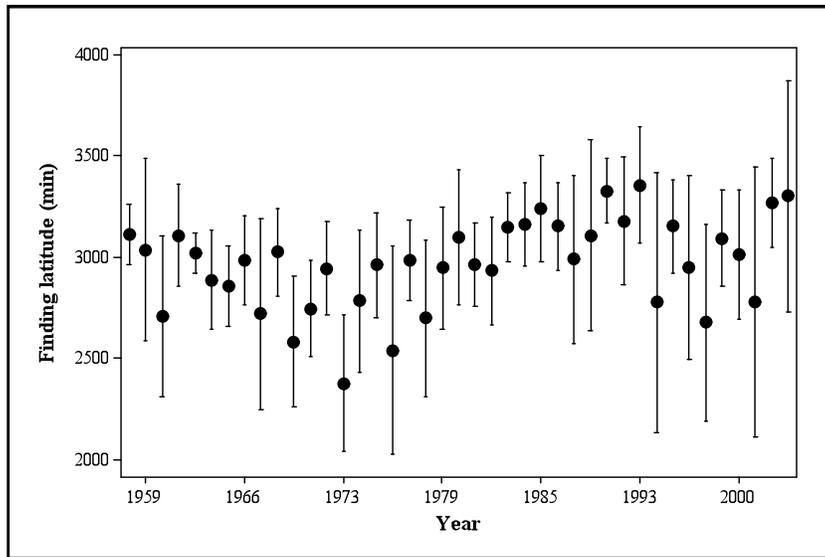
Figure 2-12. Annual mean finding latitude during non-breeding months for age class 1 individuals. Some years were not included because they presented no more than 3 recoveries.

In the case of age class 2 individuals (between 1 and 3 years old), tendencies among months were similar to those observed with individuals of age class 1 (fig. 2-13), with marked differences between months (Kruskal-Wallis; H = 38.18, DF = 8, p < 0.001).

Variations between years in the finding latitude for age class 2 individuals, in the non-breeding period were not marked (Kruskal-Wallis; H = 24.85, DF = 24, p = 0.098; fig. 2-14). One reason for the non-significance in the differences between years is the high values of standard deviations from several years (especially during the first half of the 1970's decade).
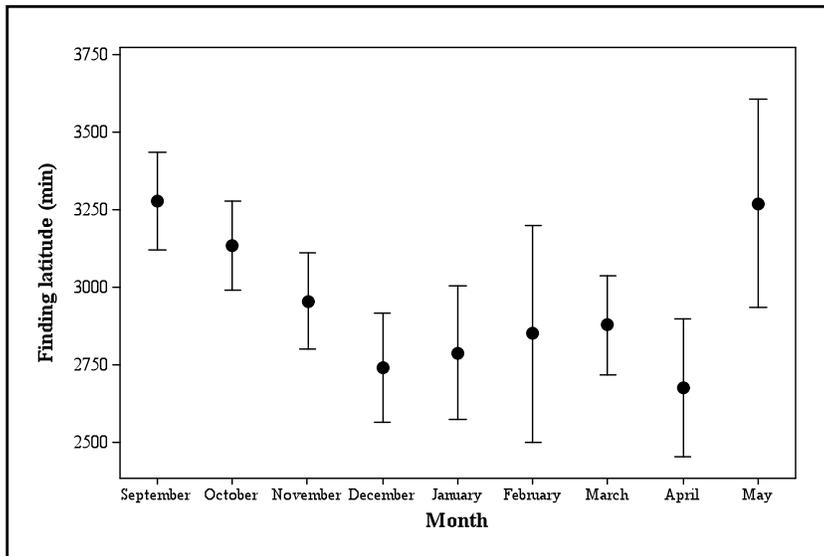
Figure 2-13. Mean finding latitude between non-breeding months for age class 2 individuals.
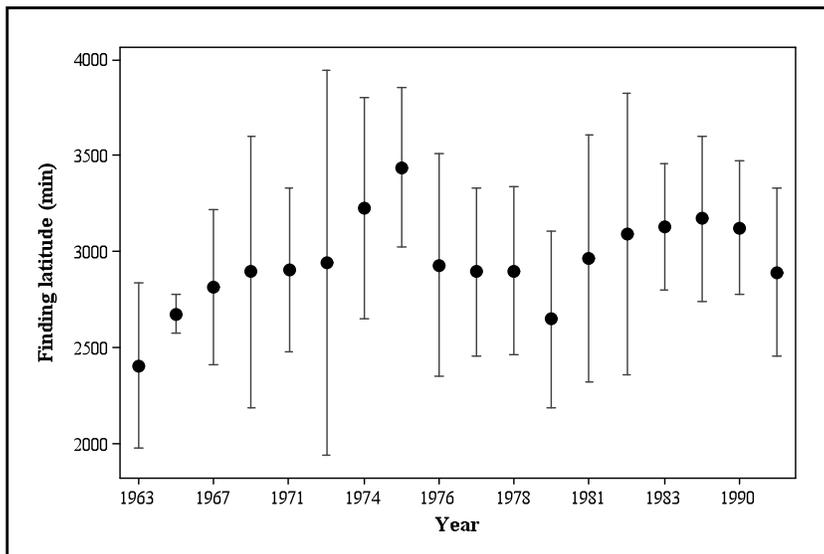
Figure 2-14. Annual mean finding latitude between non-breeding months for age class 2 individuals. Some years were not included because they presented no more than 3 recoveries.

Age class 3 individuals (more than 3 years old) showed marked differences in finding latitudes among the non-breeding months (Kruskal-Wallis; H = 286.34, DF = 8, p < 0.001). These differences consist of high finding latitudes during May, maybe because the age class includes reproductive adults attending their nests which do not migrate until their chicks fledge. On the other hand, lower latitudes were reported in February (fig. 2-15).
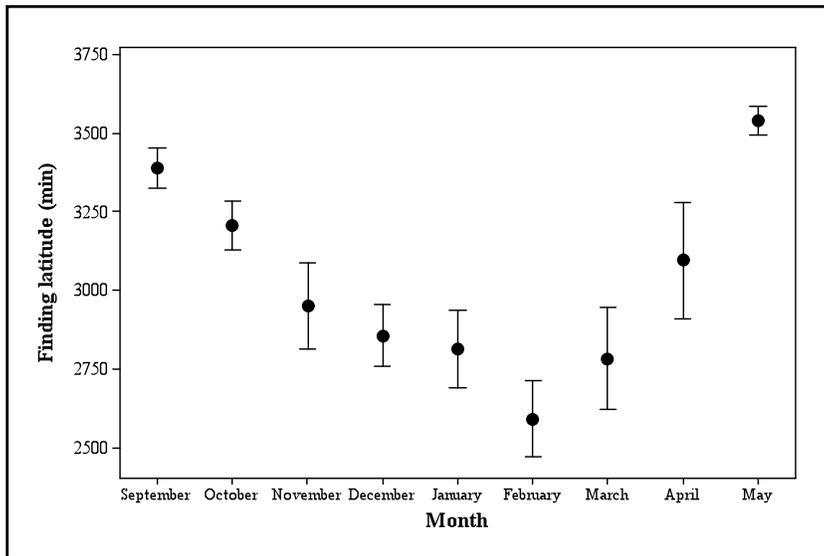
Figure 2-15. Mean finding latitude between non-breeding months for age class 3 individuals (birds more than 3 years old).

In the case of analyses between years for age class 3 birds, variations were not large but were statistically significant (Kruskal-Wallis; H = 72.45, DF = 40, p = 0.001). In contrast with age classes 1 and 2 cases, here the standard deviations were small (fig. 2-16).
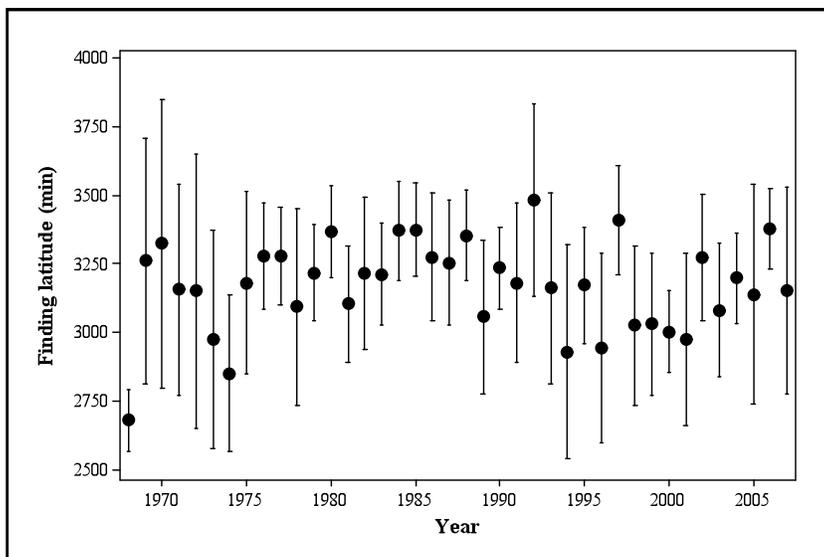
Figure 2-16. Annual mean finding latitude during non-breeding months for age class 3 individuals. Some years were not included because they presented no more than 3 recoveries.

Wintering period (December to March)

Differences between months for all individuals during the winter period (fig. 2-17) showed lowest values during February. Observed differences are statistically significant (Kruskal-Wallis; H = 15.88, DF = 3, p = 0.001). But there were no marked differences between age classes during the winter period (Kruskal-Wallis; H = 3.13, DF = 2, p = 0.209; fig. 2-18).
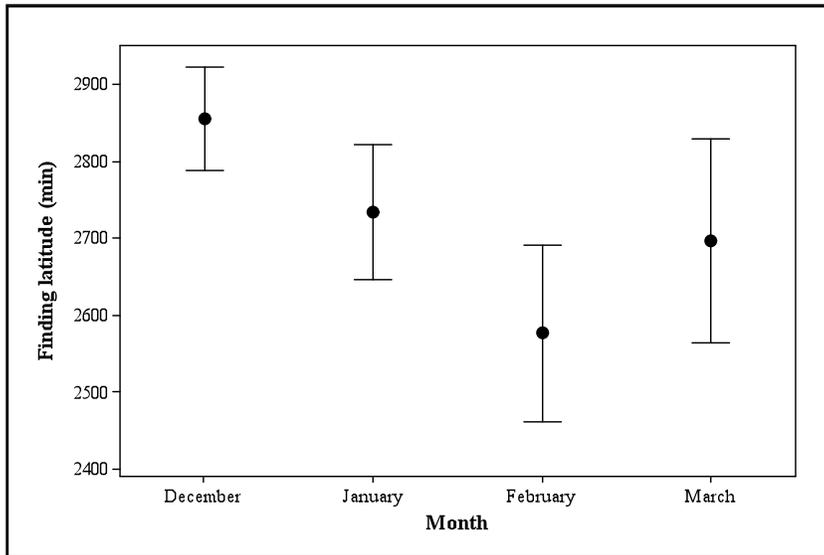
Figure 2-17. Monthly mean finding latitudes through the wintering period, including all age classes.
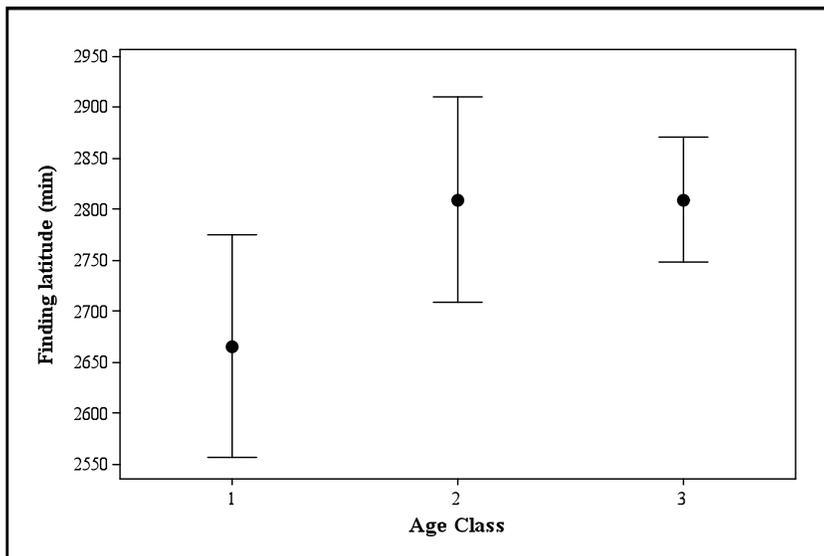
Figure 2-18. Mean finding latitudes in different age classes through the wintering period.

Differences between years were statistically significant (Kruskal-Wallis; H = 163.19, DF = 39, p > 0.001) for all individuals in the winter months. Lowest latitudes were reached during the 1960's period (fig. 2-19). Some years (from 1959 to 1961) presented high standard deviations.
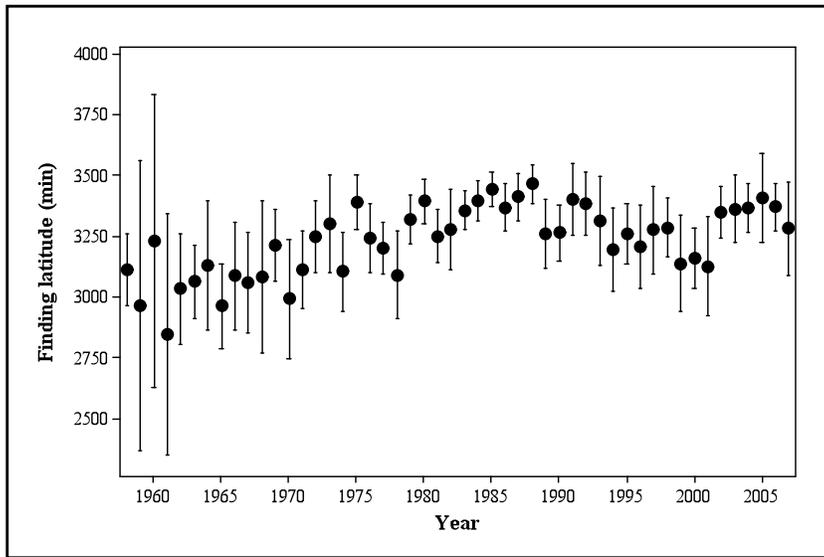
Figure 2-19. Mean finding latitudes by year considering the winter months for all individuals.

Age class 1 individuals moved to southernmost areas between February and March, during the winter months (fig. 2-20). Observed differences are statistically significant (Kruskal-Wallis; H = 9.01, DF = 3, p < 0.029).
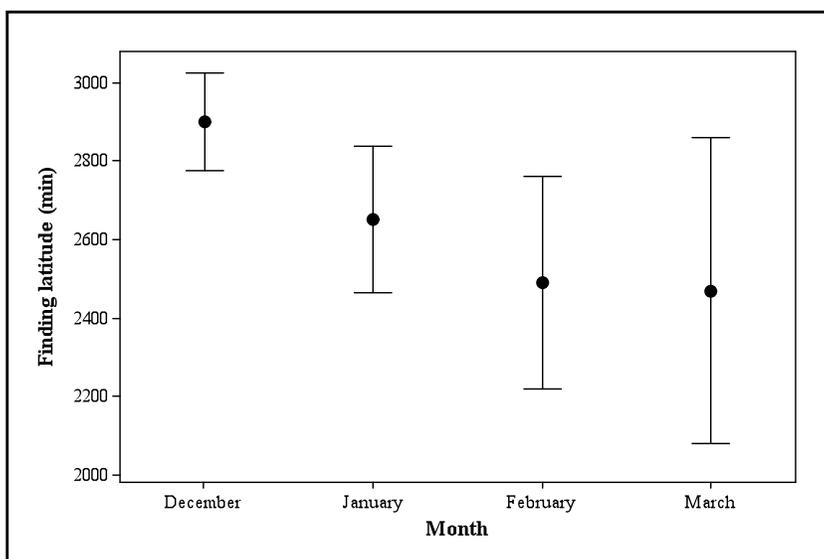
Figure 2-20. Mean finding latitudes by month, during the winter period, for age class 1 individuals.

During the 1970's period, age class 1 individuals migrated to lowest latitudes during the winter months (fig. 2-21). Because differences in latitude between years are not statistically significant (Kruskal-Wallis; H = 14.83, DF = 28, p = 0.390) there is no clear pattern or tendency, maybe due to the high standard deviation for some years.

Age class 2 individuals do not show marked differences between finding latitudes during winter months by month (Kruskal-Wallis; H = 0.96, DF = 3, p = 0.811; fig. 2-22) or by year (Kruskal-Wallis; H = 4.82, DF = 10, p = 0.186). Actually, only four years presented more than three data (fig. 2-23), so the power of this analysis is extremely low.
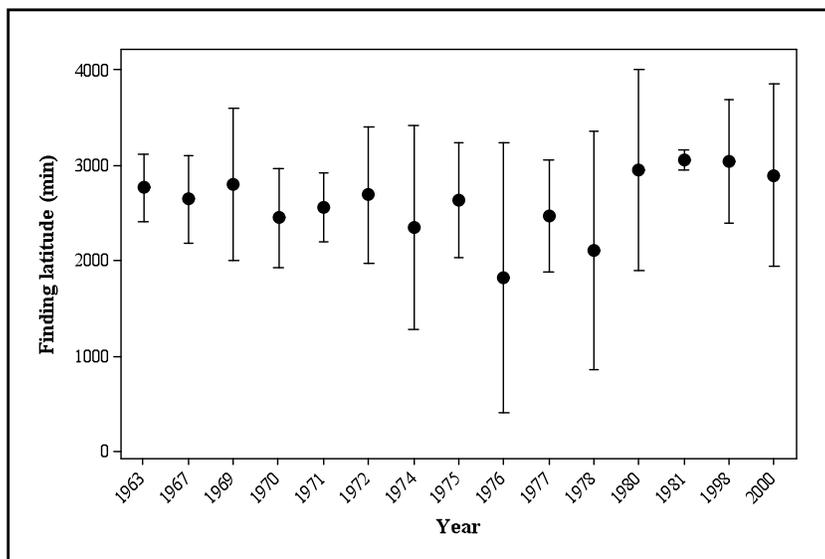
Figure 2-21. Mean finding latitudes by year, considering only the winter months, for age class 1 individuals. Some years were not included because they presented no more than 3 recoveries.
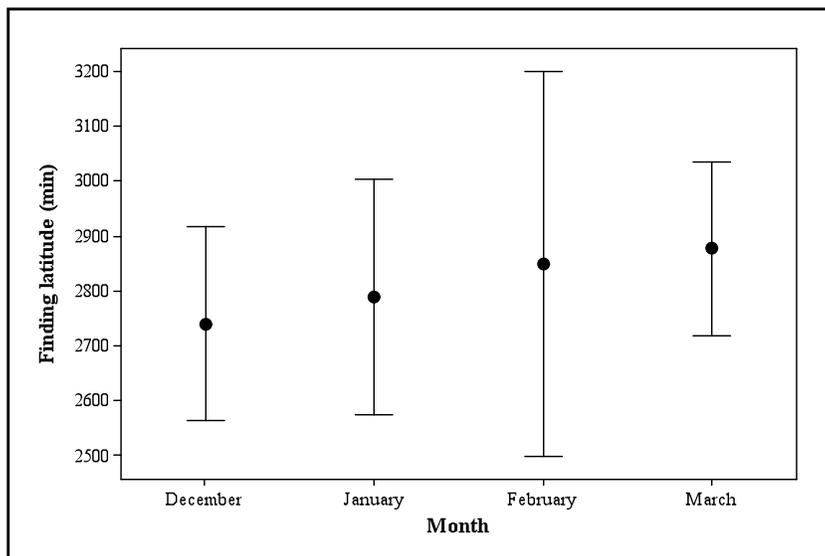
Figure 2-22. Mean finding latitudes by month, during the winter period, in age class 2 individuals.

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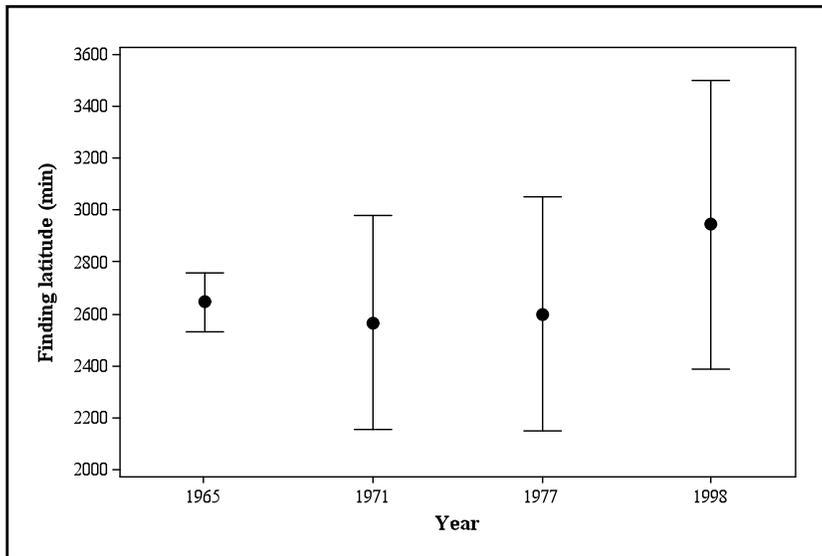
Figure 2-23. Mean finding latitudes by year, considering only the winter months, for age class 2 individuals.

Age class 3 individuals (adults) showed differences between finding latitudes during winter months by month (Kruskal-Wallis; $H = 9.71$, $DF = 3$, $p = 0.021$). February appeared as the month with the lowest finding latitudes (fig. 2-24).

In the case of the mean latitudes by year, there is a clear pattern showing periods of high mean latitudes reported, followed by a similar period with low mean latitudes (ANOVA; $F = 2.16$, $DF = 30$, $p = 0.004$; fig. 2-25). However the sample sizes are low and in some cases variances are very high.
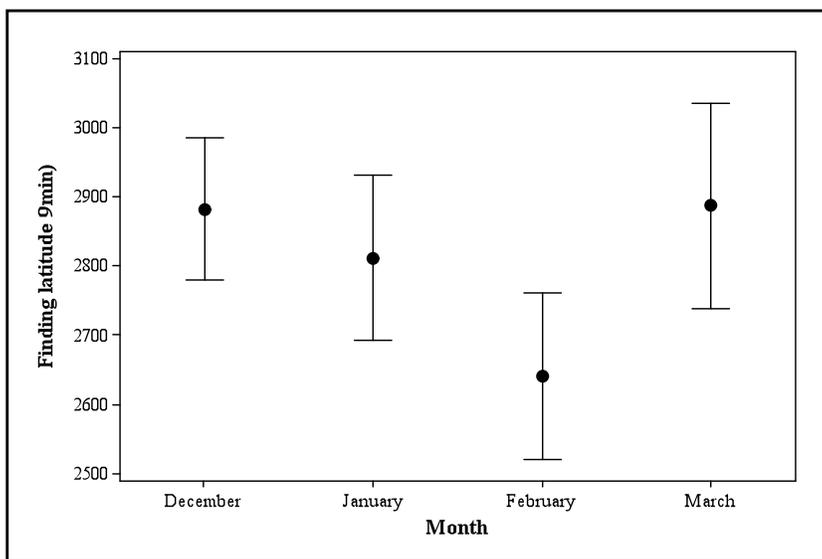
Figure 2-24. Mean finding latitudes by month, during the winter period, for age class 3 individuals.
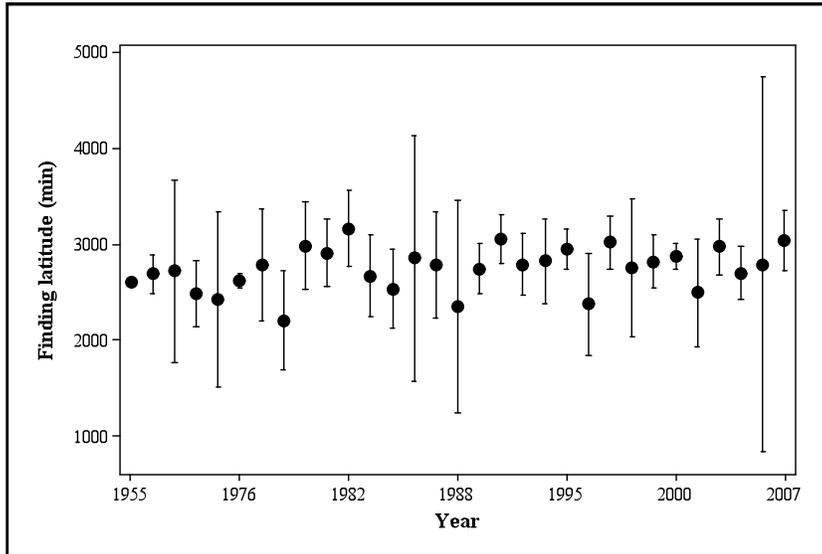
Figure 2-25. Mean finding latitudes by year, considering only the winter months, for age class 3 individuals.

Records from Africa

In order to establish the number of records, by time and age class as well, final analyses correspond to data from ring recoveries south of Gibraltar (2155 min N). 79 cases were found between 1963 and 2007.

The southernmost records correspond to individuals from age class 1, followed by those from age class 3 (fig. 2-26). During the period between 1963-1980, the number of age class 1 records were more abundant; but in recent years age class 3 occurred in increasing numbers (fig. 2-27). However, this analysis also induces samples with very small numbers of individuals.
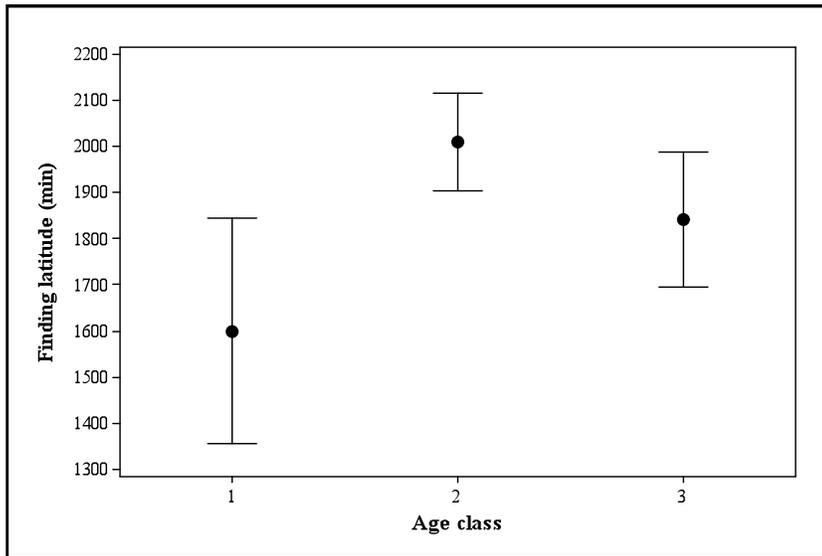
Figure 2-26. Mean finding latitudes from African records, during the period 1963-2007, for all age classes.
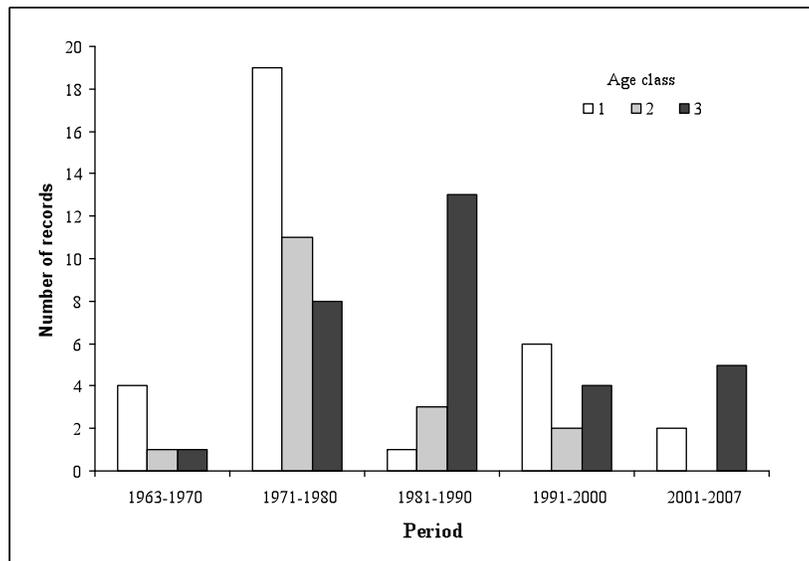
Figure 2-27. Number of ring recoveries from African latitudes by age class, during different periods of time.

Discussion

The breeding area with the most recoveries was Shetland (Table 2-III). These results accord with the literature. The largest numbers of Great Skuas nest in the Shetland Islands (Furness and Ratcliffe, 2004). In fact, most of the ringed individuals breeding in the North-eastern Atlantic and in the North Sea were ringed at Foula (Furness, 2002a).

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Great Skuas ringed in bigger breeding colonies showed the highest recovery number in the same colonies (unlike the Western Isles), supporting the idea of high philopatric behaviour in this species (Klomp and Furness, 1992).

In general, monthly migration patterns obtained accord with literature. It is well known that immature Great Skuas migrate before adults, having left the breeding areas by late July (Klomp and Furness, 1992). Because of that, age class 3 presents the highest finding latitudes during May (fig. 2-13), indicating that those individuals remain in the breeding areas, defending their territories even if they lose their eggs (Furness, 2002a). Contrasting with this, the individuals of age class 1 (fig. 2-9) and age class 2 (fig. 2-11) showed lower mean latitudes for this month. Most adults move south in August but a few may stay at the colony even later to October (Furness, 2002a). Because of that, they tend not to reach the lower latitudes until November (fig. 2-13).

Age class 1 individuals showed very large standard deviations during the period between February and March (fig. 2-9), in comparison with the rest of the non-breeding years. This could be due to the tendency of youngest immature classes to disperse widely during winter months, from South America to the high Arctic (Furness, 2002a). High standard deviations in mean latitudes by month, for the age class 3 (fig. 2-22), possibly are a result of the small number of records, especially during the winter months (Table 2-I).

Large standard deviations could be result of high variability in migration patterns among individuals (for example age class 2 individuals for winter period; figs. 2-22 and 2-23). This means that a number of individuals migrated to low latitudes; meanwhile several other individuals migrated to high latitudes, or stayed close to the breeding areas, at the same time.

The number of recoveries reported in Africa could be reduced for three main reasons: 1) lack of incentive to report ring information among local people; 2) deaths in the open ocean (individuals could be scavenging at fishing vessels and dying far from the coast), and 3) a possible high survival rate in this region (especially in adults).

However, the numbers of records of seabirds in western Africa are increasing in recent years in Great Skuas (Furness, 2002a) as well as in Common Terns (Clark *et al.* 2007). One possible

reason for this is the increasing of wintering seabird numbers migrating to this area, maybe searching for food.

Ring recovery results could be biased because of an unknown lack in the number of individuals reported in low latitudes, especially in Africa. As a result, the tendency showing higher values of mean recovery latitudes to Great Skua individuals in recent years (fig. 2-4) could be related to the lack of finding animals in tropical latitudes. In addition, the decreasing number of young Great Skuas reported in Africa, especially during the period 1971-1990 (fig. 2-27), could be related to the increasing number of individuals in higher latitudes.

On the other hand, there is an increasing proportion of adults among Great Skuas found in Africa (fig. 2-27), showing that, despite young individuals tending to travel to lower latitudes more than adults; there is some evidence of an increasing number of age class 3 individuals migrating further south. But this interpretation must be tentative, and is limited by the low numbers of adults recovered each year.

Records of Great Skua sightings off Western Africa already exist, especially during the winter months. The southernmost record of this species was one single individual sighted at Lagos, Nigeria, in January 1971 (Wallace, 1973). During February and March 1976 off coasts from Senegal and The Gambia, several Great Skua individuals were sighted and reported at densities of 0.06 to 0.01 individuals per 10 minutes, being one the commonest seabird species in the area up to the beginning of March (Brown, 1979). In May 1988 two adults and 10 immature Great Skuas were sighted at Mauritanian waters (Leopold, 1993). One individual was recorded off Senegal coast in autumn, four individuals on summer and three in April 1993 (Marr *et al.* 1998). In January 2000, 59 Great Skua individuals were observed off the coast of Western Sahara, and 165 off the coast of Mauritania (Camphuysen and van der Meer, 2005), showing that this species is a common winter migrant in the North-western coast of Africa. These observations support the idea that ring recoveries may be underreported there.

There are two opposite hypothesis explaining changes in migration patterns among Great Skuas. First, this cold-adapted species (Furness and Ratcliffe, 2004) tends to remains at high latitudes (mainly adults) especially in recent years, because global warming is promoting

suitable conditions for wintering in high latitudes. This idea is be supported by the increase in the trend of mean finding latitude during recent years (fig. 2-4).

The second hypothesis is related to the search for food in tropical latitudes because of the collapse of fisheries in the North Sea (Votier *et al.* 2004a). As a result, the proportion of Great Skua adults migrating to lower latitudes could be increasing (fig. 2-27) and visiting fishing areas in the Western coast of Africa, but ring recoveries do not clearly reflect these numbers due to absence of ring reports.

The use of data loggers, and satellite tracking devices could help to determine whether this species is migrating to tropical latitudes or whether they tend to remain close to breeding areas in the North Sea.

Chapter 3

Northern Gannet ring recovery

Abstract

Data from the BTO ring recovery scheme was used to evaluate changes in the Northern Gannet migration pattern between age classes. Analyses were made considering the entire year, the non-breeding period and only wintering months. Mean finding latitudes were high during the 1970s and 1980s decades, showing the lowest finding latitudes during the 1950s decade. A noticeable decrement in the finding latitudes is observed during the 1980s and 1990s decades. The typical annual trend shows individuals spending the spring and part of the summer in northern latitudes, moving to the south during autumn and staying in southern latitudes during the winter months. Adult gannets tend to stay closer to the breeding areas than young individuals. Nonetheless, adult recoveries from Africa increased during the 1960-2000 period, decreasing in the last decade. Data from the winter months showed adult gannets moving far south in the last years.

Introduction

By August or September Northern Gannet colonies become deserted as the immatures have begun their migration. First year Gannets disperse widely to the south as far as the Equator and into the Mediterranean Sea (Dorst, 1962), but no staying far from the Continental Shelf (Flegg, 2004). In some cases juveniles head to the north and east or west around Britain, or to the coasts of the North Sea, before to the migration to the south (Nelson, 2002). However, it has been suggested that Gannets at the Bass Rock colony are laying later in recent years, with fledging dates up to October (Hunt and Nelson, 2008), which obviously affects the timing of migration.

The most commonly used technique to track migratory movements is ring recovery. The permanent rings allow known individuals to be tracked in time and space (Marchant, 2002). Ringed animals can be followed for the entire life after rings (Clark et al. 2009), unlike electronic devices which are limited by the duration of batteries. But effectiveness of ringing depends on systematic surveys to ring and recover individuals along the entire distribution area (including the breeding and wintering zones). The BTO (British Trust of Ornithology) ringing scheme provides valuable information on Northern Gannet movements indicated by means of ring recovery, providing data related to the ringing and finding dates and latitude of

each record. With this information it is possible to calculate the age of individuals ringed as chicks, and thus assign an age class. Most Gannets are ringed as chicks.

These recoveries are reports of all ringed birds found dead, from volunteer and professional ornithologists, and members of the public as well. The BTO ring recovery data include information of recoveries from different parts of the world (Clark *et al.* 2007). In the case of Northern Gannets, many of the recovered individuals correspond to accidental captures on baited fishing lines, as well as in nets (Wanless, 2002).

The ringing of Northern Gannets began in the Bass Rock in 1904, and shows an increased number of recoveries through time. The average recovery rate is 5.9%, which is higher than that from Canadian populations or from other species of Gannets (Nelson, 2002). Due to the tendency to return to breed in the same area where they were hatched (Nelson, 1966); it is possible to determine the number of individuals dying during the migration period. Movements of Northern Gannet are continuous through the year, but there is a general migratory pattern from northern colonies in Scotland and Ireland to Iberia and western Africa (Nelson, 2002), with some individuals moving towards the Mediterranean (Mead, 1983; Nelson, 2002). Gannets are abundant winter migrants in the waters off Western Sahara and Mauritania, especially near the shelf edge (Camphuysen and van der Meer, 2005).

Materials and Methods

Using the BTO ring recovery database between 1913 and 2007, several analyses were made. In all cases years included in the analyses were those with more than three records, because years with few records tend to produce wide standard deviations.

In order to detect differences in finding latitudes between months, years and age classes, ANOVA analyses were made. In the case of non-normal distributions of the residuals, in spite of transformations of data, the non-parametric Kruskal-Wallis analysis was employed. Latitudes are expressed in minutes, and negative values correspond to recoveries south of the equator. Ages of individuals were grouped in three age classes: age class 1 (fledged up to one year old), age class 2 (individuals between 1 and 5 years old), and age class 3 (individuals 6

years old and older). Age class 3 includes adults and age class 1 includes juveniles in their first migration journey.

The recovery data are difficult to interpret because the Gannet has a prolonged breeding season. Adults could attend colonies from December-January to November, with chicks fledging between August and October (Wanless, 2002). Because of that, the analyses related to ring recovery were made for all months of the year, and then again separately for non-breeding months (September to May; Wanless, 2002) and winter months (December to March).

Results

The number of ringed birds, indicating the number of those ringed as chicks, and the number of chicks recovered the same year of ringing, are presented in Table 3-I. Numbers of records by year for the whole year, and for the three age classes for non-breeding or wintering months as well, are presented in Table 3-II.

Table 3-I. Number of ringed birds and chicks by year, number of birds recovered the same year and survival.

Year	Number of ringed birds recovered	Number of ringed chicks recovered	Number of ringed chicks recovered the same year	Percent recovered after 1 year of age
1913	7	4	4	0
1914	5	5	4	20
1921	1	1	0	100
1923	5	5	3	40
1924	9	9	5	44.4
1926	7	7	3	57.1
1927	4	4	3	25
1931	1	1	1	0
1933	10	6	2	66.6
1934	93	85	40	52.9
1935	31	30	16	46.6
1936	12	9	5	44.4
1937	30	30	17	43.3
1938	82	77	59	23.3
1939	44	40	23	42.5
1940	3	0	0	0
1945	13	7	3	57.1
1946	45	32	15	53.1
1947	44	29	6	79.3

1948	23	23	12	47.8
1949	32	31	22	29
1950	15	14	8	42.8
1951	22	22	13	40.9
1952	19	12	5	58.3
1953	18	17	6	64.7
1954	51	50	28	44
1955	59	52	25	51.9
1956	40	36	13	63.8
1957	89	85	27	68.2
1958	43	33	14	57.5
1959	63	51	23	54.9
1960	57	48	8	83.3
1961	172	167	89	46.7
1962	161	152	36	76.3
1963	223	222	89	59.9
1964	63	61	11	81.9
1965	118	114	33	71
1966	206	195	60	69.2
1967	29	28	6	78.5
1968	165	165	36	78.1
1969	85	81	24	70.3
1970	109	98	26	73.4
1971	74	69	9	86.9
1972	47	44	17	61.3
1973	37	36	13	63.8
1974	70	70	27	61.4
1975	68	64	15	76.5
1976	41	41	10	75.6
1977	40	37	6	83.7
1978	25	25	5	80
1979	45	42	7	83.3
1980	26	25	7	72
1981	53	50	8	84
1982	43	41	5	87.8
1983	35	35	6	82.8
1984	77	75	13	82.6
1985	124	120	34	71.6
1986	137	124	20	83.8
1987	133	125	25	80
1988	113	104	27	74
1989	48	46	8	82.6
1990	77	70	13	81.4
1991	72	71	14	80.2
1992	48	48	11	77
1993	46	46	14	69.5
1994	29	24	1	95.8
1995	53	53	10	81.1
1996	32	32	11	65.6
1997	47	45	9	80
1998	18	16	5	68.7
1999	35	32	9	71.8
2000	35	35	15	57.1
2001	26	26	11	57.6

2002	29	29	8	72.4
2003	17	16	6	62.5
2004	6	4	3	25
2005	19	18	14	22.2

Table 3-II. Annual ring recoveries by age class, for each year with all months included, and for non-breeding or winter months only.

Year	All year Age Classes			September-May Age Classes			Winter Age Classes		
	1	2	3	1	2	3	1	2	3
1913	4	1		4					
1914	4			4			1		
1916		1	1			1			1
1917			1			1			1
1923	3			3					
1924	6	1		6	1				
1925		3			3			1	
1926	3	1		3					
1927	3	3		3	2			1	
1928		2			1			1	
1929		1							
1931	1			1					
1932			1			1			
1933	2			1					
1934	40	4		30	3		1	1	
1935	26	22		25	18		10	4	
1936	7	14	2	7	10	2	3	9	2
1937	18	8	2	15	6	2	2	6	1
1938	59	14		54	11		8	6	
1939	29	17		22	11		1	5	
1940	3	5	1	3	3	1	3	3	
1941		5			3			1	
1942		3			2			2	
1943		5	2		2	1		2	
1944		1	2			2			
1945	3	2	1	3	2	1			
1946	15	1	2	14	1	2			1
1947	6	7	3	5	5	2	1	3	1
1948	16	23	3	16	13	2	5	3	2
1949	23	15	1	21	10	1	2		1
1950	11	10	3	6	7	3	1	4	3
1951	13	8	3	13	6	3	2	4	2
1952	6	8	4	6	7	4	1	3	2
1953	7	5	3	5	3	1		1	1
1954	28	12	1	28	8		3	3	
1955	24	11	3	18	9	2	2	3	2
1956	16	11	2	14	7	2	5	3	1
1957	24	13	1	18	12	1	3	3	1
1958	16	17	3	12	13	3	1	6	2
1959	23	23	2	17	16	1	5	7	1
1960	7	15	1	7	10	1		4	

Year									
1961	77	22	5	72	13	3	9	2	2
1962	39	15	5	35	13	2	7	6	1
1963	87	30	5	82	22	3	10	7	
1964	16	20		15	15		5	6	
1965	30	27	7	28	19	7	5	4	6
1966	51	31	6	45	22	4	3	11	1
1967	12	30	15	12	24	11	3	8	5
1968	29	24	18	22	18	12	1	12	5
1969	23	28	23	20	23	19	1	7	8
1970	24	31	18	20	21	12		3	2
1971	11	24	17	10	15	12	2	6	5
1972	16	16	15	16	14	15	1	6	7
1973	14	22	15	11	20	10	1	9	4
1974	25	19	14	20	11	8	1	3	3
1975	17	8	25	13	4	20	1	2	11
1976	8	14	19	5	8	13	1	7	8
1977	4	10	30	4	5	19	1	2	10
1978	6	13	33	4	10	24	3	5	7
1979	6	7	29	1	5	24		3	12
1980	9	12	35	8	9	29	2	4	12
1981	8	13	35	6	9	30		3	16
1982	7	7	24	6	5	20	2	1	12
1983	7	7	20	3	4	20	1	1	9
1984	11	8	29	8	5	19	2	2	12
1985	32	18	36	27	8	26	1	1	10
1986	24	29	24	19	17	17	3	5	10
1987	23	32	21	20	14	14	2	2	8
1988	26	23	18	22	14	11	2	3	6
1989	8	39	18	6	26	13	2	5	7
1990	15	31	35	10	21	31	4	7	16
1991	17	36	30	14	25	20	1	9	5
1992	11	24	21	9	17	15	2	2	6
1993	16	26	32	14	19	22	2	6	10
1994	4	18	37	3	6	29	1	2	15
1995	11	17	31	6	14	21		10	9
1996	12	20	33	8	13	17		3	5
1997	10	11	42	6	8	30		3	12
1998	6	24	28	5	19	26	1	6	13
1999	11	15	25	8	7	16	1	3	3
2000	15	16	32	9	12	23	1	4	10
2001	14	11	35	8	10	24	2	4	8
2002	10	22	28	9	14	22	2	4	14
2003	9	14	24	5	10	18	1	4	11
2004	5	16	20	5	11	18	2	2	3
2005	14	4	22	8	2	15			6
2006	2	12	25	2	9	19		2	4
2007		1	12		1	10			6

The periods of time with the highest numbers of ringed chicks recovered were between 1960 and 1970, and between 1985 and 1990 (fig. 3-1). From 1980 to 1997 the percentages

recovered after the first year of life were high, with a large decrease in the following years (fig. 3-2).
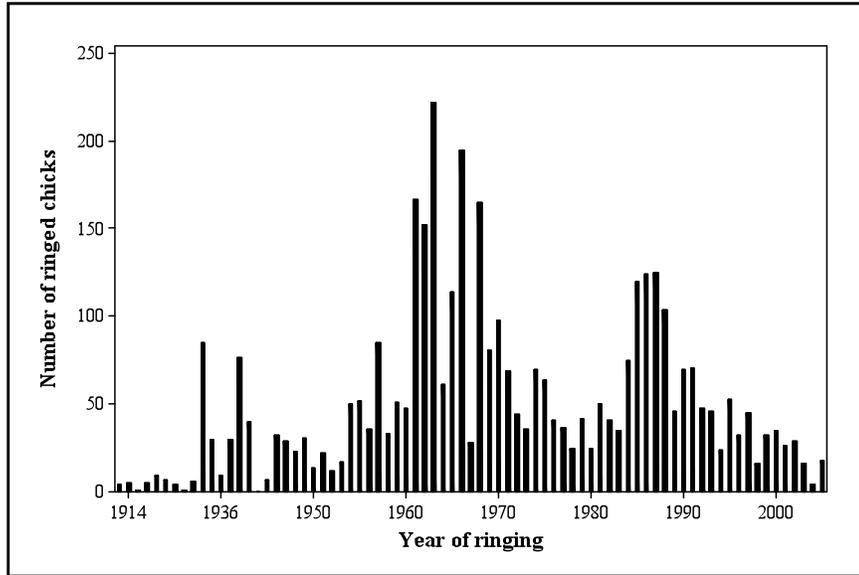
Figure 3-1. Number of recovered Northern Gannet chicks ringed by year.
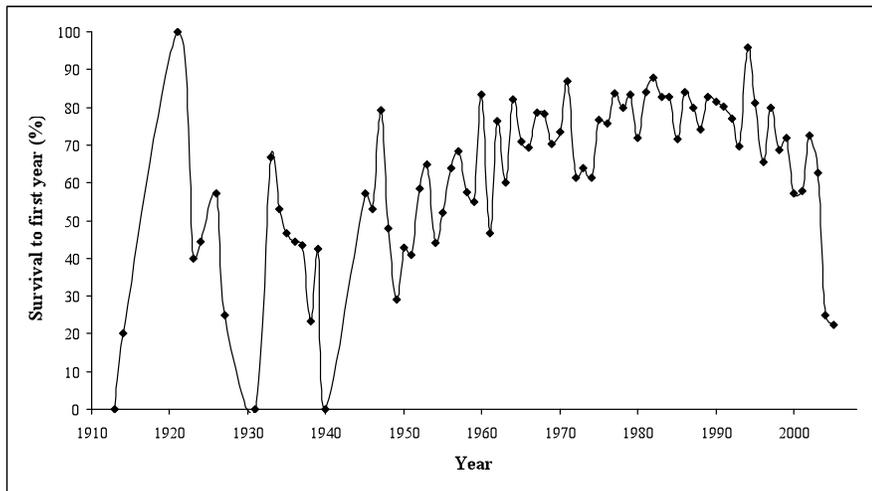
Figure 3-2. Percentage of Northern Gannet chicks recovered after their first year during the period 1913-2005.

Most of the recoveries of individuals were made in British, French and Spanish waters, and originate mainly from the Bass Rock (Lothian), and Ailsa Craig (Strathclyde) breeding areas (Table 3-III). The numbers of ring recoveries by country, and by ringing area, are presented in Table 3-III, with detailed description of finding locations in maps (fig. 3-3a-d).

Table 3-III. Number of ring recoveries by country for each breeding colony, including all the data for the entire period.

Breeding colonies

Finding country	Channel Islands	Ireland	Bass Rock Lothian Region	Rest of Great Britain	Ailsa Craig Strathclyde Region
Algeria		6	9	5	5
Azores			1		
Belgium			17	4	1
Ceuta					2
Channel Islands			7	2	1
Denmark		5	59		7
Faeroe Islands		2	2	3	2
Finland		1		1	
France		119	211	136	110
Germany		20	44	4	6
Gibraltar			1		
Great Britain	88	91	481	390	120
Guinea Bissau					1
Iceland			3		
Ireland	5	142	24	37	52
Israel		2		1	
Italy		3	5	3	4
Ivory Coast		1			
Libya				1	
Lothian Region		1	171	3	3
Malta			1	1	
Mauritania		4	19	10	13
Morocco		36	62	27	50
North Atlantic			4	17	4
Norway		1	31	10	5
Orkney-Shetland		3	17		6
Portugal		41	93	32	51
Russia			1		
Senegal		17	14	10	9
Spain		78	124	121	72
Strathclyde Region		5	8	1	221
Sweden		1	9		3
The Netherlands		11	107	14	11
Tunisia					2
Turkey			1		
Western Mediterranean			1	1	1
Western Sahara		18	17	13	15

Ringed in Ireland
608 records

Figure 3-3a. Number of rings recovered of Northern Gannet individuals, ringed in Ireland, in different areas of the Atlantic Ocean. White numbers correspond to areas with the biggest numbers.

Ringed at Bass Rock
Lothian Region
1544 records
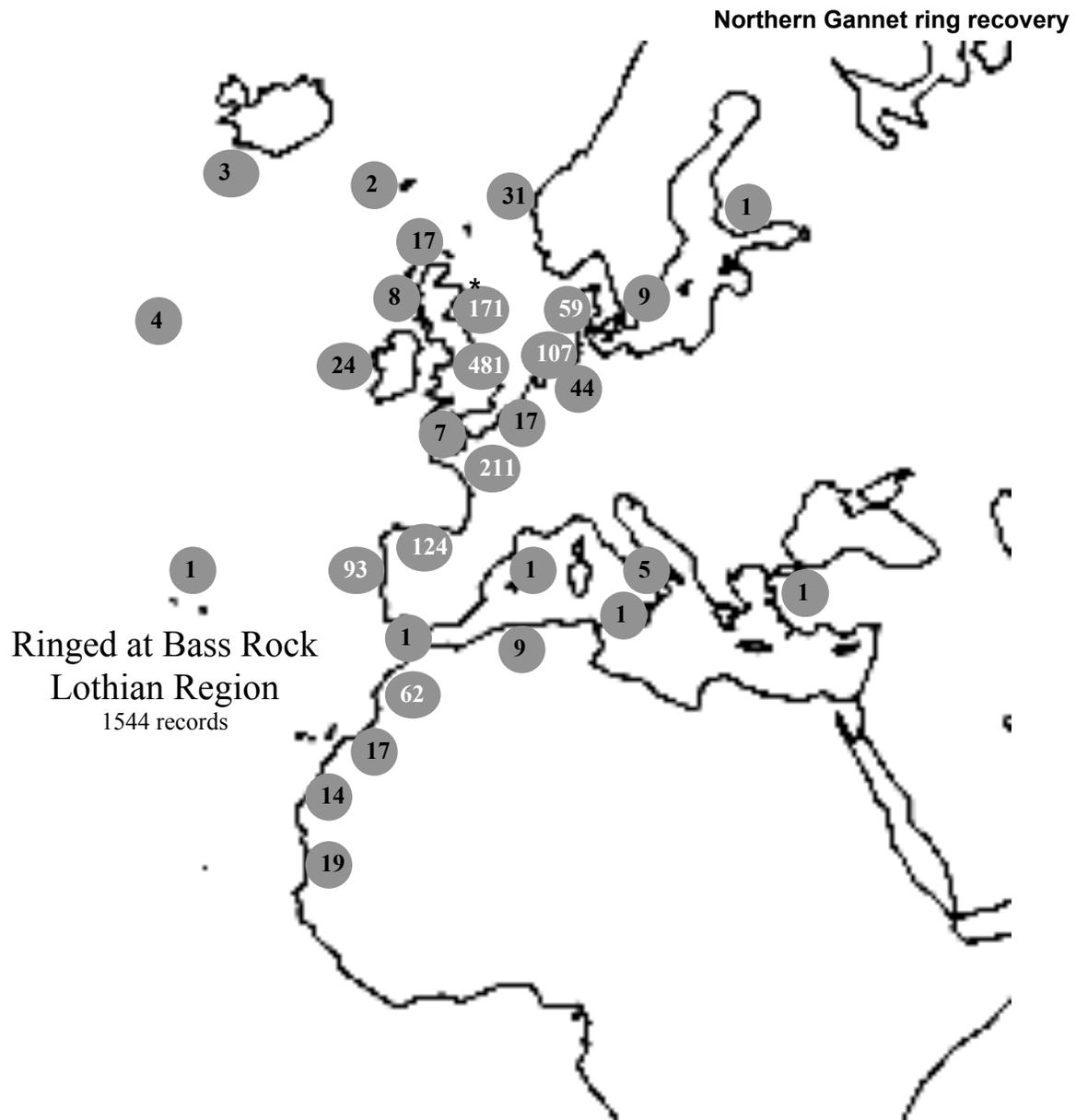
Figure 3-3b. Number of rings recovered of Northern Gannet individuals, ringed at the Bass Rock, Lothian Region, in different areas of the Atlantic Ocean. White numbers correspond to areas with the biggest numbers.

3   10   1

17

1   3

37   *   390   14

4

2   4

136

121

32

1   3

1

Ringed elsewhere in
Great Britain

Not including Shetland, Orkney,
Lothian, Strathclyde,
847 records

5

27

1

13

10

10

1

Figure 3-3c. Number of rings recovered of Northern Gannet individuals, ringed in other areas of Great Britain, in different areas in the Atlantic Ocean. White numbers correspond to areas with the biggest numbers.

Ringed at Ailsa Craig
Strathclyde Region
777 records
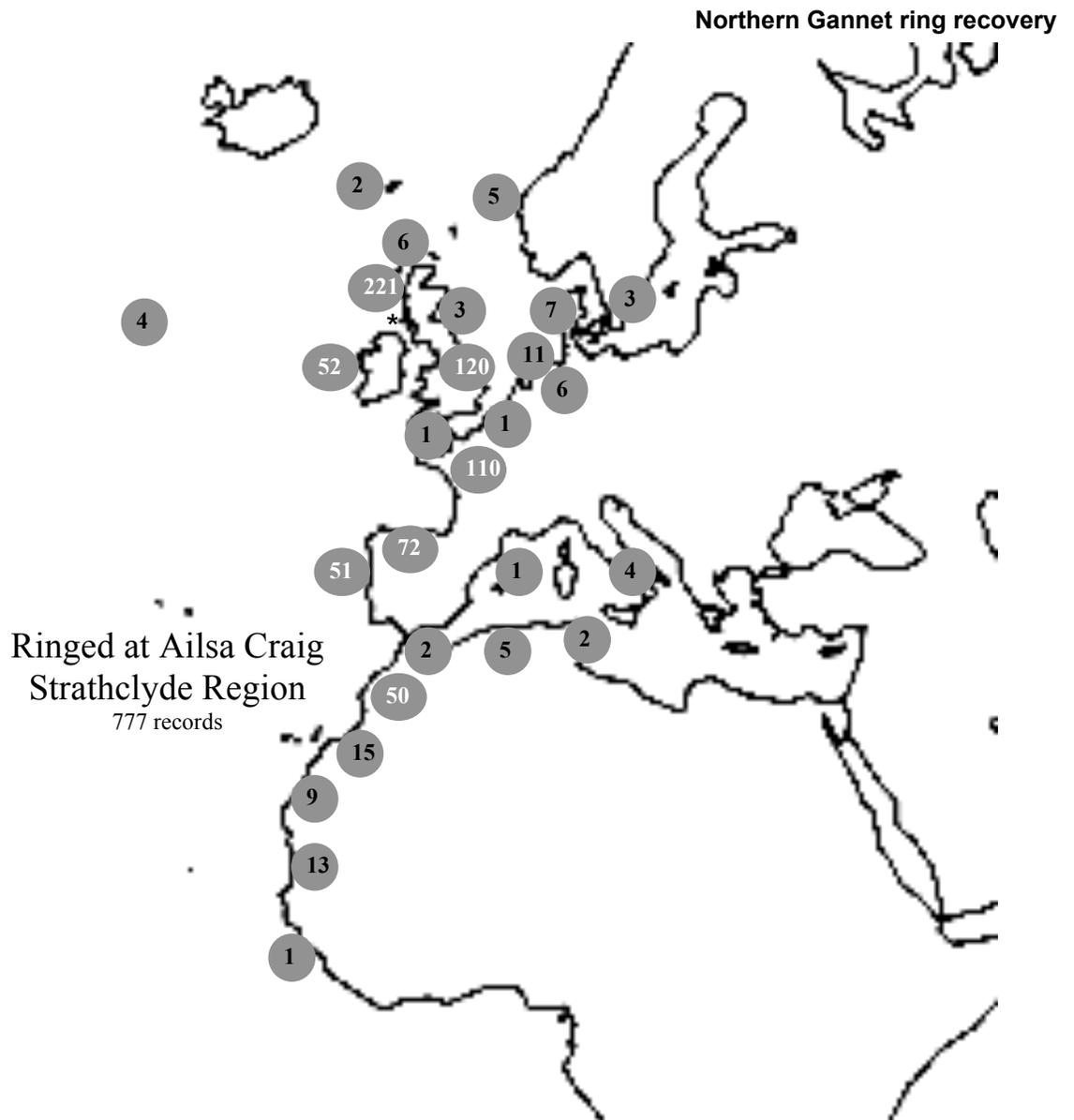
Figure 3-3d. Number of rings recovered of Northern Gannet individuals, ringed at Ailsa Craig, Strathclyde Region, in different areas of the Atlantic Ocean. White numbers correspond to areas with the biggest numbers.

For the period between 1934 and 2007 one graph of time series analysis and the trend, related to the mean finding latitude, was made. During the years between 1930 and 1970, values oscillated between high and low values (from 2600 min to 3200 min), while higher values appeared between 1975 and 1985 (fig. 3-4). Trends in recent years maintain fairly consistent values just under 2900 min of finding latitude with occasional higher peaks (fig. 3-4).
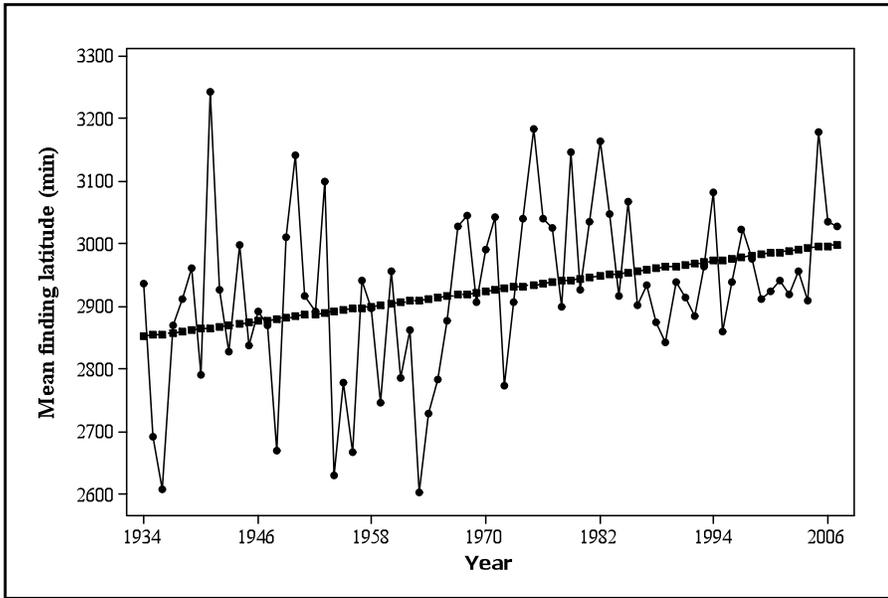
Figure 3-4. Time series analysis and trend line, for the mean finding latitude by year.

All year analyses

Major differences between ringing and finding latitudes are found in November and December, followed by January and February (fig. 3-5). This means that during these months the Gannets are wintering furthest south. On the other hand, from April to August individuals tend to stay close to their breeding areas in northern latitudes. These trends accord with the nest attendance by adults, and are statistically significant differences (Kruskal-Wallis; H = 617.13, DF = 11, p < 0.0001).
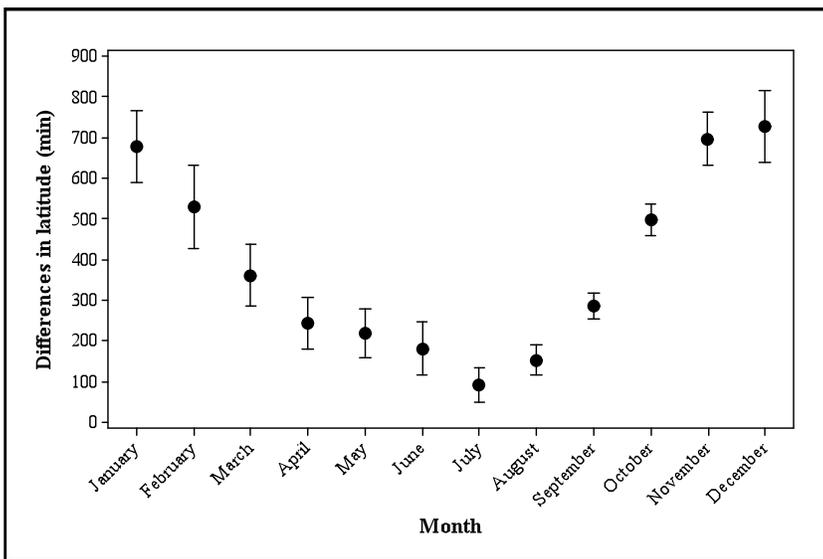
Figure 3-5. Mean differences between ringing and finding latitudes for the all months of the year.

Differences in latitudes between years are fairly similar for the whole period of time (1913-2007), but with higher values between 1955 and 1965 (fig. 3-6). In the last 20 years there is a slight trend to lower differences, maybe due to a high proportion of ring recoveries near the breeding colonies (Kruskal-Wallis; H = 234.34, DF = 79, p =<0.0001).
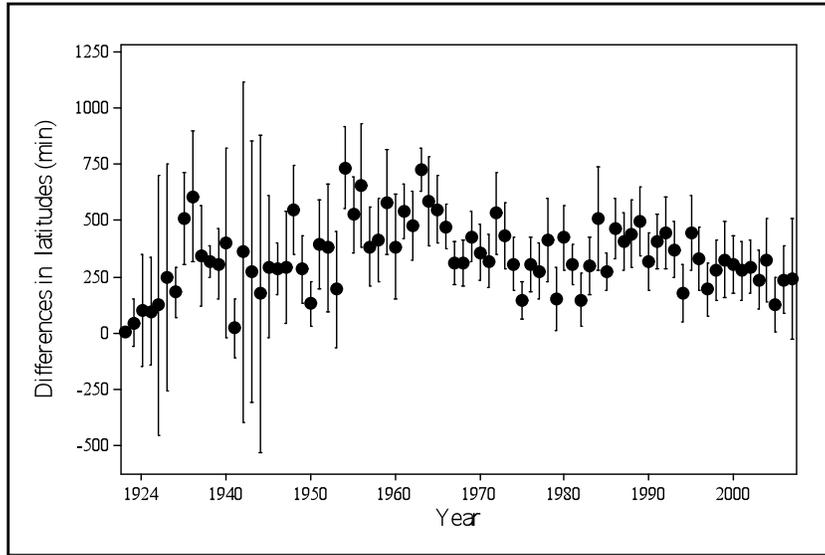
Figure 3-6. Mean differences between ringing and finding latitudes for the years 1913-2007.
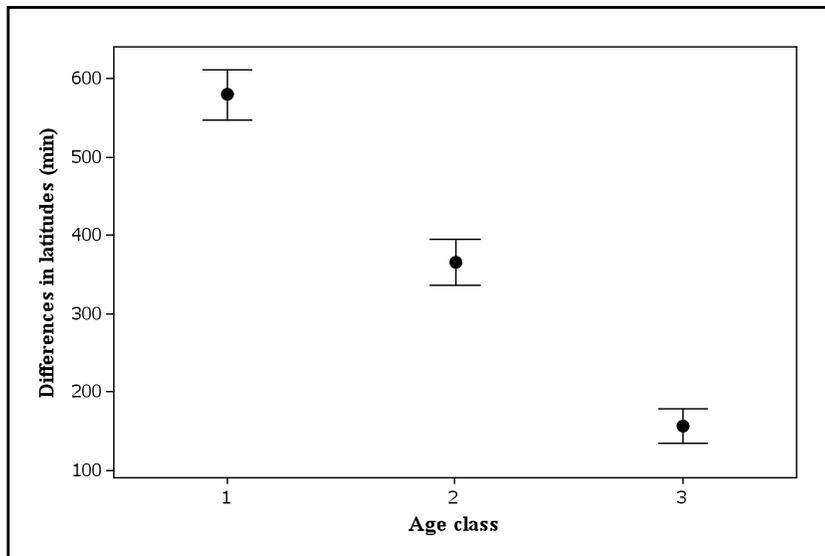
Figure 3-7. Mean differences between ringing and finding latitudes among age classes for all months of the year.

Higher differences between ringing and finding latitudes were found in age class 1 individuals (fig. 3-7), compared with differences observed among age class 3 individuals (Kruskal-Wallis; H = 363.04, DF = 2, p < 0.001).

Monthly mean finding latitudes in Age class 1 individuals show three different periods. They tend to stay at high latitudes (near the colonies) in June-October. During the periods from March to May, and November to December, movements to mid latitudes (around 2300 min N) take place. Differences in latitudes are statistically significant (Kruskal-Wallis; H = 307.16, DF = 11, p =<0.0001). Southernmost movements are observed in January and February (fig. 3-8).
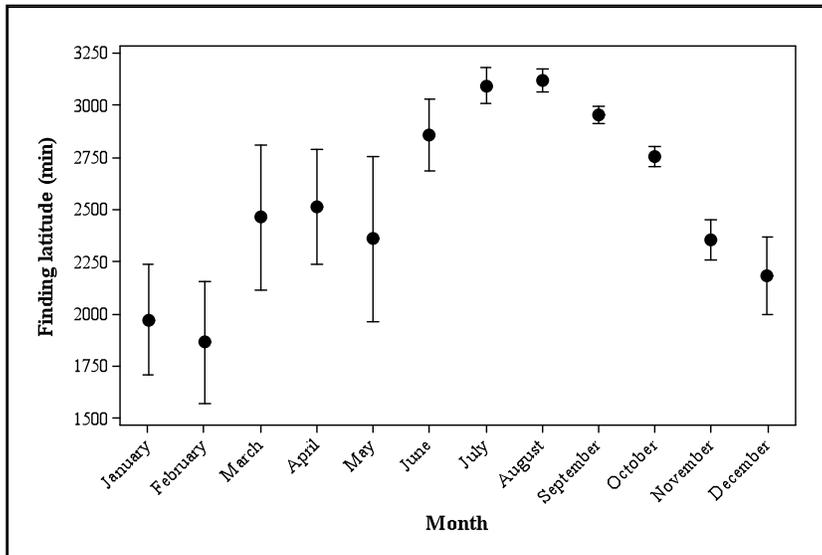
Figure 3-8. Mean finding latitudes for age class 1 Gannets, through the year.

Finding latitudes from age class 1 individuals are similar between years, with lower latitudes reached in recent years (Kruskal-Wallis; H = 213.46, DF = 61, p < 0.001; fig. 3-9). In the last 30 years higher standard deviations are noted, maybe due to an increasing number of individuals migrating to far south latitudes, and far north as well.
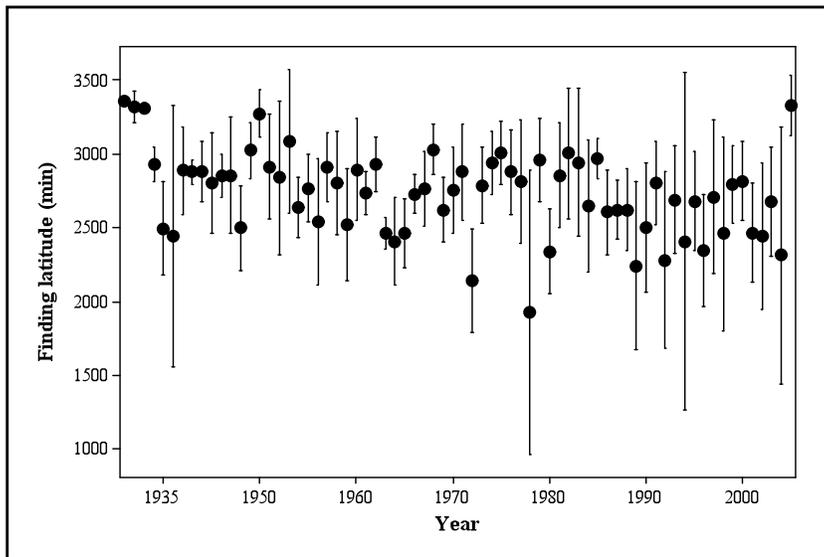
Figure 3-9. Annual mean finding latitudes for age class 1 Gannets.

The age class 2 individuals stay at high latitudes between April and October, and spend the rest of the year moving to low latitudes (fig. 3-10). The differences in latitudes among months is clear and statistically significant (Kruskal-Wallis; H = 181.41, DF = 11, p < 0.0001). Differences between years are not statistically significant (Kruskal-Wallis; H = 77.71, DF = 68, p = 0.197; fig. 3-11).
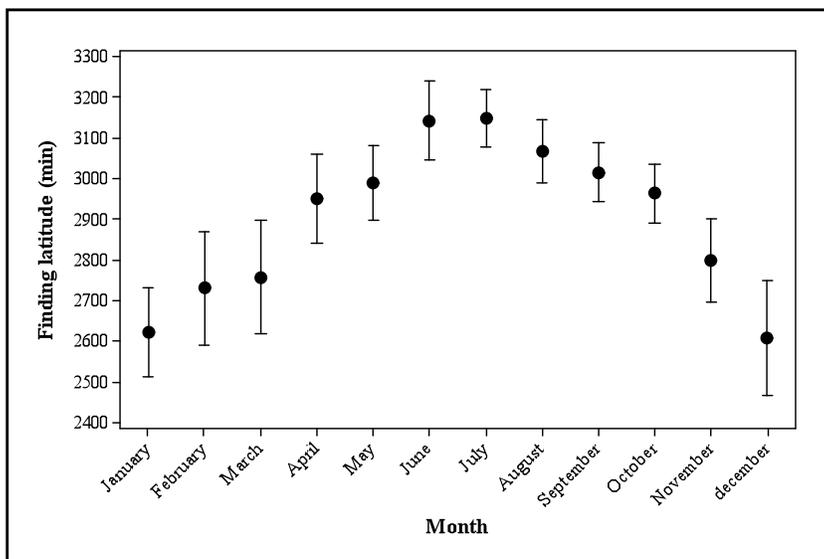
Figure 3-10. Mean finding latitudes for age class 2 Gannets.
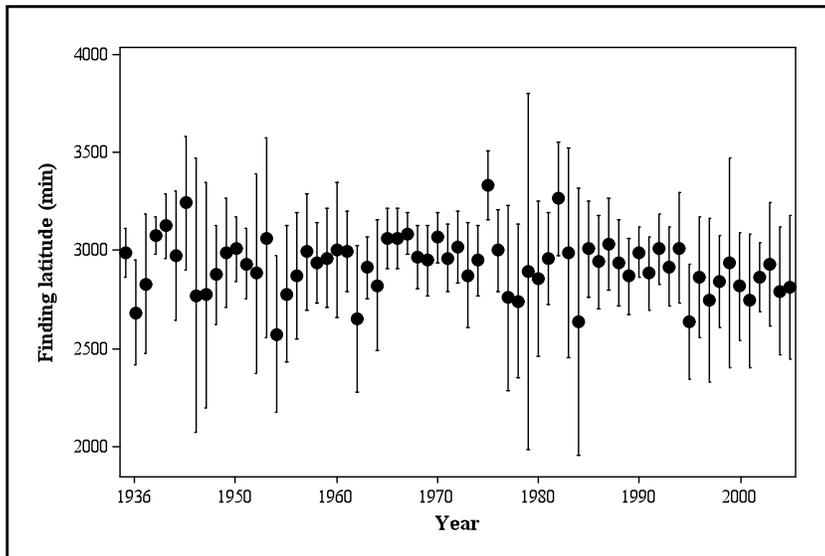
Figure 3-11. Annual mean finding latitudes for age class 2 individuals.

In the case of age class 3 Gannets, monthly mean finding latitudes shows three clear groups (fig. 3-12). From April to September, values are high (around 3200 min N), from February to March values are intermediate, whilst lower latitude values appear from October to January. The differences are clear and statistically significant (Kruskal-Wallis; H = 197.29, DF = 11, p <0.0001).
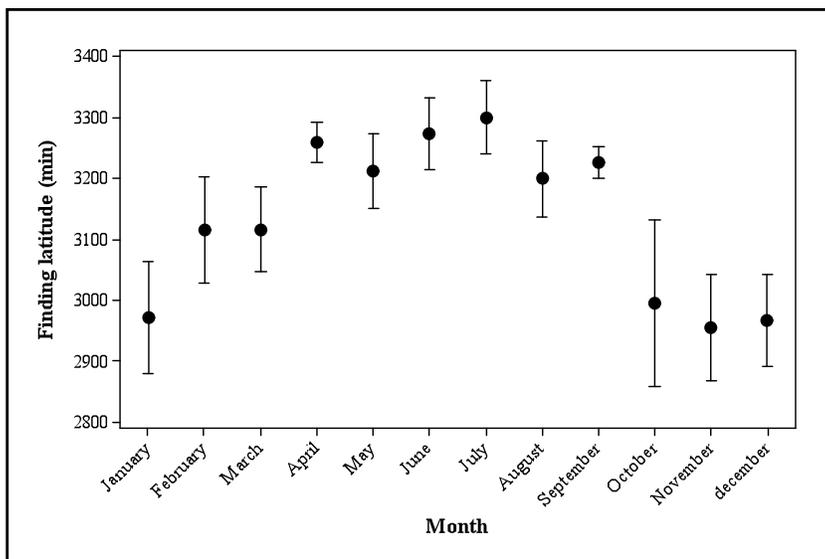
Figure 3-12. Mean finding latitudes for age class 3 individuals.

Age class 3 individuals show similar mean finding latitudes by year, but with a slight tendency to reach lower latitudes in recent years (Kruskal-Wallis; H = 77.8, DF = 45, p = 0.002; fig. 3-13).
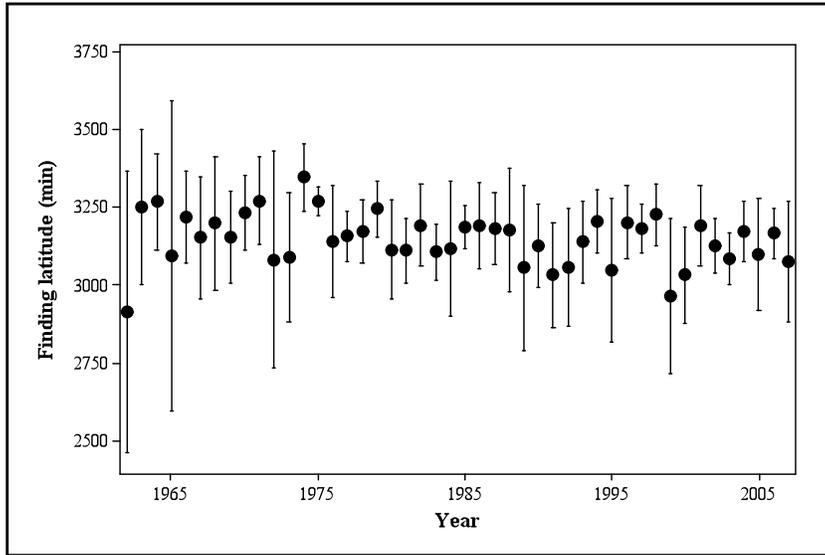
Figure 3-13. Annual mean finding latitudes for age class 3.

Non-breeding period (September to May)

Monthly mean finding latitudes, including all the individuals, shows months November, December and January having the lower latitude recoveries (fig. 3-14). April and May are the months with higher latitudes. In accordance with this, Northern Gannets tend to migrate furthest southern during the winter months. The movements to wintering areas occur from September to October, and the return movements are in February and March (fig. 3-14). Differences between non-breeding months are statistically significant (Kruskal-Wallis; H = 273.8, DF = 8, p < 0.001).
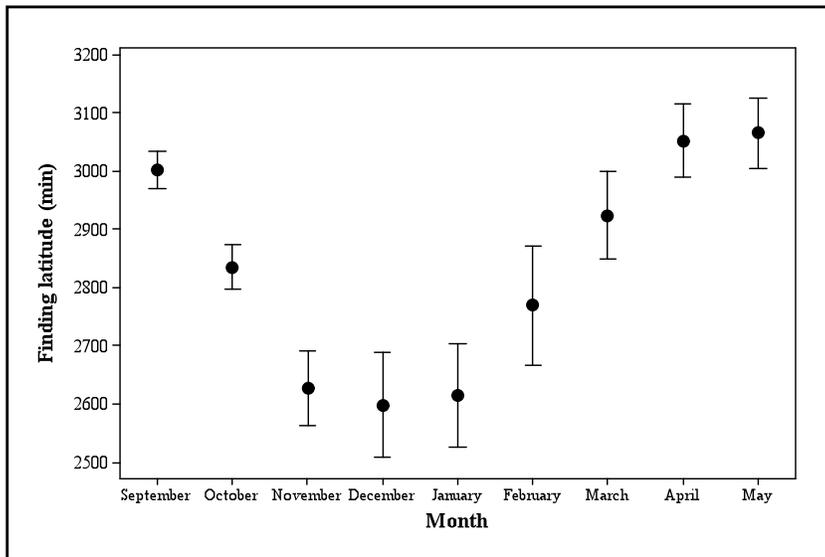
Figure 3-14. Monthly mean finding latitudes during the non-breeding period.

Annual mean finding latitudes were low during several years in the period between 1930 and 1965, and high between 1975 and 1985, and between 1950 and 1955 (fig. 3-15). Despite the high standard deviations in some years, differences are marked and significant (Kruskal-Wallis; $H = 208.4$, $DF = 74$, $P < 0.001$).
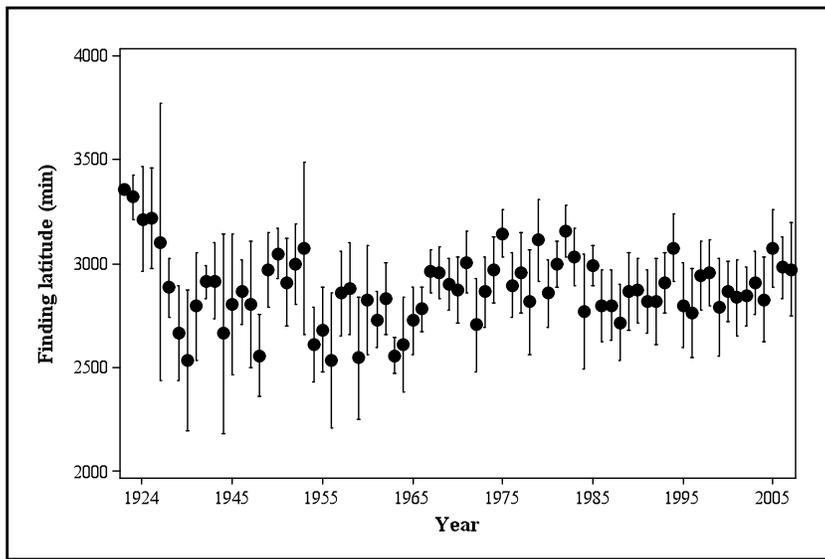
Figure 3-15. Mean finding latitudes by year. Data within years include only the non-breeding months.

The mean finding latitudes between age classes show statistically significant differences (ANOVA, F = 166.96, DF = 2, p = 0.001), with age class 1 individuals migrating to southernmost areas, followed by age class 2 individuals (fig. 3-16).
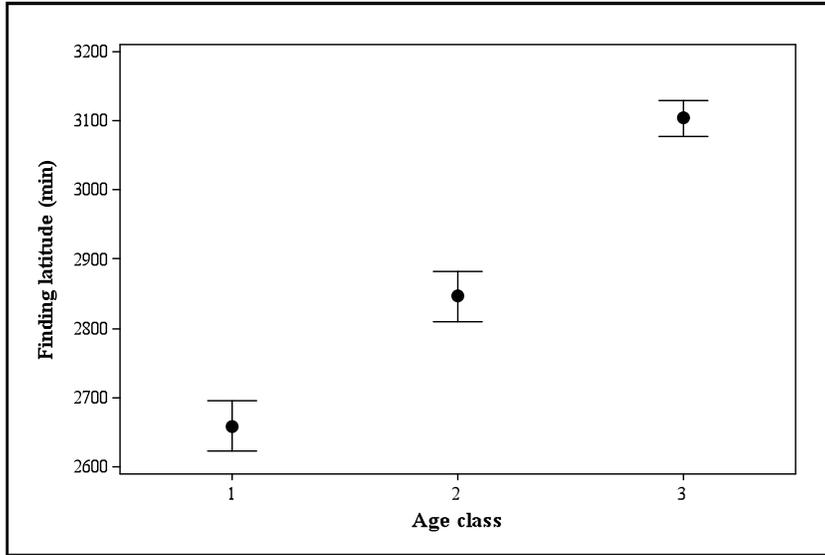
Figure 3-16. Mean finding latitudes by age class during the non-breeding months.

In the case of the individuals from age class 1, far south movements appeared in November to February (fig. 3-17). Monthly differences in mean latitudes are significant (Kruskal-Wallis; H = 211.88, DF = 8, p < 0.001).
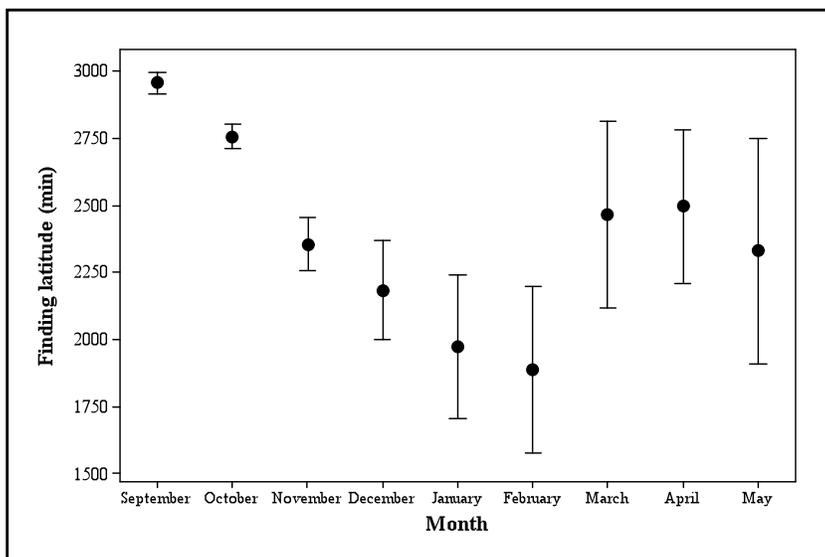
Figure 3-17. Monthly mean finding latitudes for individuals from age class 1.

In the same way, finding latitudes between years showed marked differences for age class 1 individuals, in the case of non-breeding months (Kruskal-Wallis; H = 195.99, DF = 66, P < 0.001; fig. 3-18).
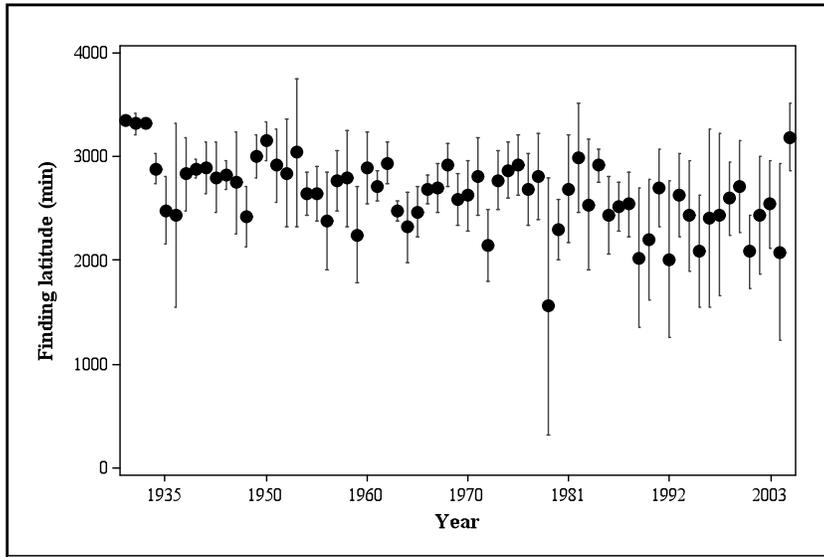
Figure 3-18. Mean finding latitudes for individuals from age class 1.

Age class 2 individuals migrated to similar high latitudes before autumn migration (September-October), and in spring (April-May), moving to low latitudes (below 2800 min) from November to March (fig. 3-19). Finding latitudes from the non-breeding months, showed statistically significant differences (ANOVA; F = 9.92, DF = 8, p < 0.001).
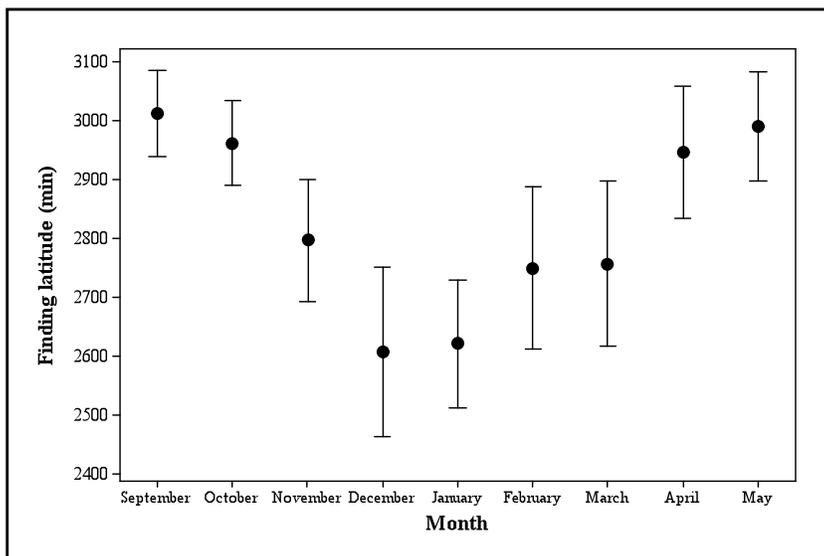
Figure 3-19. Monthly mean finding latitudes for individuals from age class 2 in the non-breeding period.

In case of the finding latitudes in the non-breeding months between years, from age class 2 individuals, there is no clear tendency (fig. 3-20), and differences were not evident (ANOVA; F = 1.11, DF = 63, p = 0.264).
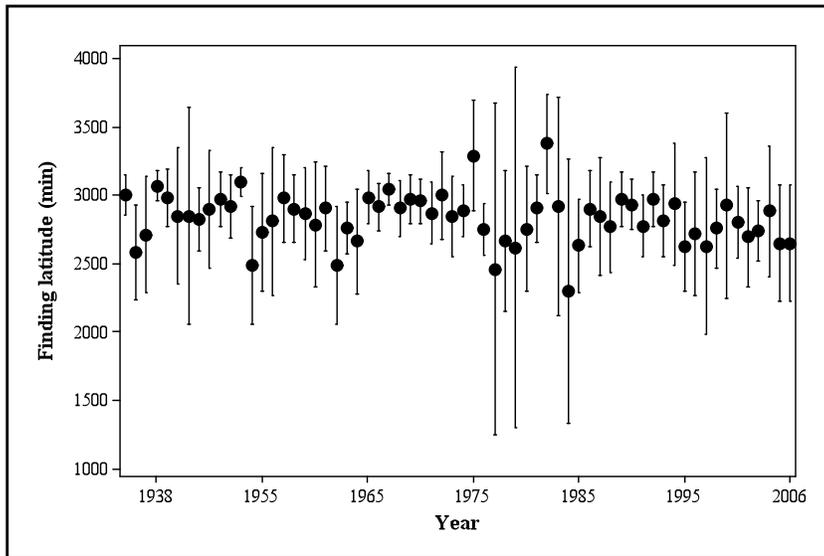
Figure 3-20. Mean finding latitudes for individuals from age class 2.

Age class 3 individuals reach lowest latitudes in their migration pattern after October (fig. 3-21). Adults remain at lower latitudes until January, and stay at high latitudes in September, April and May (fig. 3-21). Mean finding latitudes show significant differences between the non-breeding months (Kruskal-Wallis; H = 138.98, DF = 8, P < 0.001).
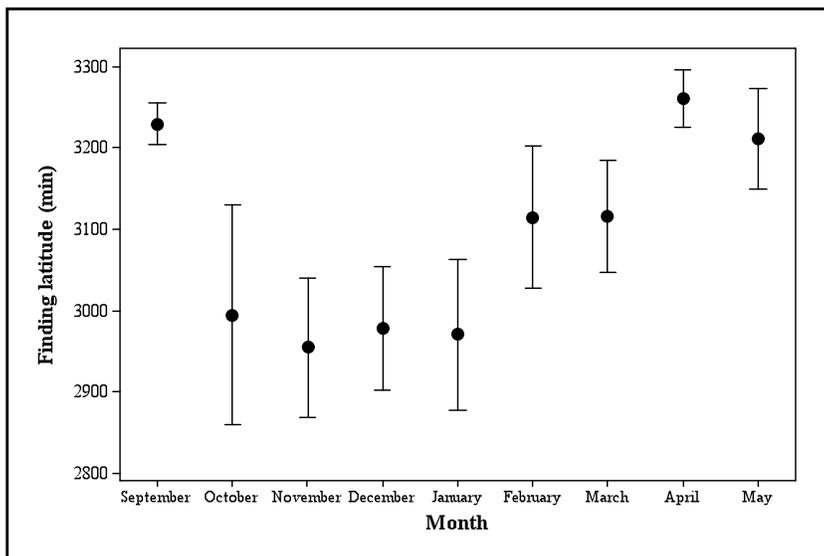
Figure 3-21. Monthly mean finding latitudes for individuals from age class 3 in the non-breeding period.

There is a tendency among adult Northern Gannets to migrate to lower latitudes in the non-breeding period (fig. 3-22). Despite large standard deviations, mean finding latitudes show significance differences between years (Kruskal-Wallis; H = 69.37, DF = 42, P < 0.005).
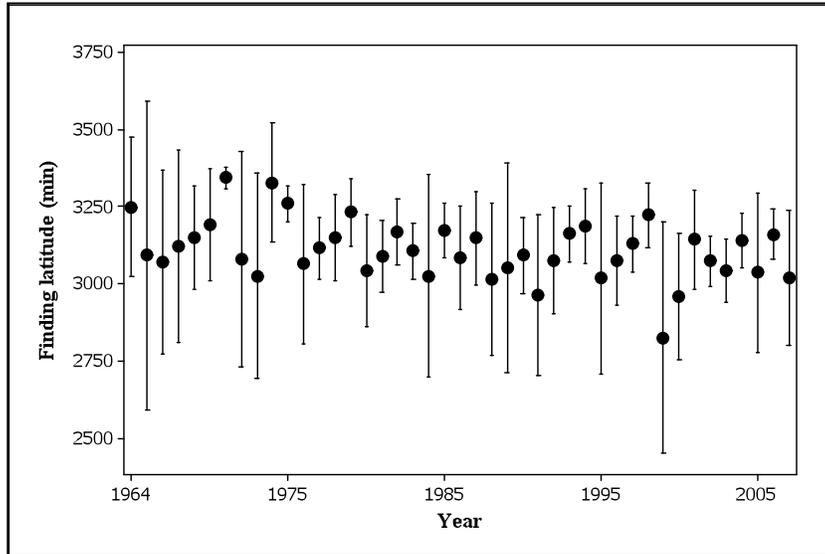
Figure 3-22. Mean finding latitudes for individuals from age class 3.

Wintering period (December to March)

In a graph including all individuals, monthly variation is great (ANOVA; F = 12.58, DF = 3, P < 0.0001), showing that ring recoveries at lower latitudes appear in December and January (fig. 3-23). From January to March it is evident that individuals are returning towards breeding colonies.

Lower mean finding latitudes were recorded in the period from 1940 to 1965 (fig. 3-24). For the rest of the time analysed, there is no clear trend in finding latitudes. Nevertheless, differences between years are significant (ANOVA; F = 2.68, DF = 64, p < 0.001).
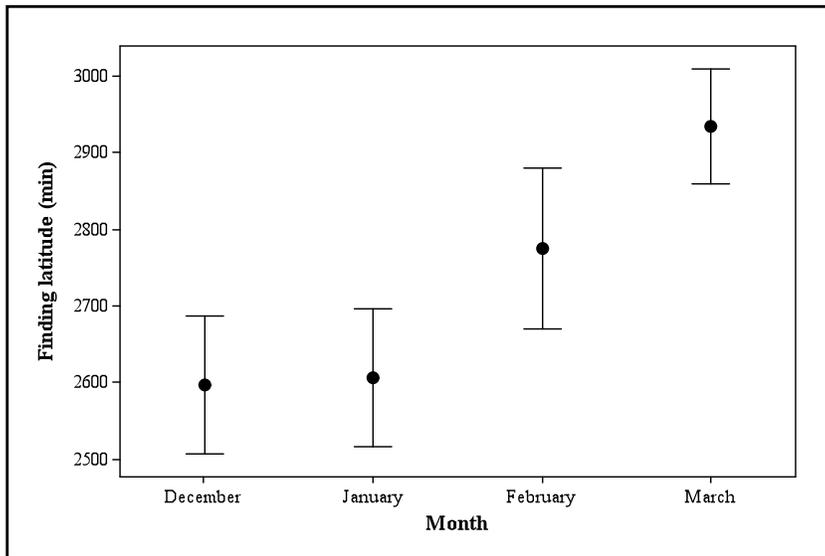
Figure 3-23. Monthly mean finding latitudes in the winter months.
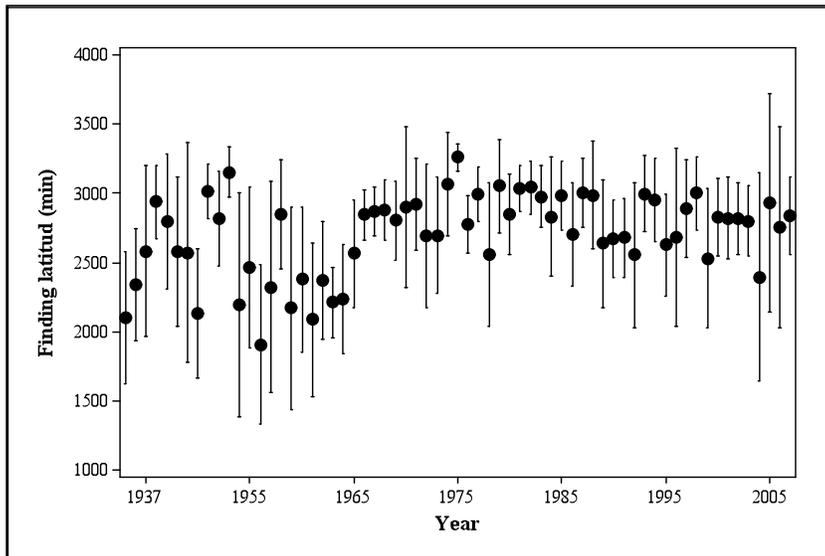
Figure 3-24. Mean finding latitudes by year. Data within years include only the winter months.

In the winter months, age class 1 individuals of Northern Gannet were at lower latitudes, meanwhile adults (age class 3) tended to stay at high latitudes (3000 min). Differences in mean finding latitudes between age classes were substantial and significant (ANOVA; $F = 160.62$, DF = 2, $p < 0.001$; fig. 3-25).
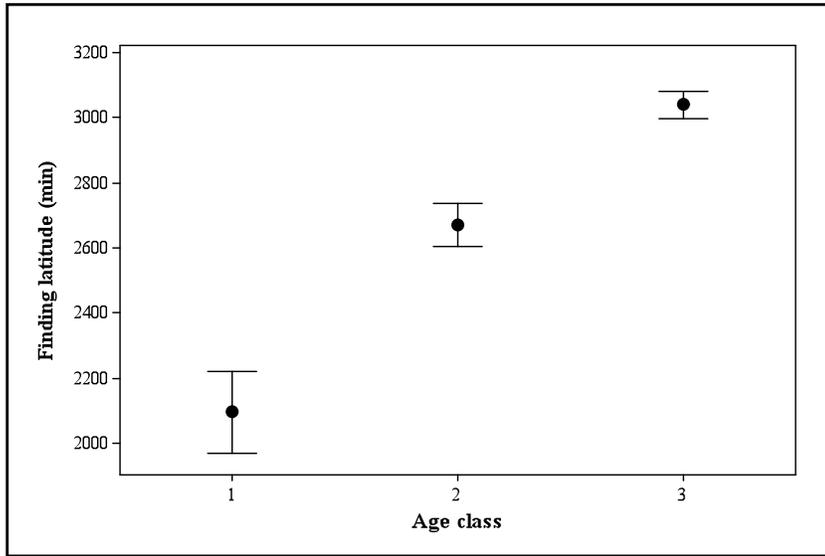
Figure 3-25. Mean finding latitudes by age class in the winter months.

During the winter months age class 1 individuals were reported in the southernmost latitudes during January (fig. 3-26), and their mean latitudes oscillated over years (fig. 3-27). But neither variations between months (Kruskal-Wallis; H = 3.79, DF = 3, p = 0.285) nor years (Kruskal-Wallis; H = 13.38, DF = 10, P = 0.261) showed statistical significance.
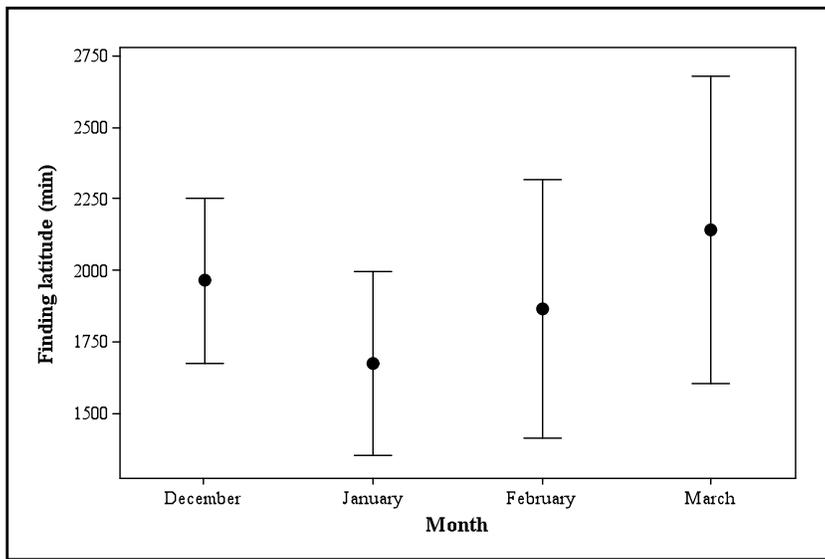
Figure 3-26. Monthly mean finding latitudes for individuals from age class 1 in the winter period.
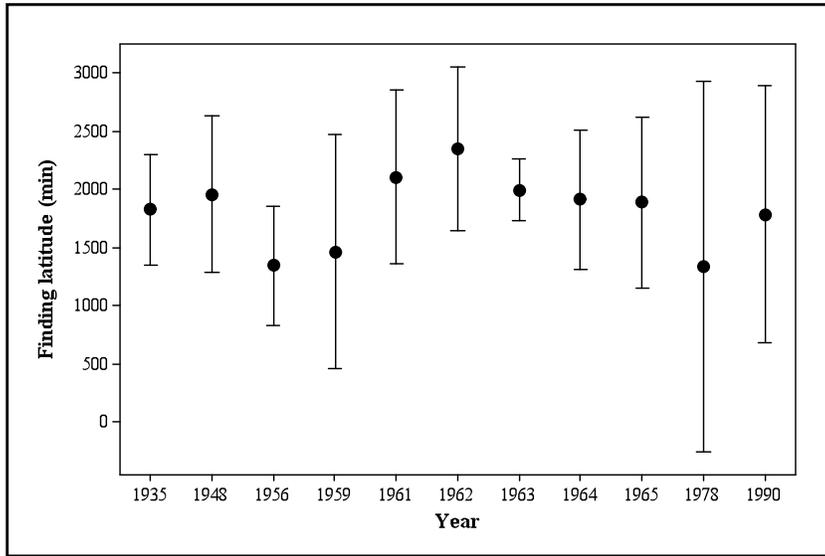
Figure 3-27. Annual mean finding latitudes for individuals from age class 1 in the winter period.

In the same way, variations across months (fig. 3-28) and years (fig 3-29) were not great for individuals from age class 2 (months ANOVA; F = 0.91, DF = 3, p = 0.435; years ANOVA; F = 0.85, DF = 34, p = 0.705).
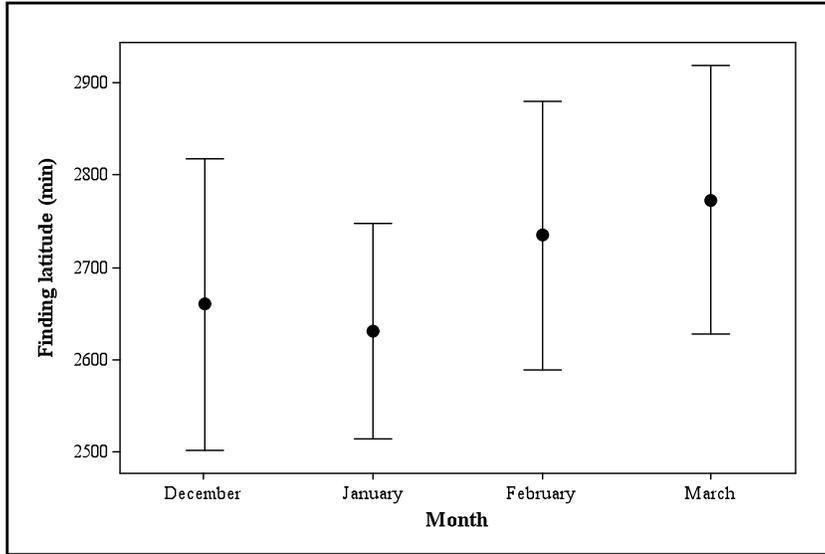
Figure 3-28. Monthly mean finding latitudes for individuals from age class 2 in the winter period.

110
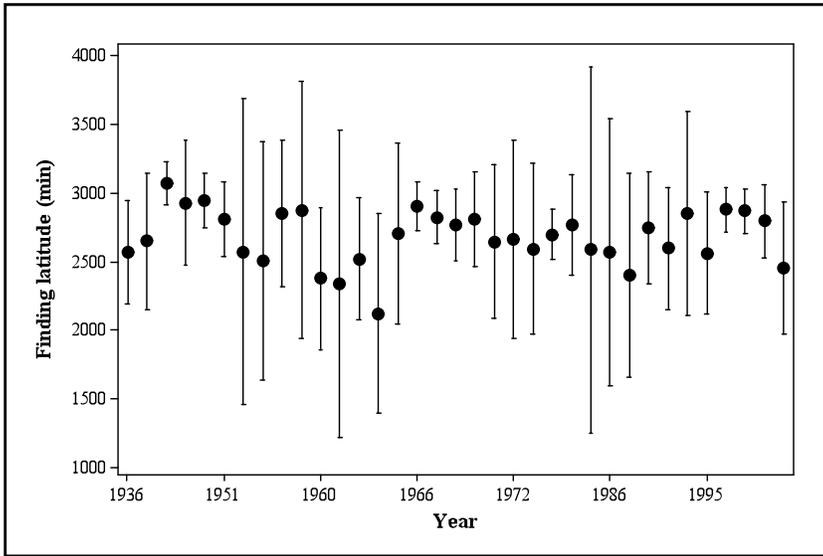
Figure 3-29. Annual mean finding latitudes for individuals from age class 2 in the winter period.

Age class 3 Northern Gannets reached their lowest mean latitudes in January, during the winter months (fig. 3-30), and the differences between months are noticeable (Kruskal-Wallis; H = 25.56, DF = 3, p < 0.001). But differences between years (fig. 3-31) were not statistically significance (Kruskal-Wallis; H = 48.36, DF = 36, p = 0.082).
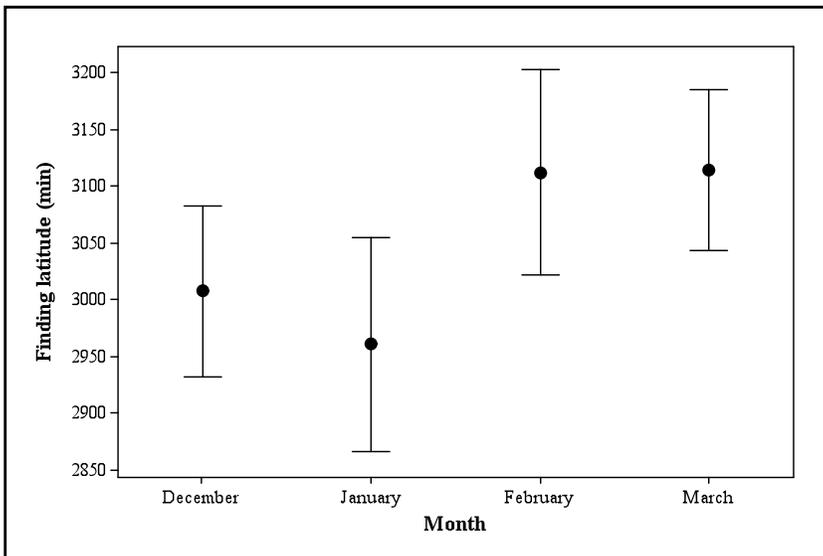
Figure 3-30. Monthly mean finding latitudes for individuals from age class 3 in the winter period.
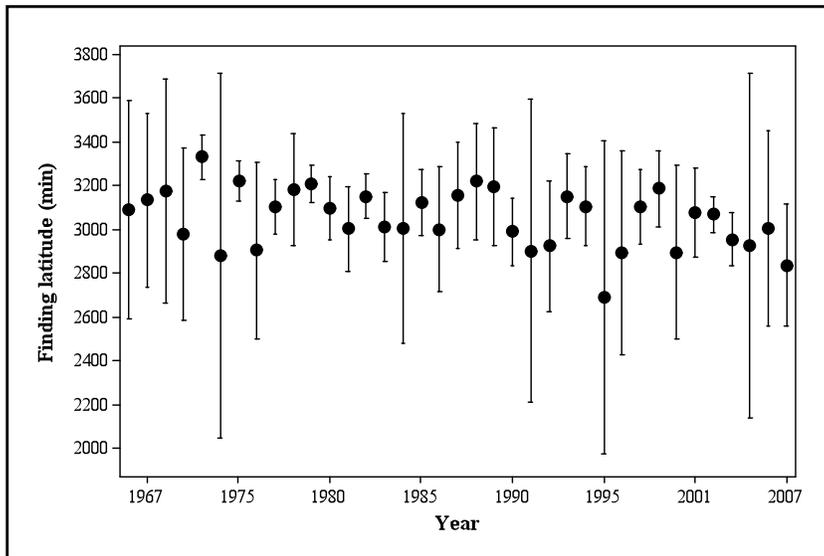
Figure 3-31. Annual mean finding latitudes for individuals from age class 3 in the winter period.

Records from Africa

During the period between 1934 and 2006, 304 ringed Northern Gannets were reported in West Africa, from Gibraltar (2155 min N) southwards. In all these cases, finding latitudes were similar between age classes, around 1600 min N (fig. 3-32).
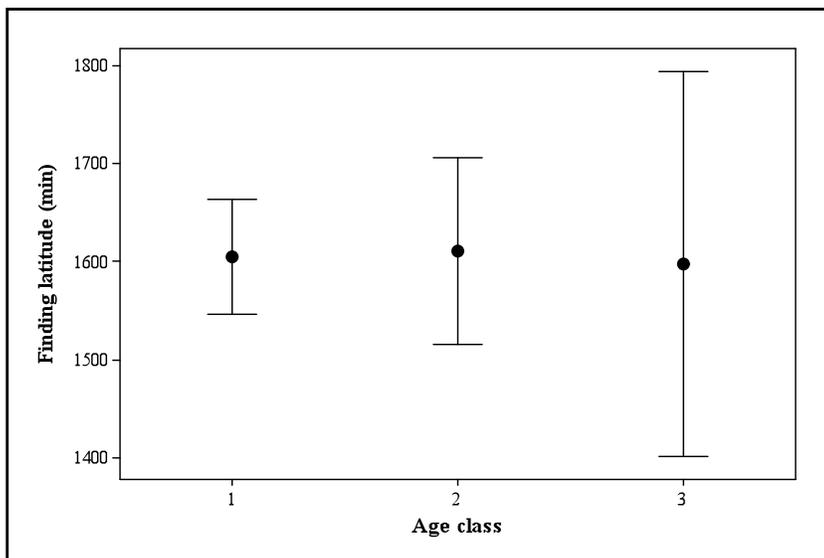
Figure 3-32. Mean finding latitudes by age class, from all ring recoveries of Northern Gannets in Africa.

From all records of Gannets recovered in Africa, age class 1 represents the majority of the cases, reaching the highest values in the period 1961-1970, but there is a noticeable tendency of decreasing numbers in recent decades (fig. 3-33).

On the other hand, the number of records from age class 3 individuals showed a tendency to increase, with a peak during the 1991-2000 period. Whilst there were no records before 1960, the number of ring recoveries is now higher. The ring recoveries for the three age classes decreased in the last period of time (2001-2007).
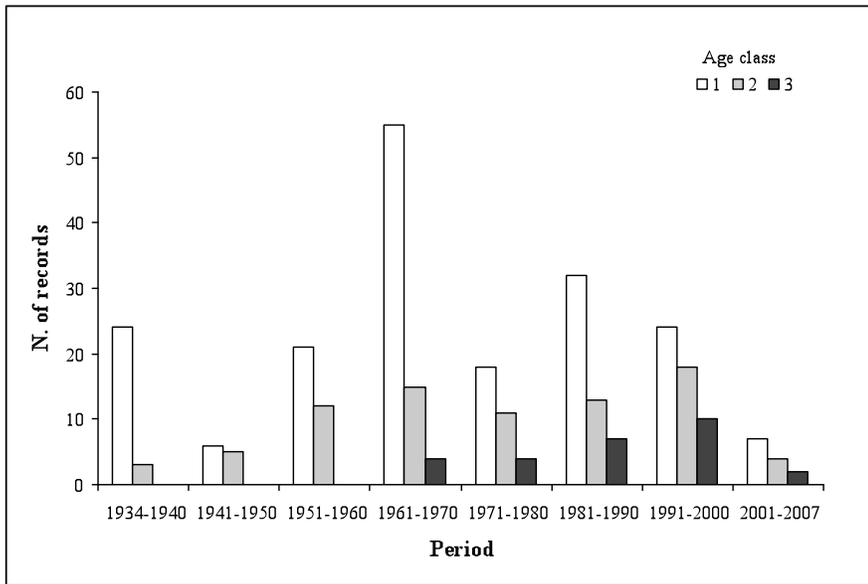
Figure 3-33. Number of records over the time period of Northern Gannets in Africa, by age class.

Discussion

The use of ring recoveries to track migratory movements in gannets has been applied to individuals ringed in northern locations (Wanless, 2002) and particularly in the Bass Rock (Nelson, 2002), in the Channel Islands (Veron and Lawlor, 2009), and in the Faeroe Islands (Danielsen and Jensen, 2004).

Mean finding latitude has tended to increase over the years. This means that individuals tend to remain close to the North Sea in recent years, while in the past they tended to move farther south. These results could be biased because an unknown lack in the number of individuals reported at low latitudes, especially off the coast of Africa, or the possibly low death rate at these latitudes, and could be biased by changing proportions of recoveries of juneniles and adults (age classes 1 and 3 in this analysis).

Another possible explanation of this is related to climate change. Considering the warming of the environment, a logical response from birds should be to winter at higher latitudes than in previous years, or to spend more time at the breeding areas (Newton, 2008). Migratory tendencies have changed over time for several species, with shorter migratory movements as a result of global warming because northern regions became more suitable for wintering birds (Siriwardena and Wernham, 2002). Based on artificial selection experiment, the current climate warming is favouring the Blackcaps (*Sylvia atricapilla*) to winter closer to the breeding grounds (Pulido and Berthold, 2010).

Human activities, and especially fisheries, are affecting seabird populations. Depletion of commercial fish resulting in the lack of fishery boats providing food for scavenging seabirds, reduces the amount of food for these seabirds in the North Sea. In the same way, the developing trawl fisheries on the continental shelf off West Africa increases the amount of food available to seabirds there. Changes in the number of bird migrants could be related to such changes in the conditions in the breeding or wintering areas, or both (Newton, 2004).

The marked differences in ringing and finding latitudes between age classes (fig. 3-7) suggest that migration movements are related to age. Whether post-breeding adults stay close to breeding areas or disperse to remote ones is not well known, but young birds travel to distant areas especially during their first year of independence (Nelson, 1980). In all cases (all year, non-breeding or winter months), age class 1 individuals migrated farther south than immatures and adults. This reflects the strong migration among first-years, with many birds from the east Atlantic reaching Senegal and some crossing the equator in the Gulf of Guinea (Wanless, 2002). Gannets experience true migration in their first year, with limited movements thereafter (Nelson, 1980).

But the decreasing number of age class 1 individuals recovered from Africa, and the increasing number of age class 3 individuals, show the increment in the proportion of age class 3 individuals moving far south in recent years.

The evident differences in finding latitudes between years, shows a slight tendency of age class 1 individuals to migrate to southernmost latitudes during non-breeding months in recent

years (fig. 3-18). A similar pattern was shown by age class 3 individuals (fig. 3-22). These observations could be a result of the better conditions for feeding in low latitudes.

Unlike movements from all individuals during the non-breeding months, (April and May were the months with higher finding latitudes, fig. 3-14), age class 1 Gannets remain close to breeding areas during September and October (fig. 17). This could be because they are still fledging, because typically the fledging period is between August and October (Wanless, 2002). They may then move to North African waters as soon as they fledge (Nelson, 1986), but many may die in these early months of independent life.

Age class 3 individuals tend to remain close to breeding areas, but they form an increasing proportion of migrants into African waters. The high standard deviations presented in age class 3 individuals recovered from Africa (fig. 3-32), could be related to a number of individuals migrating to both high and low latitudes. Adults migrating far south are maybe inexperienced individuals, trying to feed where fish is abundant, or birds that failed to breed.

Chapter 4

Time budgets for wintering Great Skuas

Abstract

In order to establish the time spent flying for the Great Skua during the migration period, five Global Location Sensing data loggers were deployed on outstanding chick-rearing adults in Foula, in summer 2003, and analyzed information recorded until March 2004. Information recorded for data loggers were temperature, to determine time flying or swimming, and intensity of light to establish the location of the bird. Individuals spent more time flying during daylight hours, independently of the wintering area, and no noticeable differences were observed in time flying by month, with highest values during winter months.

Introduction

There is a gap in our knowledge of seabirds at sea, mainly because it is difficult to follow and observe their behaviour quantitatively there (Cairns *et al.* 1987; Nelson, 2002). In addition, studies outside the breeding season are scarce, meaning that seabird activities for a long period, up to 80% of the year in the case of the Great Cormorant *P. carbo* (Gremillet and Wilson, 1999), are unknown.

Despite the possibility that use of radio transmitters could affect seabird behaviour, because of the extra weight of the device in terms of changes in foraging trips and reduction in the amount of food delivered to chicks e. g. Common Guillemot *Uria aalge* and Razorbill *Alca torda* (Wanless *et al.* 1988), the use of this tracking equipment has been beneficial in studies about dispersal and feeding ecology of seabirds (Igual *et al.* 2005). The use of data loggers could reduce the burden effect because of their lighter weight, especially when used with medium or big seabirds, like the Great Skua. In fact, Gannets carrying data loggers showed no negative effects in their activities (Garthe *et al.* 1999). Miniaturization of these electronic devices (less than 20 g) has led to the development of new ways for studying migratory movements of small birds (Bächler *et al.* 2010) considered unable to carry the rather bulky satellite transmitters.

Global Location Sensing (GLS) data loggers are often used to record environmental variables such as temperature, and light intensity. Geolocation is possible because changes in ambient light levels can be used to estimate sunrise, sunset, day length times, and hence, longitude and

latitude (Burger and Shaffer, 2008). Latitude is derived from the daylength, and longitude from local time for midday and midnight.

Temperature recorded by data loggers is generally fairly high when the bird is flying, of the order of 25°C, because the legs carrying the device are covered by the feathers. When the bird is resting in the sea surface or fishing, it extends its feet into water and temperature recorded decreases (Wilson *et al*. 2002). Because the Great Skua is a diurnal species that does not visit land during the winter period, it is established that the temperature recorded overnight reflects the sea surface conditions (except for species like Frigatebird *Fregata sp* that spend the night on the air). This is because it's assumed that birds spend the night resting at the water. However, it is important to note that night-hours recordings should be stable for several minutes to determine that these are related to sea temperature, because the temperature sensor of the logger needs some time to stabilize.

One possible problem of the use of data loggers is the need for the double capture of one single bird. Birds are equipped with data loggers in the breeding colony and recaptured after returning from their wintering area, and only when the logger has been recovered is it possible to download stored data (temperature or other data). As a result, the deploying and recovering of the loggers should be done during the breeding season, usually in the vicinity of the nest, involving successful-breeding adults. This is possible because of the philopatric behaviour of the Great Skua breeding at Foula (Klomp and Furness, 1992). Despite this, new colonies formed from individuals ringed at Foula could indicate a non-strong philopatry for all individuals. A major problem impossible to solve is the malfunction of the device, because such faults are realized only after the data downloading.

Breeding colonies provide an opportunity to investigate different aspects of the biology of seabirds, and studies at colonies are relatively easy to conduct. Observations over a great number of individuals are possible, due to the restricted movements of adult seabirds attending nests and feeding their chicks. Because of that, several studies related to the daily activity patterns, or time budgets on a considerable number of seabird species, have been carried out during the breeding season. These studies showed that variations in nestling food demand (brood size), are related to differences in time budgets of Pigeon Guillemot *Cepphus columba* (Litzow and Piatt, 2003) and Great Skua *Stercorarius skua* (Ratcliffe and Furness, 1999). On

the other hand, in Common Guillemot *Uria aalge* more than 80% of time at sea was on or under water during the incubation period and chick rearing (Cairns *et al.* 1987; Cairns *et al.* 1990), and Crozet Shag *Phalacrocorax melanogenis* spend only 2% of their daily time budget flying during the breeding season (Tremblay *et al.* 2005). Otherwise variations in time budgets are related to different characteristics of the species. Whilst some species spend more time flying during the breeding season, other species spend more time on the sea. Gray-headed Albatrosses *Diomedea chrysostoma* spent about 15% of the daylight time, and 50% during darkness, at the sea surface. In fact, 26% of the total time recorded with this species was spent sitting on the sea, whilst 74% was spent flying (Prince and Francis, 1984).

Because practically all the studies related to time budgets in seabirds are limited to the breeding season, there has been little discussion about non-breeding activities, including research on time budgets. The lack of this kind of information mean that are a poorly understood part of the ecology of seabirds and their activities at sea (Gremillet and Wilson, 1999; Tremblay *et al.* 2005). This is especially true in the case of migratory species wintering in tropical latitudes.

Wintering seabirds may be exposed to difficult condition throughout the year e. g. severe weather in northern latitudes in winter, and shortage food in lower latitudes, resulting in a different allocation of time for different activities at different times of the year. For such reason, it is important to store great amount of energy at the beginning of the migratory movement. Unfortunately, studies related to migrant seabird activities during the winter period are scarce.

One important aspect to consider is the reduction in the daylight period during winter in northern latitudes, reducing the time available to search for food in diurnal species. For example, in the case of geese, they are unable to increase the amount of food consumed during night hours to compensate the reduction of intake rate from depleted pastures (Owen *et al.* 1992). In response to short daylengths at high latitudes in winter, several seabird species could migrate to lower latitudes, where the daylight period approaches half of the day more closely in winter. However, such a migration means that it is necessary to switch prey species and fishing tactics, changing the time spent in the search for food. One such wintering seabird is the Great Skua. This species breeds at colonies from 58°N to about 70°N (west Scotland to

Svalbard and Jan Mayen), and particularly large breeding populations exist in Shetland (Furness and Ratcliffe, 2004). Non-breeding for Great Skuas involves the period between September and May and the migration starts with immature birds (3-8 years old mainly) from June to July, followed by the juveniles in August, and adults from late July (most of them migrating during late August), with a peak number seen on autumn migration in September at the North Sea (Furness, 2002a). On the other hand spring migration to the north takes place during March and April (Furness, 2002a).

While breeding, time spent searching for food differs according to the kind of prey. Reproductive adult Great Skuas feed on fish, fishing discards, and other seabird species. Individuals that specialize on bird prey spend less time foraging than those individuals feeding mainly on fish at Shetland (Votier *et al*. 2004a) maybe because it is quicker to kill a bird on land than heading out to sea in search of fish. Activities and time budgets of Great Skua in the migration period and winter are unknown. However this species is particularly suitable for a study of activity at sea outside the breeding period because it is believed that Great Skuas do not come onto land at any time after leaving the breeding colony until they return to the breeding colony next spring (Furness, 1987). Therefore, activities involve either flying, or sitting on the sea, and do not involve periods spend ashore.

Materials and Methods

Five data loggers (Earth & Ocean Technologies, Kiel) deployed on chick-rearing adult Great Skuas in Foula, Shetland, in summer 2003 were recovered by recapturing individuals the next breeding season at the same nest site. These loggers were intended to record data from July 2003 to June 2004, but one of the loggers failed at some stage during deployment due to battery problems (moisture discharged from the battery causing corrosion within the electronics). As a result, each logger gave data for a particular period from deployment. Analyses were carried out with data between September 2003 and March 2004 (sea surface temperature estimated by means of temperature recorded by loggers at night hours indicated the end of March as the time when birds returned to the colony).

When Great Skuas migrate they remain at sea and so there are two basic activities that can be inferred from logger data. When loggers record consistent low temperature the bird can be

classified as sitting on the sea surface. When loggers record higher and more variable temperature the bird can be inferred as flying since loggers will be tucked into the body plumage and so will record a much higher temperature than ambient. So temperature recorded every 3 minutes and stored in memory was used to determine the activity displayed by each bird. Activities were divided into two categories: Flying (with high temperature records) and Swimming (with low temperature records that match the expected sea surface temperature, SST). From all the period recorded for each logger, data for each five-day period were analysed. For each one of these days, all data were grouped into 12 periods of two hours each (00:00-01:59, 02:00–03:59, and so on until 22:00–23:59), and mean percentage spent flying was calculated for all the individuals according with the number of days analysed. A graph including mean time flying by individual was made, including a Kruskal-Wallis analysis to detect differences between individuals. In addition, monthly percentage by activity was estimated for all individuals.

Time spent flying for a day was divided into bouts. Each bout consists of a period of continuous flying. The number of bouts of flying by day was used to estimate the monthly mean bouts flying by day.

Information from the two data loggers with more months covered (T26 logger with 7 months and T30 logger with 6 months) was used in more detailed analyses. These analyses were the comparison between mean time flying, in terms of percentage, by months and by time of the day by means of GLM analyses. Additional analyses were the comparison of mean time in percentage flying between daylight hours (08:00-20:00) and night hours (20:00-08:00) and between migrating months (September-October) and wintering months (December-February) by means of GLM analyses. Finally, mean time flying by month was divided into the monthly mean number of bouts flying to obtain the mean time flying per bout.

Results

Data per individual for between 1 and 7 months were obtained. One data logger only recorded 3 days, two data loggers worked up to November, and two loggers recorded data up to the end of winter (Table 4-I).

Table 4-I. Data obtained per individual indicating the number of days analysed, bouts and months covered.

Individual	Period	Days analysed	Bouts flying per day
T17	09/2003 – 11/2003	14	32.7
T25	09/2003	3	76
T26	09/2003 – 03/2004	41	38.1
T29	09/2003 – 11/2003	17	33
T30	09/2003 – 02/2004	32	37.3

All individuals spent more time flying between 08:00 and 20:00 (fig. 4-1). Observed differences in time spent flying between individuals were not significant (Kruskal-Wallis H = 5.67, DF = 4, p = 0.225; fig. 4-2). The mean number of flying bouts by day showed similar values for all individuals and months (Table 4-II), with the exception of the very high value in September for the T25 individual. However, this number was obtained from only 3 days of records.

Table 4-II. Monthly mean number of flying bouts by day for all individuals.

Individual	September	October	November	December	January	February	March
T17	33	33	31				
T25	76						
T26	32	35	47	38	41	38	37
T29	38	28	35				
T30	37	34	33	41	44	33	
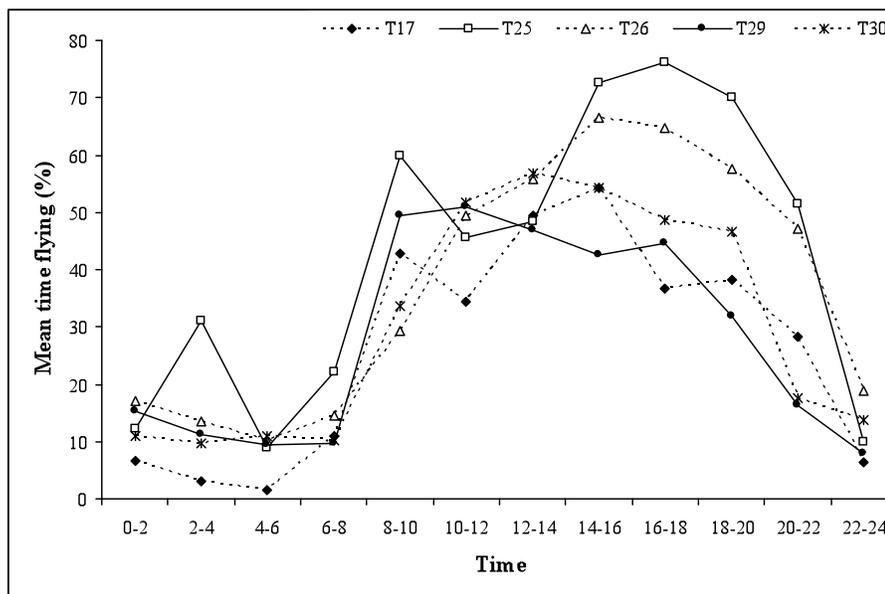
Figure 4-1. Time spent flying (in terms of percentage) for all days analyzed by individual.

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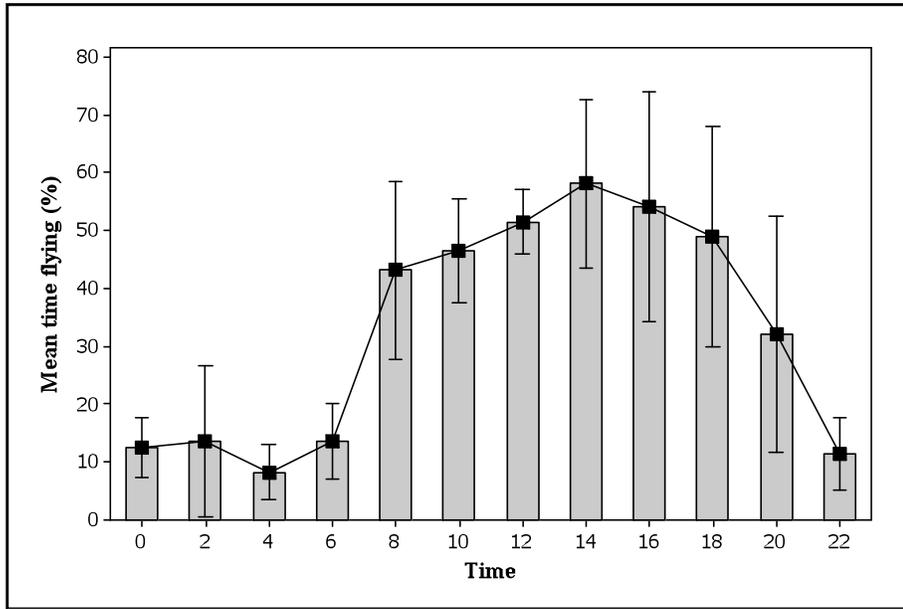
Figure 4-2. Time spent flying (in terms of percentage) by time of day for all individuals. Observed differences are significant (Kruskal-Wallis H = 5.67, DF = 4, p < 0.01).

In the case of the individual T26 mean time flying was similar for all months recorded, showing more time flying during the period between 08:00 and 22:00 (fig. 4-3). Individual T30 showed more time flying during the period between 08:00 and 20:00 (fig. 4-4).
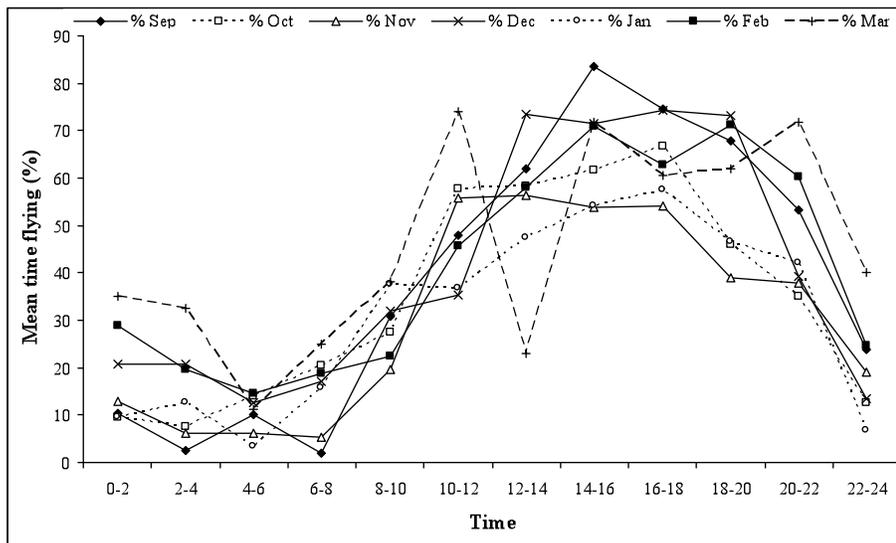
Figure 4-3. Time spent flying (in terms of percentage) by time of day for each month for the individual T26.
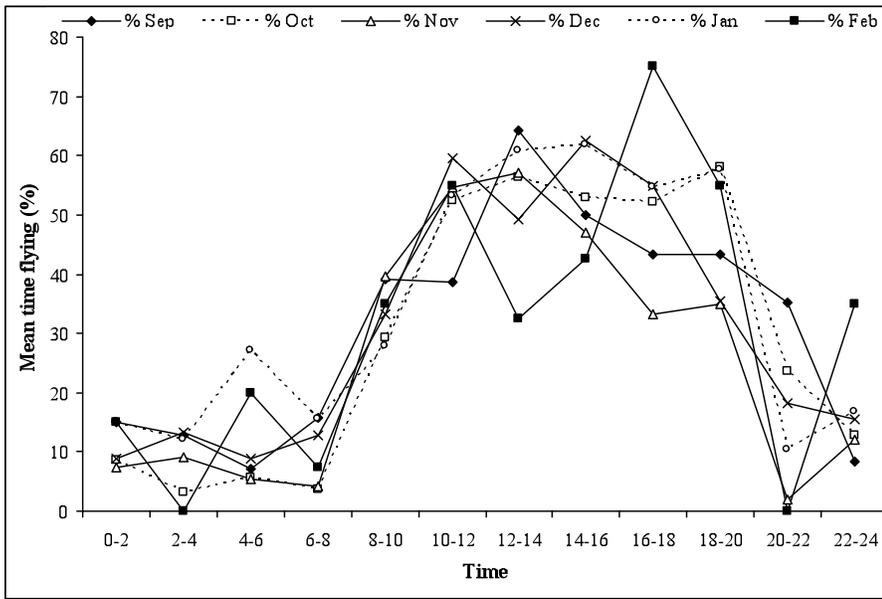
Figure 4-4. Time spent flying (in terms of percentage) by time of day for each month for the individual T30.

Time spent flying by individual T26 was significantly different between months (GLM; F = 4.63, DF= 6, p < 0.001; fig. 4-5), with highest values during December and March, and also between times of the day (GLM; F = 44.45, DF= 11, p < 0.001; fig. 4-6), with highest values between 10:00 and 20:00.
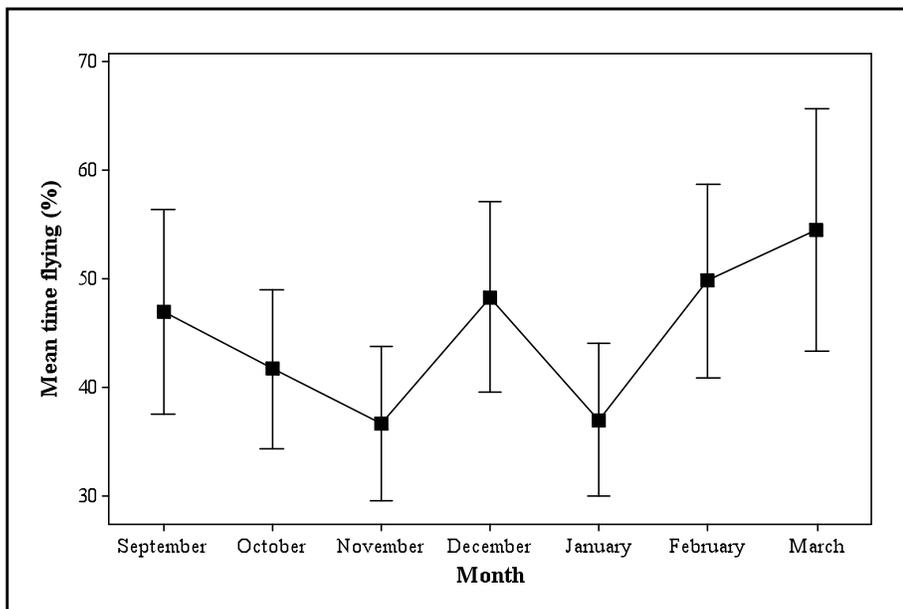
Figure 4-5. Percentage of time spent flying by month for the individual T26.

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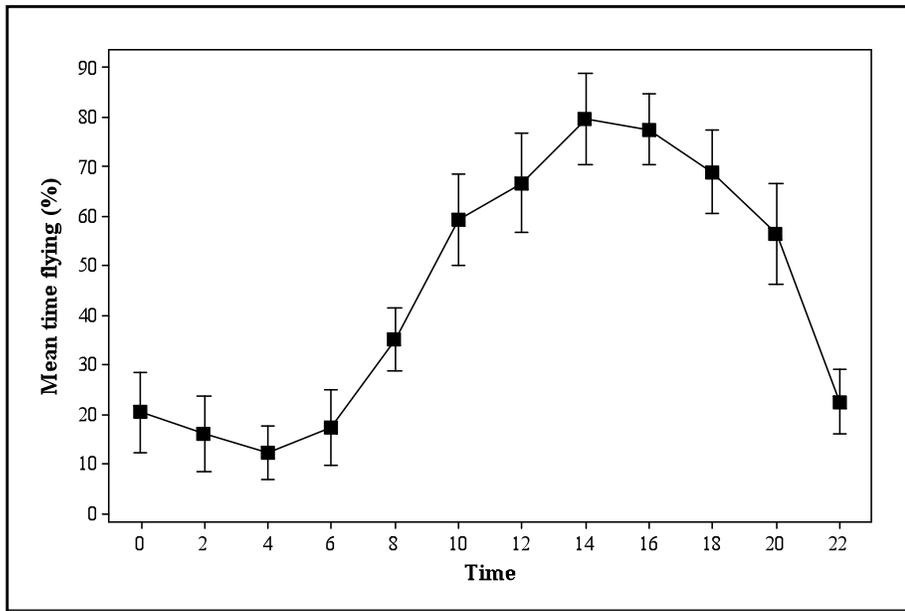
Figure 4-6. Percentage of time spent flying by time of day, including all months recorded for the individual T26.

Time spent flying by individual T30 was not significantly different between months (GLM: F = 2.22, DF= 4, p = 0.067; fig. 4-7), with highest values during December and January, but was significantly different by time of the day (GLM: F = 38.25, DF= 11, p < 0.001; fig. 4-8), with highest values between 08:00 and 18:00.
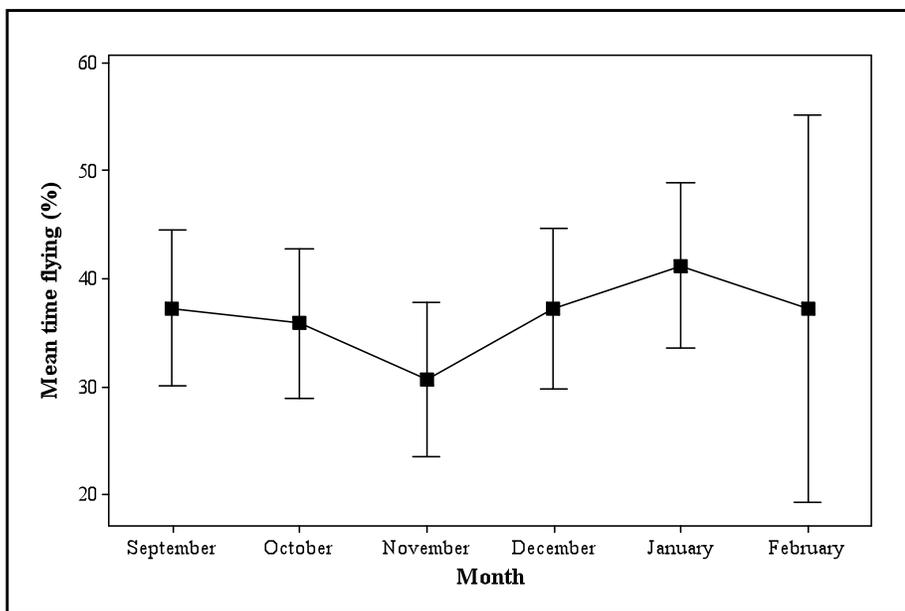
Figure 4-7. Time spent flying by month for the individual T30.
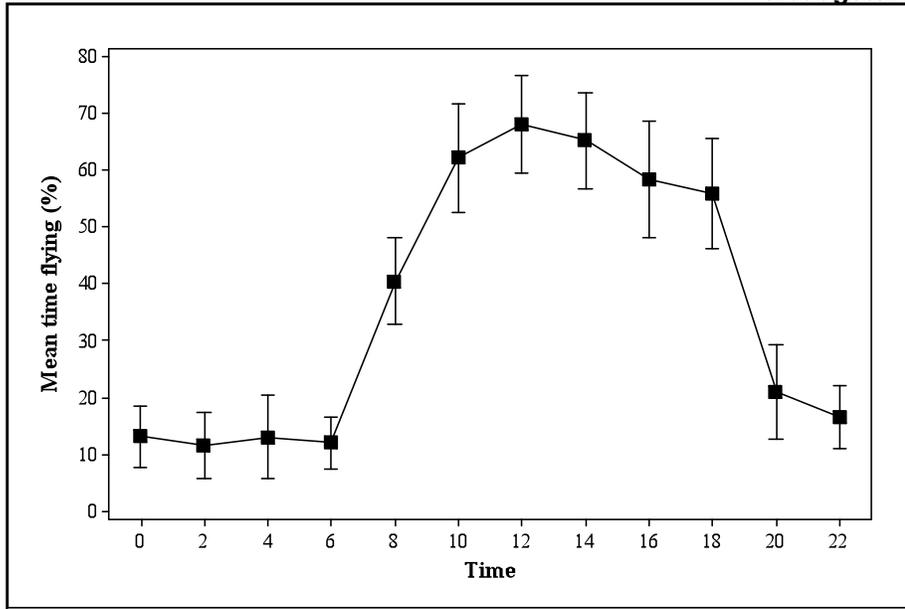
Figure 4-8. Time spent flying by time of day, including all months recorded for the individual T30.

In the case of the mean time flying by bout, values were higher during September, December and January (more than 1% of the time per bout) in the case of the T26 individual (Fig. 4-9). Values were higher in October and February (less than 1% of the time per bout) in the case of the T30 individual (Fig. 4-10).
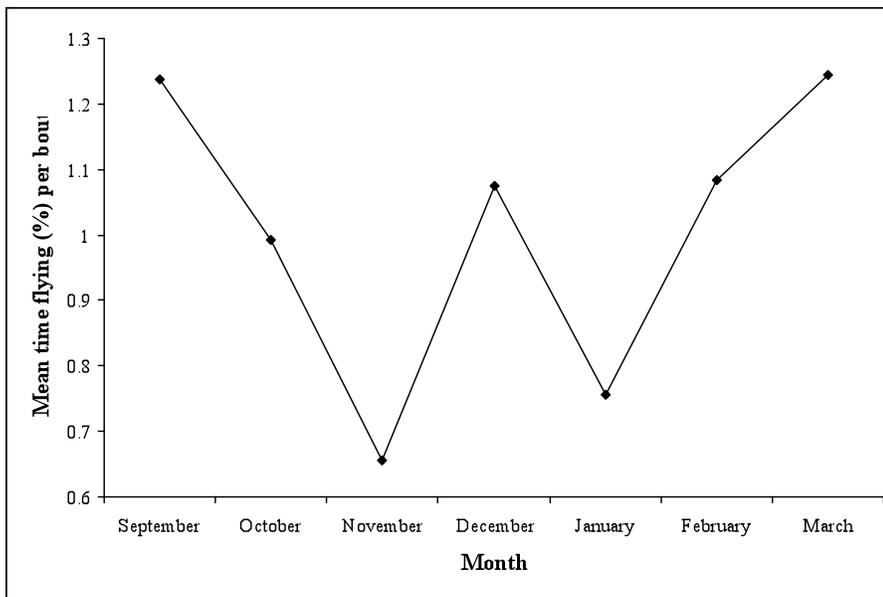
Figure 4-9. Mean time flying per bout for the individual T26. Data represents the percentage of the entire day (24 hr) spent flying by bout.
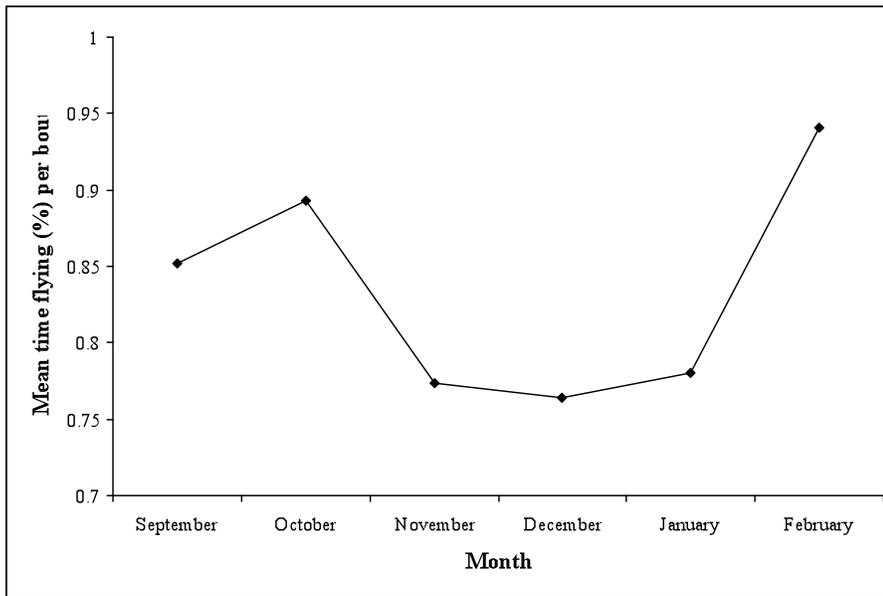
Figure 4-10. Mean time flying per bout for the individual T30. Data represents the percentage of the entire day (24 hr) spent flying by bout.

Individual T26 was flying about 21.13% of the night hours and 53.92% of daylight hours during winter, and 16.75% of the night hours and 57.09% of daylight hours during migration. Differences in time flying between night and daylight hours were significant (GLM: F = 39.06, DF = 1, p < 0.001). Despite apparent differences between wintering and migrating periods, they were not significant (GLM: F = 0.01, DF = 1, p = 0.958). Individual T30 was flying about 13.98% of the night hours and 50.30% of daylight hours during winter, and 12.66% of the night hours and 48.34% of daylight hours during migration. Differences in time flying between night and daylight hours were significant (GLM: F = 15.13, DF = 1, p < 0.001). Despite apparent differences between wintering and migrating periods, they were not significant (GLM: F = 0.31, DF = 1, p = 0.588).

Discussion

In spite of the fact that Great Skua could feed on seabirds at night at St. Kilda during the breeding season (Votier *et al*. 2006), this is normally a diurnal species when breeding, usually carrying out their feeding activities during daylight hours (Furness 1987). Results from the data loggers for the migration and winter periods show less time spent flying during the night, because is they were assumed to be resting on the sea surface inactive at night, and so showing the same diurnal behaviour as normally seen at breeding colonies.

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Two individuals (T17 and T19) recorded data up to November, which includes the important migration period. In the case of the individuals with records until February (T30) and March (T26) it is possible to observe time budgets during migration south and during wintering.

In a quick view of time spent flying by time for all individuals, it is possible to establish that Great Skua maintain diurnal behaviour observed in the breeding colony, flying mostly during daylight hours (between 08:00 and 20:00). No statistical differences between individuals indicate that diurnal habits are similar independently of the wintering area (assuming that individuals wintered in different locations). Mean number of bouts per day goes in the same direction because values are similar (with the exception of individual T25 with only 3 days analyzed).

The mean number of flying bouts by day showed some months with noticeable high values, coinciding with the months with lowest percentages flying for the T26 individual, and the opposite relation for the T30 individual (lowest percentage flying coincided with the month with the lowest number of bouts). As a result of this, additional analyses were made, to obtain the mean time flying per bout by month. Results are different for the two individuals indicating that maybe these individuals wintered in different areas or simply that they showed individual differences in their behaviour patterns. However, the first suggestion is supported by results of time flying. Time flying for individual T26 was higher between 10:00 and 20:00 and for T30 it was between 8:00 and 18:00, maybe because they migrated to different places (T29 in an area to the west of the area for T30).

Mean time flying per bout for individual T26 clearly decreased in November. This decreasing trend could indicate that this individual spent more time flying during migration to the south, and less time flying when it had reached the wintering location. The opposite trend is observed from January through March, increasing the time spent per bout with the migration north. However, this individual flew for longer per bout in December. This could be explained by some hypothesis: a) wintering location was not ideal forcing this individual to spend more time flying in the search for food, b) wintering location was not ideal forcing this individual to search for another location to winter, c) this individual was a scavenger in the wintering ground flying more time following fishing boats, or d) there were no fishing boats in the wintering ground forcing to the bird to spend more time searching for possibly scarce natural

food. In the case of the individual T30 the situation was different. This bird spent less time flying by bout during the entire wintering period (November-January), indicating that it reached a possibly ideal wintering area where the search for food involved less time. Nevertheless, it is important to observe that time spent flying was not significantly different between months, so any conclusion must be made carefully being only indicative. However, it is possible to see a clear trend. These results could support the long held view that seabirds probably expend less energy during winter than they do while breeding (Furness and Monaghan 1987).

Despite the fact that this study presents information from only five individuals, and only one of them related to the entire winter period, results showed a marked tendency in the time budgets of the Great Skua during the winter period. These results could be a baseline for future research, especially related to distribution and movements of this species. Information about these issues in relation to food is necessary (Nelson, 2002). Results also suggest that Great Skuas spend much time, even during daylight more than 50%, sitting on the sea surface.

Chapter 5

Time budgets for wintering Northern Gannets

Abstract

To evaluate time spent for the Northern Gannet flying during the non-breeding and wintering period, 30 GLS data loggers were deployed on outstanding chick-rearing adults at the Bass Rock, in August 2008, and 21 were retrieved in April 2009. Information recorded for data loggers were temperature, to determine time flying or swimming, and intensity of light to establish the location of the bird. Individuals spent more time flying during daylight hours and those wintering in NWA and Portugal flew more time, with no differences between individuals. All individuals spent more time flying in October. Differences in wintering areas by sex were noticeable with almost all females wintering in the NWA area, whilst males wintered mainly in areas north to NWA. Females could migrate far south because males have to stay close to breeding areas in order to search and defend territories.

Introduction

Time allocation to different activities in seabirds need to be adjusted to optimize survival through the nonbreeding period and to maximize life-time reproductive success by optimizing reproductive effort during the breeding season. Often this involves minimising energetic costs in winter. The breeding season usually coincides with the period when food is abundant, in terms of available fish in the surrounding sea, and migration to lower latitudes occurs when food is scarce in autumn-winter. During migration time allocation changes in response to the increased flying times for travel, and the search for food in an unpredictable environment to which the bird is not so familiar.

A central question about the migratory behaviour of seabirds breeding in high latitudes is why some individuals migrate far south while others, from the same colony, may stay in winter rather close to the breeding site. An individual migrating south has an additional energetic cost due to the travel, and an increased risk of mortality during migration as well. As a result, it is believed that for migration behaviour to evolve, costs need to be small in comparison with the benefits of moving to a more favourable region during winter. For an individual remaining in the breeding colony during winter, costs are associated with a number of factors, but especially with reduced food availability and the adverse climatic conditions (Newton, 2008).

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During breeding, adult gannets fly most of the time at sea searching for food for themselves and their chicks. Searching time tends to increase for individuals breeding in the largest colonies (Lewis *et al*. 2001). Time budgets for breeding gannets have been studied before, and results indicate that they spent 39-40% of their time in the colony, 22-30% flying and 22-34% swimming (Garthe *et al*. 1999). This species does not fly during night hours, constraining the time spent flying to daylight hours. Some studies have detected differences between the daily activities during breeding, depending on the time of day. The activity patterns of gannets equipped with data loggers showed that they are more active during the daylight period, flying mostly in the early morning and in the evening (Garthe *et al.* 1999). A closely related species, the Cape Gannet *Morus capensis*, spends about 60-70% of the time resting at the sea surface between 10:00 and 14:00 hours, and individuals spend the night at sea showed longer flight periods (Ropert-Coudert *et al.* 2004).

Although Northern Gannets spend a lot of time at sea outside the breeding season, their activities at this time are not well known (Nelson, 1989). Logically seabirds at sea are fishing, resting, moving between locations or food patches, and possibly defending themselves against predators or competing with other seabirds, but there is a lack of information related to the time dedicated to those activities at sea for wintering individuals. In addition, the timing of flying or fishing could be different between latitudes along the migration route, with latitude-related differences in the diurnal behaviour of this species because daylength in winter is a function of latitude.

Migratory behaviour of birds has been studied intensively over many decades; with a variety of tools employed such as calibrated visual observations (e.g. Heinemann, 1981; Mateos *et al*. 2010), ring recoveries (e.g. Wernham *et al*. 2002), systematic catches within standardized programmes (e.g. Hüppop and Hüppop, 2003), physiological measurements in the field (e.g. Atkinson *et al*. 2007) and radar studies (e.g. Lack and Varley, 1945; Gauthreaux and Belser, 2003). Direct observations of migrating birds from land is very challenging, even using radar technology, being more difficult in the case of seabirds, which in many species are usually out of sight from the shore. Thus, seabird migration studies are mainly based on ring recoveries or on systematic seawatches along the coast (this last kind of study restricted to days with good weather, and ignoring individuals moving on the open ocean beyond the range of identification). In addition, study is complicated for Gannets in wintering areas because they

remain at the sea at all times, making it difficult to observe individuals from survey points on land. This makes it difficult to follow a particular individual to record its activities. When feeding, gannets tend to disperse, avoiding the presence of the others, spacing out the distribution of individuals at sea, making it possible to observe gannets in large numbers only when feeding on a particular shoal of fish, or scavenging from fishing vessels during discarding.

Since the 1950s, bird migration has been tracked by means of radar, especially when it is difficult to observe individuals during night or at a distance (Cooper *et al*. 1991). Radar target detection has undergone important changes in recent years, thanks to the introduction of High Definition Digital technology. One problem with radar, especially marine radar, is the need to move the system over a wide area to detect seabirds. This is particularly difficult at sea, where mobile platforms are needed to track seabirds. Another problem is the difficulty of identifying the species being tracked by radar, especially when individuals could move either alone or in mixed species flocks.

Recent studies using satellite telemetry are providing new information in relation to foraging trips, feeding grounds and routes (Hamer *et al.* 2000), but duration of information obtained is restricted due to the limited capacity of the batteries. In addition, satellite transmitters (or PTTs) are expensive, restricting studies to few individuals, and sometimes equipment represents a burden to the bird (Afanasyev, 2004). The use of data loggers on seabirds has a widespread use nowadays (Burger and Shaffer, 2008), making possible to evaluate the activity by means of records of different kind of data, such as temperature, during several months (Afanasyev, 2004; Burger and Shaffer, 2008). In gannets, data loggers allow the recording of the amount of time spent flying for a particular individual, by day or time of the day, even during the entire winter period (Kubetzki *et al.* 2009) because of the lightweight and the long-lasting battery capacity (and low power requirements) of these devices. All the information recorded is stored in a memory and retrieved into a computer. To do this it is important to catch the bird two times, once to deploy the data logger and other time to recover it. Fortunately Northern Gannets tend to breed not only in the same colony every year but also at the same nest site within the colony, making possible the recapture for any particular individual in a high rate.

Knowledge of bird migration has been advanced enormously by use of satellite telemetry and data loggers in studies with Geese (e.g. Green *et al*. 2002), Swans (e.g. Pennycuick *et al*. 1999), raptors (e.g. Ueta *et al*. 2000), Shearwaters (e.g. Shaffer *et al*. 2006) and very recently even small songbirds (Stutchbury *et al*. 2009; Bächler *et al*. 2010).

Data loggers such as geolocators (Global location sensing or GLS), commonly deployed on the legs of seabirds are used to monitor environmental variables such as sea temperature and providing important information on bird migration and activity (Igual *et al*. 2005). Light-level geolocators measure the intensity of the ambient sunlight (Bächler *et al*. 2010) and geolocation is possible because changes in ambient light levels can be used to estimate sunrise, sunset, day length times, and hence, longitude and latitude (Burger and Shaffer, 2008). Latitude is derived from the daylength, and longitude from local time for midday and midnight. Two records per day are taken, one indicating the position of the bird at midday the other at midnight. Between 10 and 20 days on either side of the equinox is not possible to estimate latitude accurately (Wilson *et al*. 2002) but this is estimated most precisely at solstice. Position estimates could be affected by clouds, but this problem is solved by increasing the luxmeter resolution. The spatial resolution using GLS presents an error in the order of 185– 200 km. Temperature measures can also be compared with the sea surface temperatures from the estimated location in order to more accurately estimate the daily position of the bird to a 1–2° error reduction (Burger and Shaffer, 2008). Data loggers have been used in long-range movement studies of seabirds outside the breeding period, revealing noticeable movements across the ocean (Burger and Shaffer, 2008) mainly to winter areas.

Although recent tracking technologies have increased the information on seabird migration routes and distribution (Daunt *et al*. 2006; Shaffer *et al*. 2006; Phillips *et al*. 2007a, 2007b, Guilford et al. 2009), many aspects of seabird ecology during their migration and wintering, such as at-sea activity patterns, are still poorly understood (Mackley *et al*. 2010).

The Northern Gannet is a seabird that migrates to a wide variety of wintering areas, from close to their breeding sites (e.g. in the North Sea) to many hundreds of kilometers (about 3200 to 4700 km) south, some going as far as northwest Africa (NWA) (Nelson, 2002). A high proportion of breeding adult birds equipped with geolocation data loggers on the Bass Rock,

employ an intermediate strategy, and winter in the Bay of Biscay (Kubetzki *et al*. 2009). So, individual gannets from the Bass Rock present different migration strategies.

Deployment of data loggers on gannets permits the measurement of the amounts of time spent flying each day, and the temperature of the water in which birds are resting (over night stable temperatures recorded). These data may shed light on costs and benefits of wintering in different regions. For Gannets wintering in NWA there are several hypotheses to be considered:

- Do gannets wintering in NWA fly more during migration than Gannets wintering near to the breeding areas?
- Do gannets need to exploit hours of darkness during migration for flying or for foraging?
- Do gannets have reduced flight activity in their wintering area because of potentially better food availability?
- Do gannets wintering at lower latitudes have more temporal flexibility because of longer daylight?
- Do gannets wintering off NWA avoid the need for foraging at night?
- Do gannets wintering off NWA have lower thermostatic costs due to roosting on warmer water?

Gannets wintering further south may return later in spring to the breeding area.

Material and Methods

Estimating the returning dates

One important clue for a successful logger recovery is to establish the returning dates, from the wintering areas to the breeding colonies. With temperature records from previous 4 data loggers recovered in 2003 and 5 recovered in 2004 it was possible to establish the arriving date to the Bass Rock colony. Daily temperature records between 23:00 and 03:59 (150 records per night) were analyzed to obtain a single modal value by date. Night hours were chosen to have temperature values from the sea, assuming that this species does not fly by night. This modal value was related to date by means of a scatterplot graph, with the obtained records connected by a line. In order to show differences in the temperature values, this variable was transformed to $\log_2$ values. A theoretical graph should show three distinctive parts. In the first part higher temperature values appear, indicating the sea surface temperature

at lower latitudes. The second part corresponds to a decreasing slope, indicating the movement of individuals along the migration route to the north. Finally, a part with the lowest values corresponds to the sea surface temperatures at higher latitudes, specifically at the breeding colony in the North Sea (fig. 5-1). This third part of the graph can then be used to establish the date when gannets return to the Bass Rock colony area. Once birds start to spend the night at their nest site on the rock, the temperature of the logger at night should be very much higher as the logger will then measure temperature when the bird is sitting on the ground and heating the logger with body heat, whereas at sea the temperature indicates sea surface water temperature.
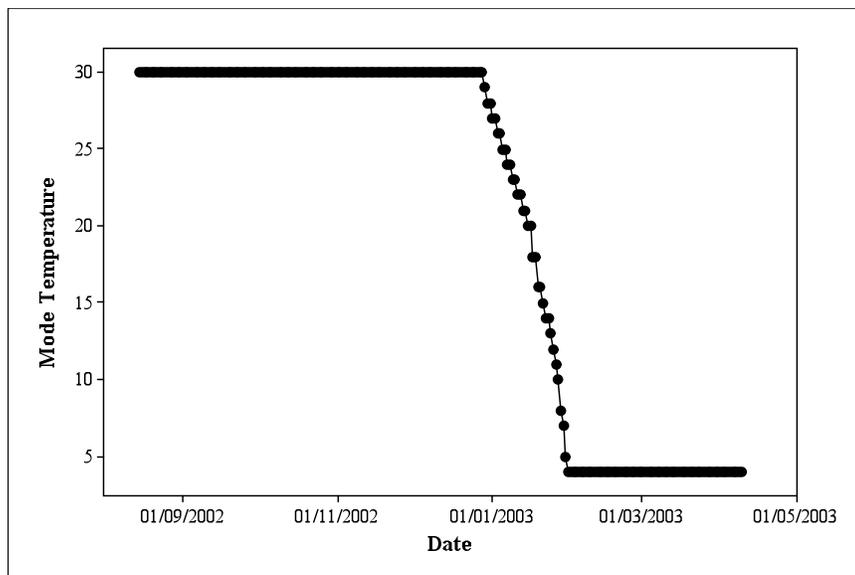
Figure 5-1. Typical graphic trend of logger night-time temperature records by calendar date, showing high values at lower latitudes, followed by a decreasing slope obtained during northern migration and lowest values al high latitudes.

Data loggers

In August 2008, at the end of the breeding season in the Bass Rock, Firth of Forth, east Scotland (56.078°N, 2.639°W), 30 data loggers were deployed on the legs of chick-rearing adult Northern Gannets, attached to a custom-built leg band (photo 1). Twenty-one data loggers were retrieved in April of 2009 and the data recorded for each one were analyzed. Two more recovered data loggers failed, showing no information stored. Recoveries were made during April because previous analysis indicated that February-March is the returning period for gannets breeding in the Bass Rock, and we used the opportunity to recover loggers before birds began to lay eggs or even to construct nests. This made it easier to see which

birds carried loggers (since incubating birds have the logger hidden beneath them) and also avoided the problem of disturbance caused by catching birds possibly resulting in losses of eggs or nesting material.

GLS data loggers (GeoLT; Earth & Ocean Technologies, Kiel, Germany) included light and temperature sensors, and were protected in a pressure-tight seawater-resistant casing. The main sensor of the device was a luxmeter recording intensity of light. Temperature sensor recorded ambient temperatures every 120 s throughout deployment, the sensor measuring in the 0-32°C range. Light measurements allow geographic position to be calculated by means of day length and time of local midday and midnight, using MultiTrace Geolocation from Jensen Software Systems, Germany (For more details see Kubetzki *et al*. 2009). Temperature records were used to establish the activity displayed by the bird. For all birds recaptured sex was determined from DNA extracted from feather bases, using standard molecular methods (Griffiths *et al*. 1998).

Photo 5-1. Data logger deployed on a leg of a Northern Gannet.

Data analyses

Information from four months was analyzed, in order to compare activities during different periods of the year and along the migratory route: from the 1st to the 10th of September at the beginning of the autumn migration, from the 20th to the 30th of October during migration, from

the 1st to the 10th of January during wintering, from the 1st to the 10th of March during colony attendance early in the pre-laying period.

The activity of the bird at sea was deduced from records of thermal fluctuations (following Garthe *et al*. 1999; Wilson *et al*. 2002). In general, when temperature remained constant and relatively low, the bird was considered to be swimming (fishing or resting on the water surface) with the logger submerged and indicating sea surface temperature (SST). On the other hand, when temperature record varied slightly within a higher range and within the range recorded for air temperature at that latitude, the bird was considered to be flying. During March, it was possible to establish an intermediate band of constant temperatures recorded, assuming that the bird was on land. In a more detailed description, the activity of each bird was divided into the three categories (flying, swimming and nesting), and deduced according with the following criteria:

- Estimated sea surface temperature in the area was used as a reference.
    - Variation during the day was considered, assuming that sea surface temperature is slightly warmer during midday.
- According with the sea surface temperature, a threshold was determined in order to establish records from the bird possibly in the water (values around the sea temperature record).
    - Threshold was determined specifically for each individual and each month, by means of a previous revision of the data.
    - Broadly, this threshold was around 12-13º C during September, 10º C during April, 15-16 º C during January for individuals wintering in Africa, and 7-8 º C for individuals wintering in The English Channel or the Bay of Biscay.
- When the temperature records remained constant and low (around the established threshold), the bird was considered swimming.
    - In some cases there was a slight variation in the temperature record, but below the threshold, possibly because of slight changes in the sea temperature (for example effect of the waves, upwelling, or currents).
    - In some cases temperature records dropped for a few seconds, possibly because the bird was diving.
- When temperature records were high (more than 19-20º C) and showed a noticeable variation, the bird was considered flying.

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- When temperature records were slightly high (above the threshold), showing less variation, the bird was considered to be "nesting" which means standing or sitting in the colony (mainly in March).

  o In cases with temperature remaining constant, but slightly high, the bird was considered nesting assuming that it stayed quiet.

  o In cases with temperature showing variation, but below the 20-21 degrees, the bird was considered "nesting", assuming that it was moving or standing (and variation was considered to be produced by the action of the wind).

- Change in the activity was determined when changes in temperature were noticeable (more than 1° C).

  o When changes were slight over a long period of time (about 20 minutes), changes between activities were determined according the switch in the trend of the temperature records.

In most cases it was possible to classify activity with confidence based on these temperature data, the main difficulty being to distinguish between birds flying and birds standing in the colony "nesting". This last problem only applied to the March data, since we know that gannets do not normally go ashore during winter or migration. Analyses were centred on the flying data as a measure of the time spent migrating and searching for food. For each day data were grouped into 12 periods of two hours each (00:00-01:59, 02:00–03:59, and so on until 22:00–23:59). All flying times were transformed into percentages because this made analysis simpler. Finally the percentages were grouped representing the time spent flying for each period of time. Data from the 10 days of each month were grouped to obtain the monthly mean time flying by period of time.

General Linear Models (t-test, one-way ANOVA and balanced ANOVA) were used in order to compare differences in mean times spent flying by month and by sex. Tukey post analysis was used to determine the significance of observed differences. When residuals showed non-normal distribution in the ANOVA, even after a numeric transformation of data, a non-parametric Kruskall-Wallis test was applied. Additional comparisons between times spent flying, by wintering area and between daylight and night hours, were made using Generalised Linear Mixed Models (GLMMs) and considering the months of October, January and March.

Differences between the numbers of males/females wintering in NWA or no-NWA were made by means of F_{Fisher} test. Analyses were carried out using Minitab software, version 16.

Results

According to the examination of the returning dates during 2003 and 2004, the shapes of the trends were quite similar to those expected (fig. 5-1). In terms of returning date, individuals tended to return to the breeding colony during the month of February (fig. 5-2), with one exception of one individual from Iberia. In all cases, individuals were around the colony in the North Sea during the second half of March (more detailed data in Table 5-1).

Table 5-I. Estimated return dates to the North Sea colony by individual.

Data logger number	Wintering area	Returning dates
3	Iberia	Between 16/02/04 and 01/03/04
20	Iberia	Between 05/02/03 and 15/02/03
26	North Sea	Between 01/02/03 and 15/02/03*
28	Africa	Between 21/02/03 and 01/03/03
29	Africa	Between 25/02/03 and 15/03/03
35	Africa	Between 11/02/04 and 21/02/04
48	Iberia	Between 01/03/04 and 11/03/04
50	Africa	Between 15/02/04 and 21/02/04
51	Iberia	Between 01/02/04 and 11/02/04

* It is believed that this individual spent the winter at high latitudes.
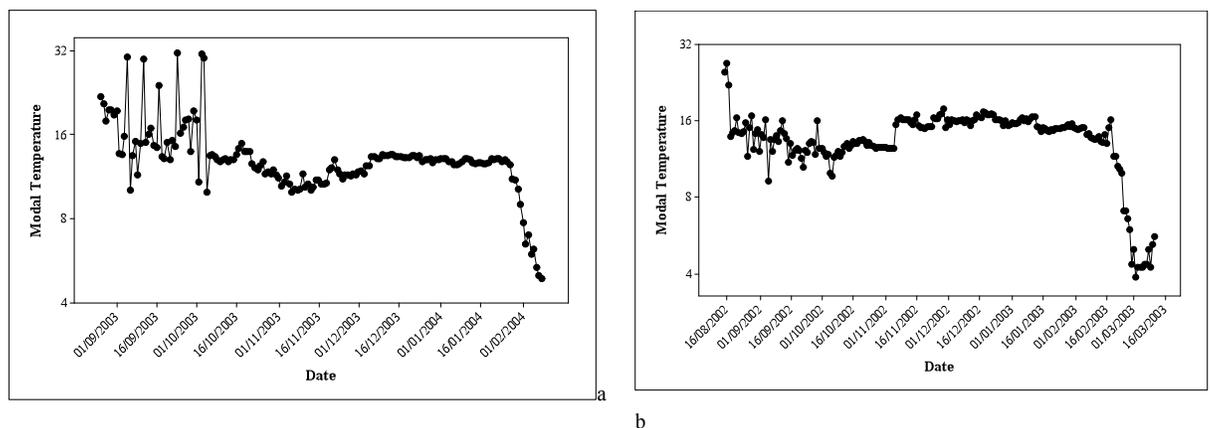
Figure 5-2. Graphs showing the trend in the modal temperature for an individual wintering in a) Iberia and b) Africa.

Surprisingly, most of the individuals recovered in 2009 wintered in NWA (11), followed by the Bay of Biscay (3), and none wintered in the North Sea (Table 5-II). In spite of the fact that females spent more time flying than males, differences were not significant (ANOVA; F = 2.64, DF = 1, p = 0.108). On the other hand, all females wintered in NWA except one off Portugal. In the case of the males, they tended to winter at different locations. So, the distribution of gannets wintering in the NWA or in areas further north (non-NWA) by sex showed significant differences (F_{Fisher} = 8.96, p = 0.0043).

Table 5-II. Number of individuals by wintering area and sex.

Wintering area	Males	Females	Total
North Western Africa	4	7	11
Gibraltar	2	0	2
Portugal	1	1	2
Bay of Biscay	3	0	3
English Channel	2	0	2
Celtic Sea	1	0	1
Total non North Western Africa	9	1	10

Individuals wintering in NWA and Portugal spent more time flying during the entire period analyzed (4 months), and the individual that flew least was one that wintered in the Celtic Sea. Mean percentage of time flying showed non-significant differences between individuals (Kruskal-Wallis; H = 26.33, DF = 20, p = 0.154). Actually, all the individuals showed differences in the time spent flying between days. Mean time flying including all individuals showed the highest values during October and the lowest values in January. Observed differences between months were significant (ANOVA; F = 6.57, DF = 3, p < 0.001; fig. 5-3). Differences observed between months were significant for individuals (GLM; F = 9.19, DF = 3, p < 0.001) but not wintering areas (GLM; F = 0.70, DF = 1, p = 0.405).
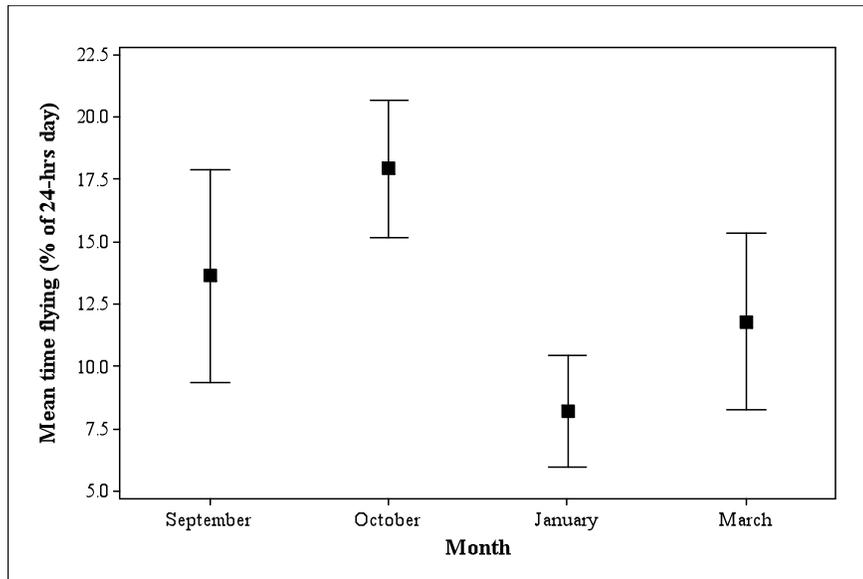
Figure 5-3. Mean time flying by month for all individuals.

Gannets migrating to NWA flew significantly more (19.2 ± 1.6 % of the 24-h day) than birds staying in areas from the English Channel to the Bay of Biscay (12.1 ± 1.8 % of the 24-h day. GLMM; χ^2 = 6.738, p = 0.009). Individuals wintering in NWA in January flew 9.4 ± 1.6 % of the 24-h-day while those wintering from the English Channel to the Bay of Biscay flew 4.6 ± 1.3 % of the 24-h-day at the same month; this observed difference was significant (GLMM; χ^2 = 6.533, p = 0.011).

In the case of the time of the day, all individuals spent more time flying during daylight hours for the four months analysed. Gannets wintering in NWA flew on average 17.7 ± 2.5 % of the daylight time during January, whilst gannets wintering further north flew 9.6 ± 3.1 % of the daylight time, the observed difference being significant (GLMM; χ^2 = 5.716, p = 0.017).

Discussion

Observed differences in time flying by day for all individuals could be due to changes in climatic conditions or fish distribution. It has been reported for anhingas that these often forage less frequently during cool, cloudy periods, compensating the heavy foraging effort when weather is warmer (Hennemann, 1985). Because of this, differences in the time spent flying by day in Gannets could be related to the administration of the periods of flight and

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fishing, in order to fly more time when conditions are good and less time when weather conditions are adverse.

No significant relationship between sex and time flying was detected, but the tendency of females to migrate further south than males is clear and significant. On the other hand, experienced males are the first to return to breeding colonies (Nelson, 2002) so females are able to stay in the wintering grounds for a little longer. Females may be more suited to feeding conditions in the tropics (e.g. the depths at which fish occur) or they be better suited to the warmer climate. Further study is needed on the preference for particular wintering locations by sex.

Individuals wintering in NWA and Portugal spent more time flying during the entire period analyzed than those wintering in northern latitudes partly because they travelled much longer distances. This observation, in addition to the highest time spent flying being during the month of October, confirms the hypothesis that Northern Gannets spent more time flying during migration to reach southernmost wintering areas. In the winters of 2002-2003 and 2003-2004, Gannets migrating to NWA flew for about 48% longer than birds remaining in the North Sea (Garthe *et al*. unpub. data). Gannets spent less time flying during January maybe because of the abundance of food in the wintering grounds or as strategy to save energy before the return journey to breeding colonies.

Finally, time spent flying was higher during daylight hours, confirming the diurnal behaviour of this species. However, time of the day considered (2-hours period) is not independent. Because of this, it is important to observe carefully the differences in time flying/swimming by period of time. Fishing by night, even on small pelagic fish (mainly caught by the commercial fishing fleet during the night hours) is difficult to observe because gannets are visual hunters (Garthe *et al*. 2003; Hamer *et al*. 2000). Gannets wintering in NWA spent more time flying during daylight hours in January than individuals wintering in the north, maybe due to a) the abundant fish, b) the need to acquire energy for the returning journey, c) the need to recover the energetic cost of the southerly migration, or d) competition for food with other seabirds and man. An alternative explanation could be that birds fly more in NWA during winter because of the lack of food. In all cases, it is important to note that gannets spent less

time flying during winter than during the rest of the year, implying that the energy expenditure in winter is likely to be rather less than during the breeding season.

During breeding, the Northern Gannet can spend up to 44% of its time flying (Garthe *et al*. 2003), because the search for food is a very demanding process when chick rearing.

Chapter 6

Northern Gannet and Great Skua migration records

Abstract

Using information provided from academic and non academic literature, observational point reports, and birdwatching groups, it was possible to map the migration movements of both Northern Gannets and Great Skuas. For both species it was possible to detect the timing of the route from de Scottish colonies through the North Sea and English Channel to reach in winter months the Bay of Biscay and the coast of NWA. Distribution in waters off Africa is wider in the case of the Northern Gannet, being gannets and skuas fairly common distributed in the area.

Introduction

Migration

Seasonal changes in weather conditions, resulting in the scarcity of particular resources such as food, cause some animals to migrate seasonally to distant regions where resources are abundant (Cohen, 1967). In most cases, these movements are between breeding areas (with better conditions for reproduction), and wintering areas (with better conditions for survival during the winter months). The main reason to migrate is the search for a favourable area from another less favourable one (Newton, 1980).

Seasonal migration involves return movements at regular periods of time (migration periods), often to well-defined destinations (Marchant, 2002; Newton, 2008). The migration from breeding areas at higher latitudes in the northern hemisphere, to wintering areas at lower latitudes, takes place in autumn, with the return travel to high latitudes in spring (Newton, 1998). This periodic movement is related to changes in weather, daylength, and food shortage (Cohen, 1967), and the non-random direction and distance of migratory travel seem to be innate (Nelson, 1980). Research on small birds has shown that migratory distance and direction are usually genetically determined (Berthold and Helbig, 1992; Bearhop *et al.* 2005) and this is thought to be true of migratory birds in general (Newton 2008).

The capacity for flight permits birds to move to distant areas in a short period of time, and their migration is more broadly and strongly developed than in other migrating animals, like mammals, turtles and fish (Newton, 2008). Migration is a normal winter response of many

species of seabirds, especially those species breeding at high latitudes (Gaston, 2004), and the most remarkable features of this migration are related to 1) the navigation, to find remote nesting areas for example, 2) the timing of return to breeding areas at similar date, and 3) the gain of energy in form of body mass during the wintering period (Newton, 2008). As a result, migration is mainly an adaptation to take advantage of resources during some seasonal periods of abundance, avoiding the lack of these resources during other periods (Alerstam *et al.* 2003).

With weather conditions changing, birds follow routes as a result of natural selection (Bairlein *et al.* 2002). Long distance migrants, including some seabirds and shorebirds, do not breed until they are several years old, and the young may migrate further than their parents, reaching better wintering zones usually in tropical regions. During their first year, the movements of some seabirds (kittiwakes, shags, fulmars, puffins, boobies, frigatebirds and many gulls, for example) are more extensive than in following years (Nelson, 1980). Some of these young birds overwinter in low latitudes and return to breeding areas, or return partially, two springs after (Bairlein *et al.* 2002). Migratory tendencies have changed over time for several species (Sandwich Tern and Lesser Black-backed Gulls are two well known examples), with shorter migratory movements, as a result of global warming because northern regions became more suitable for wintering birds (Siriwardena and Wernham, 2002).

Direct observations are one way to study bird migration, recording numbers of individuals, their distribution and seasonal changes, and watching the direction of their flight movements (Marchant, 2002). In these cases, it is usually possible to observe these birds both in their breeding and wintering areas, and at some points along their migration route e. g. at bird observatories which are often located at hot spots (Knudsen *et al.* 2007). Birdwatching clubs and societies have been organizing periodic surveys to record the presence and abundance of seabirds in some places, and several checklists are available. The catch and release of ringed birds at bird observatories has also been used to evaluate individual bird movements along the migration route (Blomqvist *et al.* 2002) and to investigate migration phenology (Knudsen *et al.* 2007).

Observation points

In addition to ringing/banding at bird observatories, daily censuses by means of standardized counts are often conducted in order to provide a daily estimate of the number of birds passing through an observation point. In the case of seabird censuses from coastal points, reliable estimates of abundance and distance from the point of observation are required (Mateos *et al*. 2010). Bird observatories are located around Europe in locations considered hot-spots for such observations (Flegg, 2004), with observers including local people, both scientists and volunteers. Some information is available from the web pages from different kinds of organizations (like the British Trust for Ornithology, the Royal Society for the Protection of Birds, the Scottish Ornithologists' Club, la Red de Observacion de Aves Marinas, or the African Bird Club). At a bird observatory a census area may be established for keeping records of all observations (Mead, 1983). Along migratory pathways between foraging and breeding areas, surveys from observation points are valuable as seabird wintering populations could decline even more than residents, due to alterations of habitats used on migration (Newton, 2004).

The importance of a bird observatory goes beyond the simple recording of data. With the information obtained it has been possible to justify the declaration of conservation areas, or to facilitate the making of development decisions. One important example of this was the support of the Point Reyes Bird Observatory, in California, in solving the controversy in relation to the kill of birds by the gill-net fishery in Monterey Bay (Salzman, 1989).

Materials and Methods

Despite the lack of detailed studies about seabird migration in North-western Africa (NWA), some reports have been made, and there are some important counts published. Most of the early reports in the area were based on sea or land surveys, with information restricted to some notes (for example Winterbottom, 1936 and Moreau, 1938; both reported in Brown, 1979). Based on a literature survey, an historic record of sightings of both gannets and skuas was obtained to provide some background information about the presence of these species wintering along the coasts off Western Africa.

Information from birdwatching organizations

Birdwatching organizations around the world can be a primary source of information, since they survey specific areas, mainly for tourism. In one particular case seawatching in Senegal is considered important and some touristic reports are very eloquent: "Seawatching in Senegal – a dreamlike scenario" (Holmström, 2004), "Seawatching (in Senegal) that will beat the world" (Nilsson, 2008) or "Is the Cape Verde Peninsula the Mecca of seawatching?" (Dubois et al. 2009). Despite many of these groups being by non-academic bodies, and their records often being made without standardized methods, data obtained can at least provide a guide to a more detailed research. The African Bird Club provides detailed checklists (http://www.africanbirdclub.org/countries/checklists/index.html**)** from different areas in NWA, mainly based on specialized sources of information. By means of these checklists, the status of the Northern Gannet and the Great Skua were surveyed for countries and islands along the NWA area. In order to map the distribution of these seabird species in the sub-continent, checklists were used as simple presence/absence records.

Information from observation points

Numbers of gannets and skuas were obtained from different point counts in Europe and Northern Africa from the Trektellen organization (http://www.trektellen.nl/default.asp?). Data were obtained from different sources, including the Red de Observacion de Aves Marinas (RAM) de España y Portugal, SOVON Vogelonderzoek Nederland**,** Natuurpunt Studie & Aves-Natagora. Selected points were those with more information provided, and located along the gannet's and skua's migration route; these are Winterton (Norfolk) in the UK, Maasmond (Maasvlakte) in the Netherlands, Westerland (Sylt) in Germany, Gateville (Normandie) in France, Cabo Ajo (Bay of Biscay) in Spain, and both Melilla and Ceuta in Africa (fig. 6-1).

Figure 6-1. Location of the observation points with gannets and skuas counts

Information provided was available for 1 to 5 years, depending on the observation point, and mostly included the twelve months of the year. Seabird numbers were standardized according to the time spent observing every day, obtaining the mean number of birds observed for minute by month by location.

Analyses were conducted according to the amount of information obtained at each observation point, in order to obtain the most detailed results in relation to migration of the Northern Gannet and the Great Skua. Basically, analyses included graphs to observe the variation of the seabird numbers recorded, and some comparisons were there made between winters. Data from Iberia provided by the RAM were analysed in more detail, and the region was divided into three areas (fig. 6-2): the south of the Bay of Biscay, Portugal and the Atlantic coast, and the Southern Iberia including the Gulf of Cadiz, Maderia and two points in Africa (Melilla and Ceuta). Each area provided information from several observation points, up to 11, and data was transformed into mean number of gannets or skuas by month for minute of observation. In the case of the south of the Bay of Biscay, data obtained were divided into two years, according to the presence of seabirds during the autumn migration in the area, from November of 2005 to October 2006 and from November 2006 to October 2007. In order to detect

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differences between years, a paired t-test was applied. A one way ANOVA was employed to detect differences between the three areas.

The RAM provided information about three age classes of Northern Gannet according to the plumage colour: Age Class 1 (Juveniles) including individuals during their first year, Age Class 2 (Immatures or Sub-adults) from the second up to the fourth year, and Age Class 3 (Adults) including all the individuals with body, tail and covert plumage totally white. With this information it was possible to compare the mean number of seabirds by month and per minute by age class, using ANOVA.
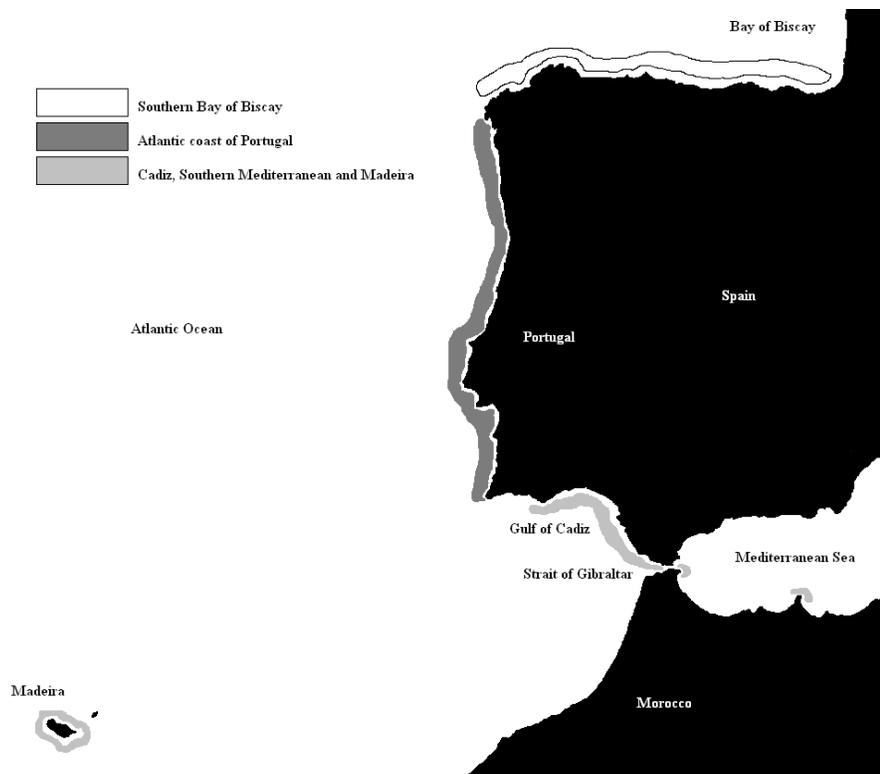
Figure 6-2. The three divisions considered from the Iberia Peninsula.

Results

Information obtained from previous reports is summarized in the Table 6-I. A detailed description is presented by species.

Table 6-I. Historic reports from Northern Gannet and Great Skua in NWA, with relative abundances.

Northern Gannet

Date	Location	Rel. abundance	Reference
Nov 1935	NWA south to Northern Mauritania	e	Winterbottom, 1936*
Apr-May 1937	Southern Western Sahara and Northern Mauritania	b	Bird, 1937
Feb 1942	Southern Western Sahara	d	Mayo 1948
Jan 1967	Senegal	d	Lambert, 1971*
April 1968	Senegal	a	Gaston, 1970
Feb-Mar 1976	Senegal	a	Brown, 1979
Winter 1982	NWA south to Guinea-Bissau	b	Brown *et al.* 1983**
May 1988	Mauritania	b	Leopold, 1993
Autumn 1990	Senegal	d	Baillon and Dubois, 1991
Oct 1994	Senegal	d	Allport, 1995
Apr-May 2003	Mauritania	b, c	Wynn and Knefelkamp, 2004
Oct 2003	Senegal	d	Holmstrom, 2004
Jan 2000	Western Sahara and Mauritania	a	Camphuysen and van der Meer, 2005
Oct 2007	Senegal	c	Nilsson, 2008
Oct 1995	Senegal	d	Dubois *et al.* 2009
Oct 1996	Senegal	c	Dubois *et al.* 2009
Oct 1997	Senegal	c	Dubois *et al.* 2009
Oct 2001	Senegal	d	Dubois *et al.* 2009
Oct 2003	Senegal	d	Dubois *et al.* 2009
Oct 2005	Senegal	d	Dubois *et al.* 2009
Oct 2007	Senegal	c	Dubois *et al.* 2009
Oct 2008	Senegal	d	Dubois *et al.* 2009

Great Skua

Date	Location	Rel. abundance	Reference
Feb 1942	Gibraltar	d	Mayo, 1948
Feb 1942	Southeastern Cape Verde Islands	d	Mayo, 1948
Jan 1971	Nigeria	d	Wallace, 1973
Feb-Mar 1976	Senegal	d	Brown, 1979
Dic 1977	Madeira	d	Furness, 1987
May 1988	Mauritania	c	Leopold, 1993
Aug-Dec 1991	Senegal	d	Baillon and Dubois, 1991
Apr 1992	Senegal	d	Marr *et al.* 1998
Oct 1993	Senegal	d	Allport, 1995
Apr-May 2003	Mauritania	d	Wynn and Knefelkamp, 2004

Relative abundance: a) Very abundant (>100 ind), b) Abundant (50-100), c) Not abundant (10-49), d) Rare (<10) and e) Abundance not established.
* Reported from Brown, 1979
** Reported from Camphuysen and van der Meer, 2005

Historic records for Northern Gannet from NWA

During April and May 1937 a large number of almost exclusively young Gannets (only one adult) were observed in the southern Western Sahara and northern Mauritania, possibly remaining there more than one winter on account of the abundant fish (Bird, 1937). During the winter of 1947-1948 a group of about 50 individuals, mostly juveniles, was sighted in

Mauritania, but the reference grouped gannets and boobies as sulids (Benson, 1948). In January 1967 one juvenile and two adults were observed in the coast off Senegal (Lambert, 1971). A large number of juvenile and immature gannets (436), identified by their brown coloration, were observed in Senegal in April 1968, and only 18 adults with white plumage (Gaston, 1968). From 750 gannets observed in 1976 mainly in the coast off Senegal, 25% were adults in February and 8% during March (Brown, 1979). In May 1988, 67 gannets, mainly immatures, were observed over the shelf break in the Cape de Arguin area, Mauritania (Leopold, 1993).

In the best systematic survey existing from NWA, the Northern Gannet was the most abundant species with 5648 individuals observed off the coast of Western Sahara and Mauritania during six days in January 2000. About 89% of these gannets were feeding behind fishing boats, concentrated on the shelf close to the shelf break (Camphuysen and van der Meer, 2005).

In addition to sea or land surveys, the recovery of dead individuals ringed in the northern colonies provide more detailed data. Based on ring recoveries, Nelson (2002) reported 17 gannet recoveries from Senegal, 62 from Western Sahara and 103 from Morocco between 1972 and 1975. Only 21 individuals ringed in the Bass Rock were found to the south of Britain, with no reports from lower latitudes than 20º N (Nelson, 1978). Only 3 recoveries from 639 (0.5%) adult gannets recovered between 1909 and 1997 were from latitudes south of 20º N (Wanless, 2002). Since 1931, 909 Northern Gannets have been ringed in the Faroe Islands. From these, 30 rings have been recovered, 9 from Morocco, 7 from Mauritania and 8 from Senegal (Danielsen and Jensen, 2004). A recent report showed that 45% of 18 adult gannets from the Bass Rock, equipped with data loggers in summer 2002, wintered in NWA, 50% of them males and 50% females (Kubetzki et al. 2009).

Historic records for Great Skua from NWA

This species has been reported as common anywhere north of the Azores Islands in winter, and occasional further south. Ring recoveries from Africa, during the period 1963-1990, represented only 5.5% of the total, being 64 individuals mainly older than one year (Klomp and Furness, 1992).

No individuals were reported in Cape Verde during the surveys in September 1912 (Murphy, 1924), and July and August 1951 (Bourne, 1955). In some reports, authors were unable to establish the species, recording a great numbers of individuals grouped just like *Catharacta* skuas, possibly Great Skuas, South Polar Skuas, Brown Skuas (Marr *et al.* 1998; Holmstrom, 2004; Nilsson, 2008; Dubois *et al.* 2009), or only Skuas (Bird, 1937; Gaston, 1968).

Information from birdwatching organizations

The Northern Gannet and Great Skua status by African country or island is summarized in Table 6-II. With this information, it is possible to observe the wider distribution of the gannets in the area than skuas (fig. 6-3). Additional checklists refer to Northern Gannets ranging at sea along the Atlantic coast to NWA and casually in the Cape Verde Islands, and the Great Skua to the Tropic of Cancer and rarely in the Canary Islands (American Ornithologists' Union, 1998).

Table 6-II. Status of the Northern Gannet and the Great Skua by African country or island according to the species checklist of the African Bird Club (data obtained from a wide sources of information, mainly: Birds of Africa vol. 1-7, 1982-2004, edited by one or more of C. H. Fry, E. K. Urban, G. S. Keith, L. Brown and K. Newman, Academic Press**).**

Country or Island	*Morus bassanus*	*Stercorarius skua*
Azores Islands*	Winter Migrant	No report
Canary Islands	Winter Migrant	No report
Madeira Island	Winter Migrant	Migrant**
Morocco	Winter Migrant	Winter Migrant
Mauritania	Wintering population***	Wintering population***
Senegal	Wintering population***	No report
The Gambia	Wintering population***	No report
Guinea-Bissau	Palaearctic****	No report
Cape Verde	Palaearctic****	Palaearctic****
Guinea*	No report	No report
Sierra Leone*	Palaearctic****	No report
Ascension Island*	No report	No report

* These locations are not part of the study area, but were included to compare the limits of the distribution for the gannets and skuas.
**Checklist does not specify the period (possibly overwinter).
***Winters commonly in the area, possibly the same population.
**** Species is a Palaearctic breeder, possible considered rare in the zone.

Information from observation points

According to data from the observation points in Europe, the Northern Gannet remains in the North Sea between February and September, moving through the Channel between August and October to reach the Bay of Biscay in November and December. Individuals moving south are observed in NWA and the Western Mediterranean between October and March (fig. 6-4). Similarly, Great Skua individuals are in the North Sea between February and September, moving through the Channel between September and October to reach the Bay of Biscay in November. Individuals moving south are observed in NWA and the Western Mediterranean between January and March (fig. 6-5).

Northern Gannet

Great Skua

Not reported
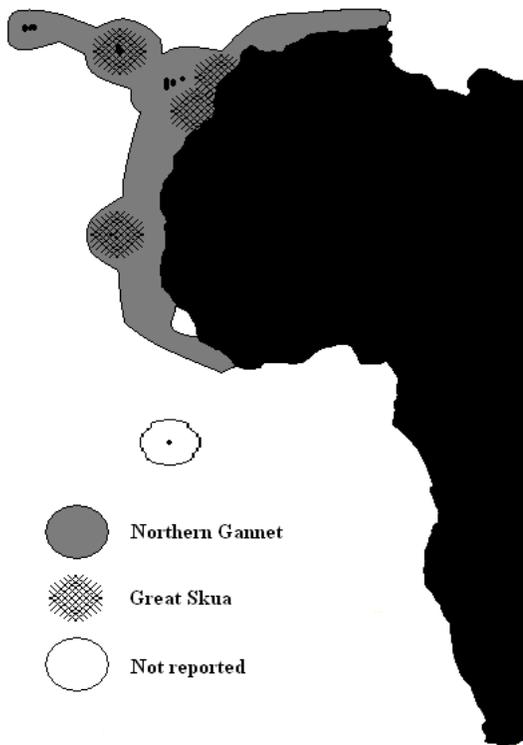
Figure 6-3. Northern Gannet and Great Skua distribution in North-western Africa, according to the checklists from the African Birding Club.

Figure 6-4. Northern Gannet migration timing showing the higheest monthly abundances in the different areas, by observation points.

Figure 6-5. Great Skua migration timing showing the highest monthly abundances in the different areas by observation points.

The Northern Gannet showed highest numbers during September and October in Gateville, France. A graph comparing for several years the mean gannet number during these months, standardized by minutes of observation, shows the highest values during the years 2006, 2007 and 2008, particularly 2007. In the case of the Great Skua, numbers were similar between years (fig. 6-6). In Cabo Ajo, Spain, numbers were higher during the winter months for both gannets and skuas. In this location, data from five winters were analyzed (from 2005 to 2010), showing the highest numbers in the 2005-2006 winter for gannets and in the 2008-2009 winter for skuas (fig. 6-7). Similarly, lowest values were observed for both gannets and skuas in the 2006-2007 winter.
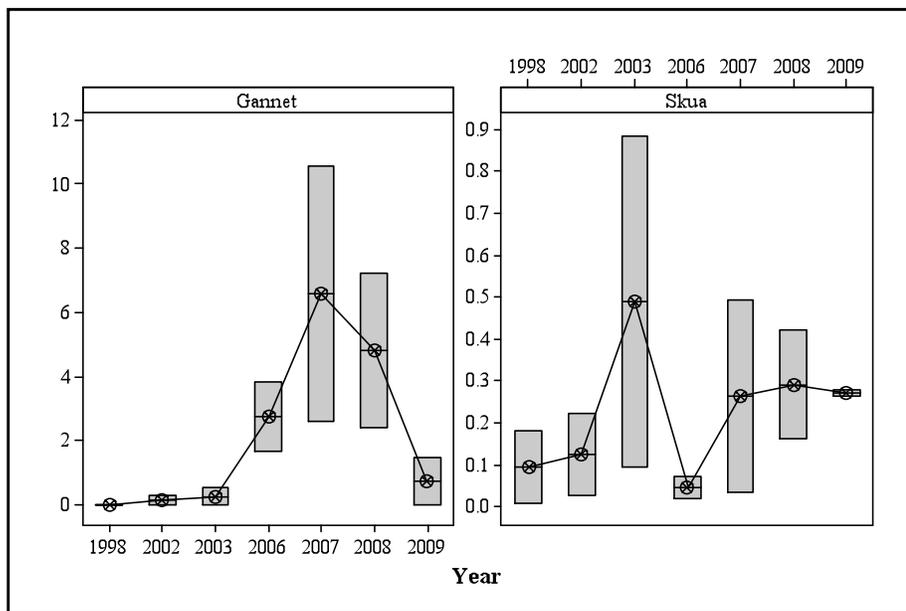
Figure 6-6. Seabird numbers by species per minute for the months of September and October in Gateville, France, showing range and median.

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Figure 6-7. Seabird numbers by species per minute for winter in Cabo Ajo, Spain, showing range and median.

Data from three winters were analyzed from Melilla and Ceuta (from 2007 to 2010), showing the highest numbers in the 2008-2009 winter for Gannets in both locations (fig. 6-8) and in the 2008-2009 winter in Melilla and 2009-2010 winter in Ceuta for Skuas (fig. 6-9).
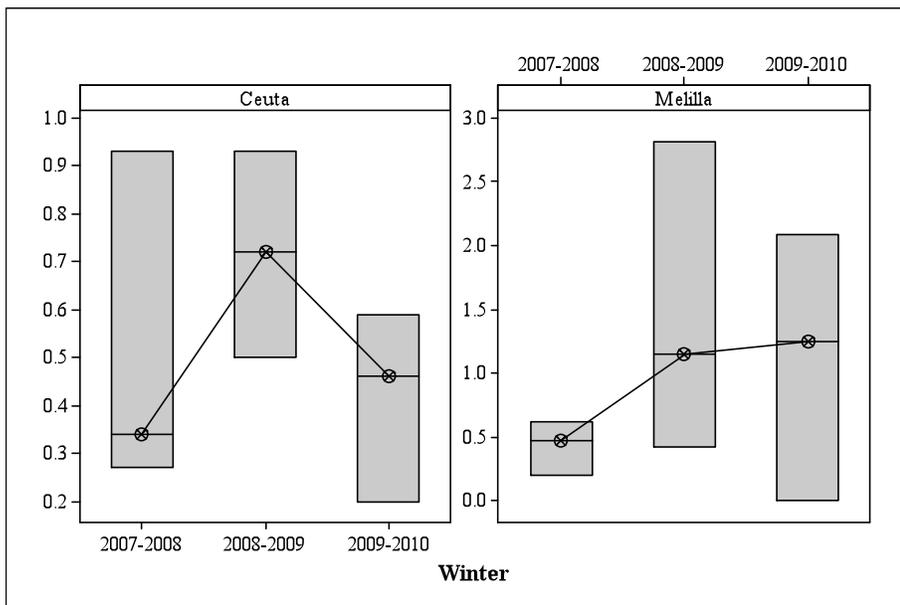
Figure 6-8. Gannet numbers per minute in two North African locations, Melilla and Ceuta, for three winters, showing range and median.

Figure 6-9. Skua numbers per minute in two North African locations, Melilla and Ceuta, for three winters, showing range and median.

Northern Gannet *in the three areas around Iberia*

Data from locations in the Southern Bay of Biscay showed higher numbers during winter months, with peaks in February, with higher numbers during the 2006-2007 winter than during the 2005-2006 winter (fig. 6-10). Differences in the monthly mean seabird numbers by minute between 2005-2006 and 2006-2007 were significant (t = -2.59, p = 0.025). Detailed analyses by age class showed a higher numbers in the Age Class 3 (adults) for both winters, with more gannets migrating to this area during the 2006-2007 winter (fig. 6-11). During the 2007 spring, numbers of Age Classes 1 and 2 were higher due to immature birds remaining after adults had moved north towards colonies. Mean numbers by age class showed a significant difference (ANOVA; F = 5.80, DF = 2, p = 0.005).

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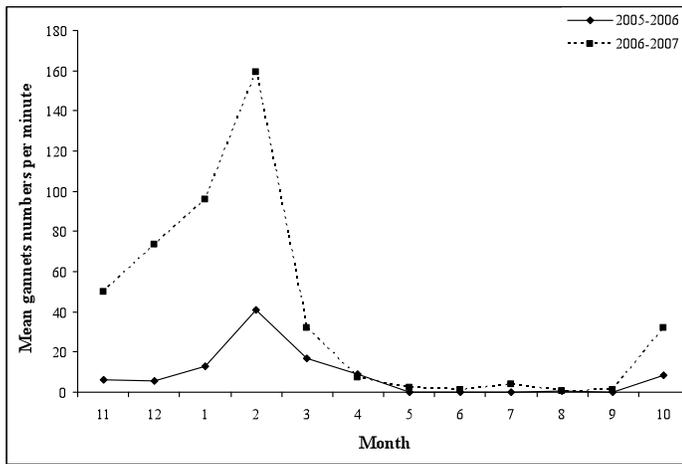
Figure 6-10. Mean number of Gannets in the Southern Bay of Biscay during two winters.
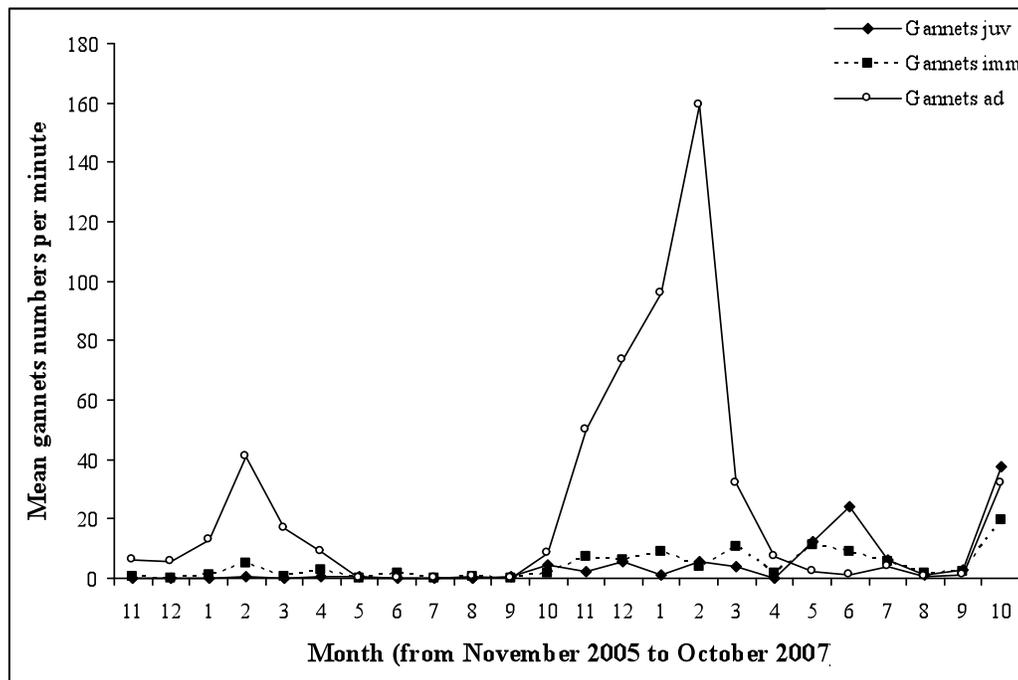
Figure 6-11. Mean numbers of Gannets in the Southern Bay of Biscay by age class.

In Portugal and the Atlantic coast off Iberia the numbers of Gannets were higher, especially from the Age Class 3 (adults), during the winter period 2006-2007 (fig. 6-12). Surprisingly, some adults remained during March and April. Observed differences between age classes were marginally significant (ANOVA; $F = 3.44$, $DF = 2$, $p = 0.052$).

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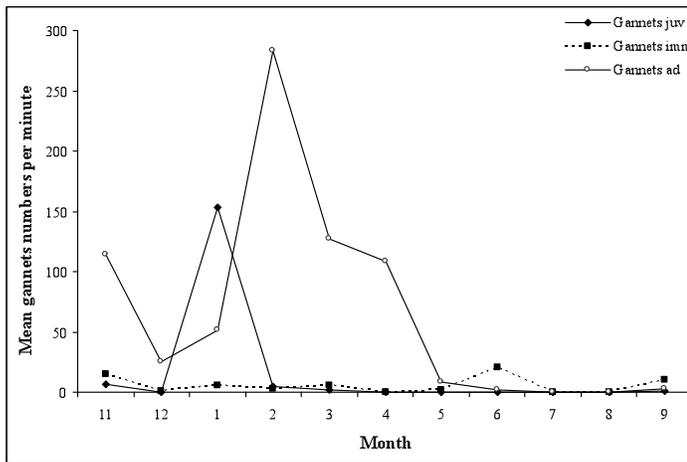
Figure 6-12. Mean number of Gannets in Portugal and Atlantic coast, by age class, during one year.

The numbers of Gannets in the Gulf of Cadiz, Madeira and Western Mediterranean were higher, mainly Age Class 3, during the winter months with peak in March (fig. 6-13). Observed differences between age classes were not significant (ANOVA; F=2.71, DF = 2, p = 0.089).
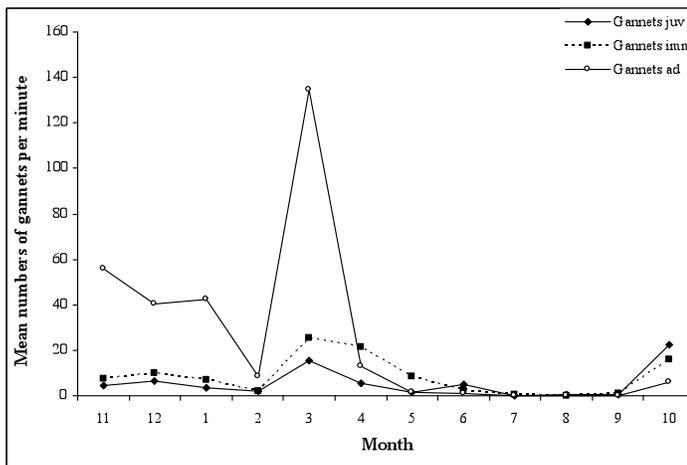
Figure 6-13. Mean numbers of Gannets in the Gulf of Cadiz, Madeira and Western Mediterranean by age class.

From the three areas around Iberia, numbers of gannets were higher in Portugal and the Atlantic coast (fig. 6-14), with the observed differences marginally significant (ANOVA; F = 3.29, DF = 2, p = 0.05).
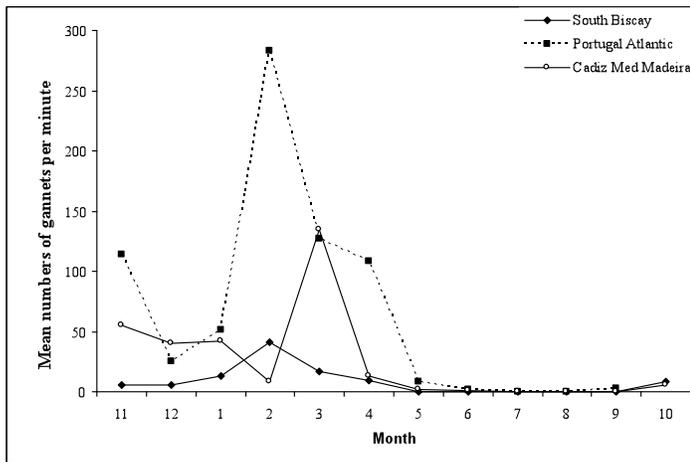
Figure 6-14. Mean numbers of Gannets in the three areas around Iberia.

Great Skua *in the three areas around Iberia*

Great Skua showed higher numbers during the winter months, and during the 2006-2007 winter in comparison with the 2005-2006 winter in southern Bay of Biscay (fig. 6-15). Similarly with gannets, Great Skua presented the highest numbers in Portugal and the coast off the Atlantic during November and December (fig. 6-16), showing statistically significant differences (ANOVA; $F = 4.71$, $DF = 2$, $p = 0.016$) between locations.
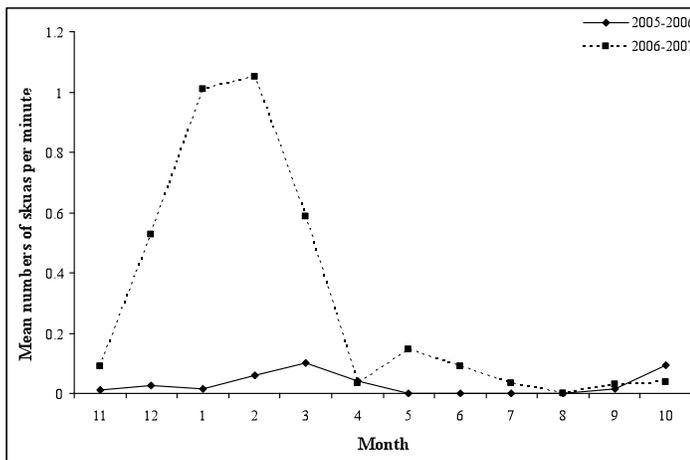
Figure 6-15. Mean number of Skuas in the Southern Bay of Biscay during two winters.

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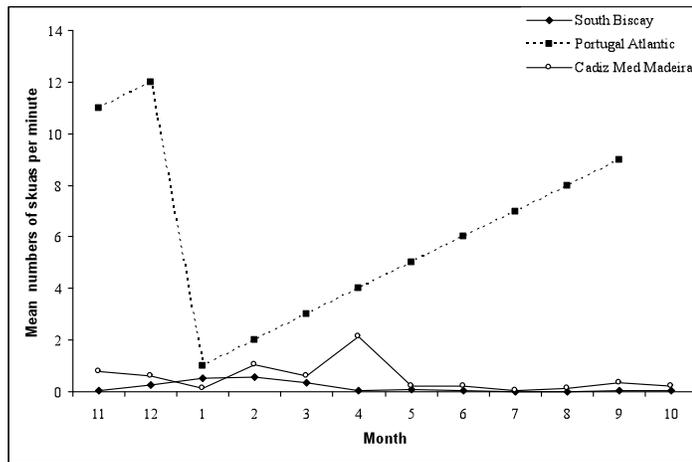
Figure 6-16. Mean monthly abundance of Skuas in the three areas around Iberia.

Discussion

According to the birdwatching checklists, the Northern Gannet has a wider winter distribution area in NWA than the Great Skua. Besides the Great Skua there are other skua species wintering in the area, the Long-tailed Skua *Stercorarius longicaudus*, the Arctic Skua *S. parasiticus* and the Pomarine Skua *S. pomarinus* (Furness 1987). In some cases individuals from these species could be misidentified, because there are plumage similarities between species especially with immature birds and juveniles. In fact it has been reported that some individuals identified as Great Skua could be South Polar Skua *Catharacta maccormicki* in Senegal (Marr *et al.* 1998).

Surprisingly, checklists from Azores and Canary Islands do not include the Great Skua. Both archipelagos have been well studied and are located in areas with a high amount of food available in terms of pelagic fish, fishery discards and local seabirds. It is difficult to believe, especially in the Canary Islands, that information about Skuas is scarce in these locations given the number of visiting ornithologists and birders. On the contrary, this species is included in the checklists from Madeira and Cape Verde. It the case of Madeira, Great Skua has been observed (Dorst, 1962) with a ring recovered (Furness, 1987). It is difficult to interpret why the Great Skua has been reported in Madeira and not from in the near islands, and some hypothesis could be suggested: a) Madeira is located in the migration route of the Great Skua, b) Azores and Canary Islands are more dense populated areas and c) there are errors in at least one of the checklists.

There are no reports from Ascension Island because this location is far south and away from the continent. A location without any report is Guinea (fig. 3) but this could be due to a lower birdwatching effort in the country, or because this area is at the southern limit of both Northern Gannet (Nelson, 2002) and Great Skua (Cramp *et al*. 1983), with only one report in Lagos, Nigeria (Wallace, 1973). Political problems and poverty may cause the lack of interest in ecological research in some NWA countries.

Based on previous reports of Northern Gannet and Great Skua near the coast off NWA it is possible to establish that these species are fairly common in the area, mainly during winter. Nonetheless, variations in recorded abundances are great maybe due the constant movement of individuals in their search for food, or the lack of systematic surveys. In last two decades the number of reports of wintering seabirds in NWA is increasing, and this could support the idea that seabird numbers wintering in NWA are increasing in recent years or extending their range.

During winter, gannets are numerous on the shelf waters in southern latitudes south to Guinea-Bissau (up to 10º N), mainly associated with fish shoals or fishing boats (Brown *et al*. 1983; reported in Camphuysen and van der Meer, 2005).

Some surveys from NWA do not report gannets or skuas in the area (Moreau, 1938; Bierman and Voous, 1950; both reported in Brown, 1979), maybe due to a low observation effort or the season. In the particular case of the Cape Verde Islands, the lack of gannets and skuas in 1912 and 1951 could be explained because those surveys took place in September, during the migration period. However, there are recent reports of gannets and skuas in Cape Verde maybe due a more recent spread of these birds there.

During the survey in Mauritania in December 1984, no gannets or skuas were observed, maybe because the surveyed area only included the coast (Hazevoe, 1984). On the other hand, the very wide variation in gannet numbers from Senegal (Dubois *et al*. 2009) indicates that those wintering in NWA could be moving over a large area maybe according to the fishing activities. Because this is an area with low human development, fishing activities could change between years by chance alone. Nevertheless, large fishing fleet activities are centred in the shelf break of Mauritania and Western Sahara, in the upwelling area, showing a more

uniform distribution than seabirds (Camphuysen and van der Meer, 2005). Finally, seabirds could choose their wintering ground according to the food availability rather than migrating to a specific area, especially because natural food (i. e. not from fishing boats) is sparse.

Migration timing maps show clearly the southern movement of the bulk of seabirds. Returning maps are difficult to draw because returning dates are quite different between individuals, showing no clear pattern of individuals flying northwards, and some young could overwinter in the south. More detailed analyses could include the direction of the birds passing by the observation point, but this information is not always recorded.

There is no detectable trend over years in the numbers of gannets wintering in Biscay, according to records from Cabo Ajo, but skua numbers show a tendency to increase in recent years. The 2006-2007 winter shows the lowest numbers of both species, maybe because that was a "bad year" in terms of weather or food available. On the other hand, the two following winters were "good" with highest numbers of skuas (2008-2009) and the previous winter for gannets (2005-2006). The period 2008-2009 was good with higher numbers of gannets in Melilla and Ceuta, and 2008 autumn in Gateville, France. Overall, the 2008 autumn and following winter was the period with the highest records of gannets and skuas wintering around Iberia. Despite the lower values during the 2006-2007, numbers of both gannets and skuas were higher than previous winter (figs. 6-11 and 6-16) in the southern Bay of Biscay area. This could indicate that these seabird species are increasing in numbers wintering there in recent years.

Age Class 3 (adult) gannets were more abundant than younger individuals during winter months. This is an unexpected result because adults are considered to tend to remain closer to the breeding areas, in comparison with juveniles.

The coast off Portugal was the area with highest numbers of both gannets and skuas. This could indicate the tendency of these species to move further south in recent years. The increasing trend in the number of migrants in NWA is not possible to detect here because the area Cadiz-Madeira-Mediterranean is not representative for the NWA. But it is important to mention that both gannets and skuas could be wintering in the Mediterranean Sea or Madeira rather than the Bay of Biscay, a traditional wintering ground.

Chapter 7

Fisheries status and climate in the distributional area of Northern Gannet and Great Skua

Abstract

Fishing activity has changed along the entire distributional area of the Northern Gannet and the Great Skua, from the colonies in northern waters to the tropical latitudes in the NWA. These changes were studied by means of international fishing reports from FAO, and related with changes in the climate (sea surface temperature and NAO Index). Demersal and pelagic fish species are the main fisheries in the entire North-eastern Atlantic. Overall, fisheries present a decreasing trend in the European countries and a slight increasing trend in NWA countries, observed in the discard volumes. With exception of the Archipelagos areas, the coast of NWA presents non-noticeable increase of sea surface temperature. Fisheries are positively related to the winter NAO Index, indicating more fishing captures when oceanic conditions are cold with strong upwelling, suggesting a relationship between the climatic conditions with the abundance of fish.

Introduction

Fishing is the most widespread activity of man in the marine environment (Jennings and Kaiser, 1998) and generates the main source of protein for several millions of people. The growth of the human population and the improvement of technology have driven a fast expansion of fishing activities in the last 50 years (Jennings *et al.* 2005). As a result, the global fish catch is declining as demand is increasing, with the consequent dramatic collapse of some fish stocks, such as the Peruvian Anchovy and the Atlantic Cod which have been the focus of fisheries scientists (Myers *et al.* 1996; Jennings and Kaiser, 1998). In addition, unwanted species are taken as bycatch (Alverson *et al.,* 1994; Hall, 1996).

Marine ecosystems are under a range of exploitation rates, showing a mosaic of fish stocks declining, collapsed and stable (Worm *et al.* 2009). Overfishing represents a great problem nowadays, and the collapse of fish stocks has been documented around the world. About 25% of fisheries collapsed during 1950-2000, with no apparent improvement in sustainability in recent years (Mullon *et al.* 2005). Overfishing is a real environmental problem in the oceans with serious consequences in the reduction of biodiversity and ecosystem functioning (Worm *et al.* 2009). In addition, the average trophic level represented by fisheries landings has

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declined in recent decades at global scale, without a substantial increase in the volume landed. This trend will lead to further widespread fisheries collapse (Pauly *et al.* 1998).

In addition to the overfishing, the decline of fish species like Atlantic Cod is related too with a decline in the abundance of the planktonic prey in the North Sea, with a considerable negative effect on ecosystem function in this area (Edwards and Richardson, 2004). Impacts on the plankton and on fish as well, are related to changes in the oceanographic conditions, the most noticeable being the warming of the sea. Distributions of fish, including both exploited and non-exploited species in the North Sea, have responded to increases in the sea temperature, and future distribution shifts could be pronounced as sea temperatures are predicted to increase further in the North Sea (Perry *et al.* 2005). Despite dramatic shifts in fish biomass being driven more by environmental change rather than fishing (Jennings and Kaiser, 1998), exploitation by fisheries could have a higher impact than sea warming on the abundance and distribution of fish species (Dulvy *et al.* 2008). However, the combined effect of overfishing and climate change should be considered. Overexploitation and climate warming are the cause of negative switches in the marine ecosystem, such as variability in fish recruitment and shifts in species dominance (Cury *et al.* 2008). Examples of this are the risk of collapse of cod fishery in the North Sea (O'brien *et al.* 2000), the succession of low recruitments and collapse of the Anchovy stock in 2005 in the Bay of Biscay (Borja *et al.* 2008) and the recruitment failure of sardines in Morocco during 1996-1998 (Macu *et al.* 2000).

Changes in the ecology of fish have been recorded, and some descriptions of the ecological changes have been proposed, explaining mainly the re-distribution of the species along a gradient. Understanding is difficult when fish response to climate warming differs between areas, as in demersal species for example. Demersal fish assemblages have shown a move to deeper water in response to a temperature increment at the sea surface in semi-enclosed seas (like the North Sea, the Mediterranean or Baltic Sea), whilst latitudinal movements of fish are observed in shelf areas like Iberia or the Bay of Biscay (Dulvy *et al.* 2008).

On the other hand, changes driven by environmental factors in fish ecology are not expected to be uniform over the North Atlantic, and not all species are impacted equally (Rose, 2005). For example the Anchovy (*Engraulis encrasicholus*) is abundant in African waters in front of

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Mauritania and Senegal, but at present is restricted in the North Sea to areas receiving warm water from the North Atlantic Current and the Gulf Stream (Reid Jr. 1967).

Commercial fishing in the North Sea is among the most intense (Frederiksen *et al*. 2006), and is based mainly on few species, 11 of these support 70-80% of the total captures (Daan *et al*. 1990). North Sea fisheries harvest mainly sandeel and Sprat (Tasker and Furness, 1996), catching up to more than one million tonnes of sandeel at the end of the 1990's (Tasker *et al*. 2000). In fact, the sandeel catches alone comprised about 40% of the total North Sea fishery yield in the early 1990s (Tasker and Furness, 1996). Sandeel population around Shetland experienced a dramatic decline at the end of the 1980's, with a second drop after a small recovery period (Furness, 2007; fig. 7-1).

Most fisheries in the North Sea have been directed in the past at large predatory fish such as Atlantic Cod, Haddock or whiting (Dunnet *et al*. 1990). After several decades of stability in Atlantic Cod catches, and even with sustained increments, the captures decreased since the beginning of the 1980s. On the contrary, Herring landings dropped in the late 1970s and the fishery was closed in most areas in the North Sea, and there was a similar situation with the Sprat (Daan *et al*. 1990). Another important species is Saithe. In all cases, stocks have been declining in the last 40 years (Votier *et al*. 2004b). Overall, exploited fish species are showing dramatic changes, like high temporal abundance variation, compared to unexploited species (Hsieh *et al*. 2006; Cury *et al*. 2008).The Norway Lobster *Nephrops norvegicus* is the non-fish species more intensively fished in the North Sea (Catchpole *et al*. 2006).

Mixed fisheries are common in the Celtic Sea, and some species caught as by-catch may be landed. The highest volumes landed are from small pelagics (mackerels), followed by roundfish (OSPAR, 2000). Large benthic invertebrates, like scallops and crabs, are commercially important as well (OSPAR, 2000).
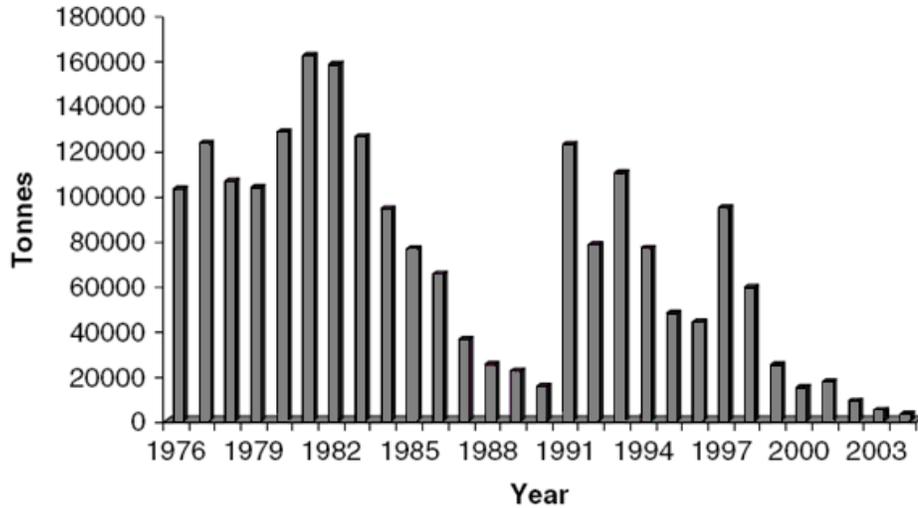
Figure 7-1. Estimated biomass of sandeels for the Shetland stock (from Furness, 2007).

In the Bay of Biscay, over a hundred of species are targeted by a wide variety of fishing vessels, mainly from France and Spain. Main fisheries in the Bay of Biscay are related to pelagic and demersal groups. Main species targeted are the Atlantic Mackerel, Horse Mackerel, Blue Whiting, Hake, and two species of anglerfish, megrims, lobsters and cephalopods (Lema *et al*. 2006). French catches exceeded 90 000 tonnes in 1997, representing more than half of the pelagic catch the Anchovy (*Engraulis encrasicolus*) and Pilchard (*Sardina pilchardus*). Hake (*Merluccius merluccius*), Sole (*Solea solea*) and anglerfish species (gen. *Lophius*) dominated the demersal catch. Hake is the principal species for Spanish fisheries in the Eastern Bay of Biscay, with annual catch nearly 16 000 tonnes (OSPAR, 2000), but annual volumes are declining in recent years (fig. 7-2).
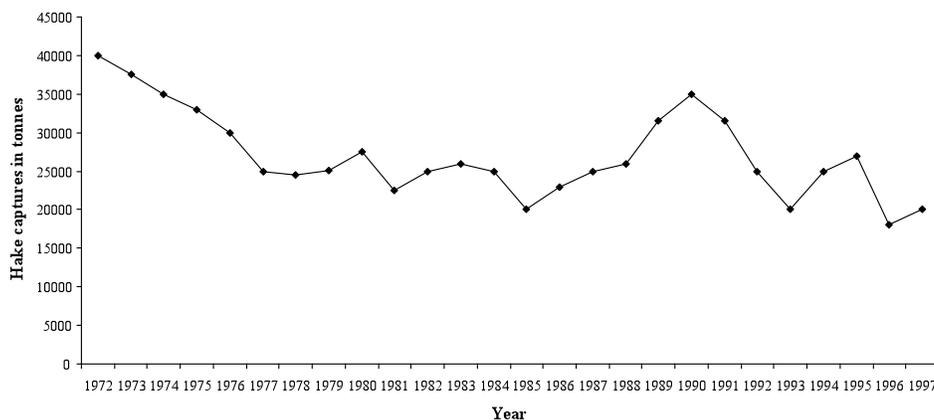
Figure 7-2. Hake landings in the Bay of Biscay (from OSPAR, 2000).

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Sardine (*Sardina pilchardus*) is the main pelagic fish resource in the Portuguese coast and has been decreasing in the last 20 years, with an oscillating trend along the entire 20th Century in relation to the industrialization of the fishing gear and changes in climate (Mendes and Borges, 2006). Similar situation is observed in the Anchovy from the Bay of Biscay (Uriarte *et al.* 1996).

Unlike the North Sea and the Bay of Biscay cases, some fisheries in North-western Africa (NWA) have been increasing in recent years, especially those related to small pelagic species (FAO, 2006, 2008). The increase in those fisheries could be related to fishing fleet moving from Europe to African waters, new fishing policies in the African countries, or the abundance of fish in the area. The richest fishing grounds in the Central-eastern Atlantic are located in the Sub-Saharan portion, in North-western Africa, along the coasts from the Western Sahara to Guinea, including coastal areas of sparsely-populated and poor countries, unable to exploit those resources (Kaczynski, 1989).

The continental shelf of NWA, from the Strait of Gibraltar to Senegal, has the potential to become one of the most important fishery areas of the world, due to a permanent or, in some areas, seasonal upwelling resulting in an enhanced primary production (Duineveld *et al.* 1993). Upwelling in the Canary Current carries nutrient-rich water to the surface. As a result, high levels of phytoplankton, zooplankton and fish are observed over a wide area. These kinds of systems are very important to fisheries. Indeed, five upwelling areas in the world represent around 25% of total global marine fish catches (California, Peru, Canary, Benguela, and Somali) occupying only 5% of the ocean area (Jennings *et al.* 2005).

Because of the environmental heterogeneity in the North-western coasts of Africa, fishing resources are different between countries and, as a result, target species and volume of catches are different as well. The areas of Cape Verde archipelago, Guinea and Mauritania differ in terms of resource exploitation and ecosystem productivity, representing three different tropical fishing scenarios with different impacts as well (Stobberup *et al.* 2005a).

Traditionally, local artisanal communities develop fisheries restricted to the coast, and relatively new industrialized fisheries are important in the entire oceanic zone, but mainly on the shelf area. Fishing effort from African countries has undergone a reduction in recent years,

transferring this effort to European countries (FAO, 2006), mainly under the licensed and chartered fishing regimes (Kaczynski, 1989). Industrial fisheries are carried out by large fleets mainly from Spain, Portugal, Germany, Holland, France, Russia and Korea (Leopold, 1993; Stanford *et al*. 2001). The beginning of industrial fishing in NWA was traced to 1910 (Ribeiro, 2002), generally fishing on small pelagic species that inhabit the near surface layers (like sardinellas and sardines), and mackerel from deeper waters (ter Hofstede and Dickey-Collas, 2006). Statistics show that the region supports important fisheries on Carangidae, Clupeidae and Scombridae species (Leopold, 1993; FAO, 2006).

The oceanic waters of Morocco, Mauritania and Senegal support a large fishery on small pelagic fish (fig. 7-3), based mainly on Dutch Super-trawlers (ter Hofstede and Dickey-Collas, 2006). The sardine and sardinella species are commercially important in Morocco from Cape Blanc to Cape Spartel where three stocks are recognized (Ettahiri *et al*. 2003). Cape Blanc was the main traditional fishing ground in the NWA, but recently the Portuguese fleet has concentrated on fishing grounds further offshore or in international waters, with target species such as Scabbardfish, Hake, Tuna (Ribeiro, 2002), and shrimp.
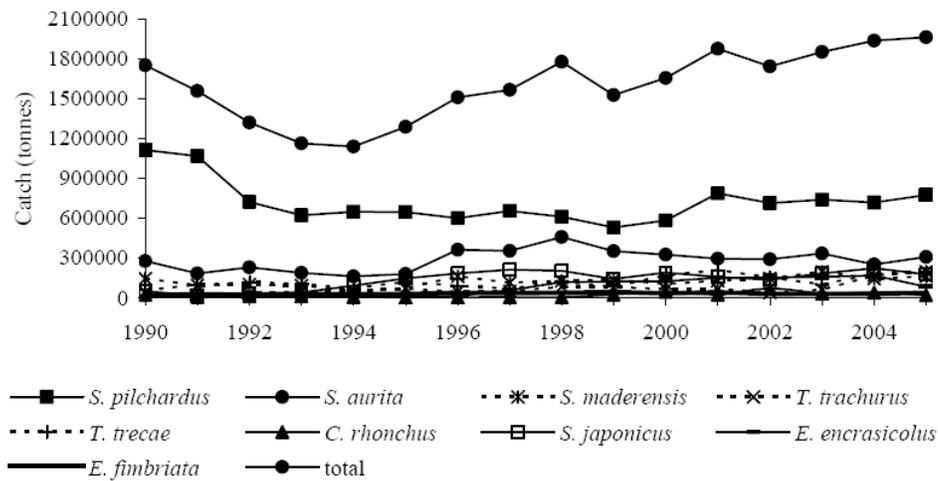
Figure 7-3. Small pelagics catches (1990-2005) in the sub-region between Morocco and Senegal (from FAO, 2006).

The Round Sardinella *S. aurita* is a pelagic fish species that is substantially exploited by both industrial and artisanal fisheries in Mauritania (ter Hofstede *et al*. 2007). This species is dominant during summer and the Sardine *S. pilchardus* is dominant during winter (ter Hofstede and Dickey-Collas, 2006). Trawlers in Mauritania operate persistently along the

shelf (Leopold, 1993). The Round Sardinella catches in Mauritania were about 48 000 t during the first half of the 90's by year, and increased to an over-exploited level of 170 000 t per year ten years later (ter Hofstede *et al.* 2007). In the period 1999–2003 the CPUE of *S. aurita* gradually diminished, and catches of Sardines *S. pilchardus* and *S. japonicus* increased (ter Hofstede and Dickey-Collas, 2006). The sub-region from Morocco through Senegal represents the most widely studied area from the entire NWA, especially in relation to small pelagic fisheries. *S. pilchardus* is the most important prey species for the sub-region, showing slight decreasing volumes of capture in recent years. Other species, like *S. aurita*, present an increasing trend in the recent years.

Senegal is a great NWA fishing nation fishing almost 90%of the total captures in the area. Small pelagics represent more than 75% of the artisanal catches and 55% of total marine catches (Dei-Ouadi, 2005). Target species are mainly pelagic fish (sardines, sardinellas and mackerels), demersal fish, crustaceans and cephalopods (Diallo, 2000). Industrial fisheries in The Gambia are related to demersal and pelagic fish, mainly over the estuarine clupeid *Ethmalosa fimbriata* (Mendy, 2004), but pelagic captures have decreased in the last 30 years, and with reduced stocks the fishery closed. On the other hand, the pelagic fishery has been reporting a sustained increment in recent years (Mendy, 2002).

The industrial fishery in Guinea-Bissau is undertaken exclusively by foreign vessels on a seasonal basis, dominated by fishing for sciaenid fish like *Arius* sp. *Galeoides decadactylus*, *Polydactylus quadrifilis*, *Argyrosoma regius*, *Pseudotolithus* sp. and *Pomadasys* sp., followed by small pelagics like *Sardinella* sp., *Ethmalosa fimbriata* and *Decapterus* sp., and to a lesser extent by cephalopods and shrimps. Tuna fishery is also important in the country (Amorim *et al.* 2004). After a civil war in Guinea-Bissau, a gradual increase in fishing effort has been observed, and simulations shows a strong impact of the artisanal fisheries, especially on shallow water species such as mullets (Amorim *et al.* 2002). In addition, abundances of commercial and non-commercial demersal fish have been decreasing (Stobberup *et al.* 2005a). Estimates of industrial trawl catches in Guinea Bissau have ranged between 20 000 t and 45 000 t during the last two decades, with main increment between 1990 and 1992 (Stobberup *et al.* 2005a).

Fishery landings in Cape Verde are dominated by pelagic and migratory species such as tuna and various small carangid species (Évora and Amorim, 2002). Some fish species in Cape Verde are under-exploited, about 25% of the estimated sustainable yield of small pelagics like Horse Mackerel, Scad and Chicharro-Bigeye Scad being caught (D' Olvera-Fonseca, 2000). Horse Mackerel is the most important species, representing almost 40% of total catches at the peak of the fishery in 1997 and 1998 (Stobberup and Erzini, 2006). Mackerel-scad catches are taken with seine gears both in the industrial and artisanal fisheries (Stobberup *et al.* 2006). A decreasing trend in demersal fish abundance in Cape Verde may be a warning signal of over-exploitation. CPUE of tunas have decreased, and increased for small pelagics (Stobberup *et al.* 2005a). On the other hand the composition of species fished has changed in last years, with an increasing importance of small pelagic species such as *Spicara melanurus* and *Selar crumenophthalmus* (Stobberup and Erzini, 2006).

The assessment of fishery resources in the NWA countries is particularly difficult due to data limitation and a lack of consistent time series. Trawl surveys have been undertaken only sporadically, especially in countries with less developed fisheries like Cape Verde and Guinea Bissau (Stobberup *et al*. 2005a). In addition, surveys in the Cape Verde archipelago are difficult due to the very narrow shelves and difficult bottom conditions (Stobberup *et al*. 2005a).

However, important information already exists about the amount of volume fished in the NWA, and some trends can be observed. The biomass of large fish has declined in the last 40 years along the NWA coasts. Fishing intensity has increased such that the resources in the area are now overfished (Christensen *et al*. 2004). In the same way fishing pressure on small pelagic and demersal fish has increased in recent years, in all the countries in NWA.

Discards are the part of the catch that is not kept by the fishery, and discarding is unavoidable due to damage to the fish, the wrong kind of species being caught, minimum length constraints. Because there is a lack of information about the fishing activities in NWA, data about discards in the zone are scarce, and it is necessary to estimate discards values using indirect data. Discard values have been estimated based upon the limited sampling of discarding rate for the fishing area (Crane, 2005). Having only some indications on fishing discards, values should be assigned carefully (Amorim *et al*. 2004). Discard densities of

demersal fish calculated for the NWA are 0.053-0.167 t per square km, with the exception of the northern Mauritania and Western Sahara, here the values are 0.167-0.31 t per square km (Crane, 2005). For the percentage discards, available data are restricted to a few areas. Discards in Mauritania includes all sizes of fish, and shows seasonality in *S. pilchardus*. The estimated amount of discards in proportion to the total catch is around 10%, supporting the idea that pelagic fisheries have a low level of discarding (ter Hofstede and Dickey-Collas, 2006). Industrial fisheries operating off The Gambian coast generate up to 20 % discards, though this is probably higher for the shrimp fisheries (Mendy, 2004). In case of the Portuguese fleet, discards have been estimated to be approximately 40% in the historical trawl fishery (Ribeiro *et al.* 2002).

Changes in fishing activities could drive changes in migratory movements of seabird species, especially those with scavenging habits like gannets and skuas, which may associate with fishing vessels to feed on discards (undersized fish, unwanted species and offal). Fishing discards are an important source of food for scavenging seabirds, although how accessible these are to seabirds depends on local fishing practices such as net mesh size, and on-board processing systems (Furness *et al.* 2007). This huge amount of food has been estimated in the order of 909 109 tonnes for the North Sea, 269 205 tonnes for the Canary System, 100 893 for the Celtic-Biscay Shelf, 37 168 for the Celtic-Biscay Basin and 5 840 for the Norway Shelf (Kelleher, 2005). Because of this, analyses of the relationship between fisheries and seabirds can employ discard values as an indirect source of food for scavenging seabirds.

On the other hand, migratory seabirds are vulnerable to the impacts of climatic change because they depend on separate breeding and wintering areas, making it very difficult to predict range shifts accurately. It has been demonstrated that some migratory birds alter their distributions in response climate warming, affecting both wintering and breeding areas, and the migratory distance between them (Robinson *et al.* 2005).

Materials and Methods

Fisheries

Data on landed volumes of marine fish and invertebrates were obtained by country involved in fisheries at the Northern Gannet and Great Skua all-year distribution area in the North-eastern

Atlantic (including Iceland, Ireland, Faroe Islands, Great Britain, Netherlands, Belgium, Denmark, Germany, Norway, Spain, France and Portugal), Central-eastern Atlantic, and in the North-western coast of Africa (Morocco, Mauritania, Senegal, the Gambia, Guinea-Bissau and Cape Verde). Only data from Western Sahara were not available.

Data by country were grouped into three main distributional areas for gannets and skuas, the North Sea (UK, Denmark, Belgium, the Netherlands, Germany and Norway), Iberia-Celtic Sea (Ireland, France, Portugal and Spain, and landings from Isle of Man and Channel Islands), and North-western Africa (fig. 7-4).
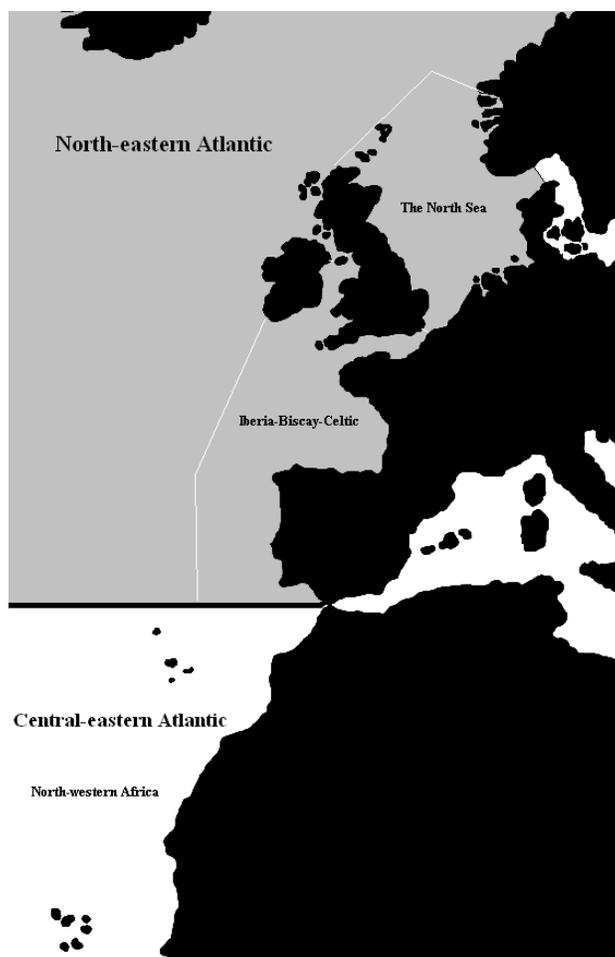
**Figure 7-4. Map of the all-year distribution area of the Northern Gannet and the Great Skua, showing the fisheries areas included in the analyses.**

Central-eastern Atlantic present two subdivisions: African countries (Morocco, Mauritania, Senegal, The Gambia, Guinea-Bissau and Cape Verde, and landings from Gibraltar), and foreign countries fishing in North-western African waters (from America, Asia and Europe).

Spanish and Portuguese landings around the Canary Islands and Madeira are reported as foreign countries fishing in Africa.

Data were obtained from the FishStat Plus (Fisheries Data Analyses Software, FAO) and FIGIS Database (FAO) for the period 1950-2008, presented as volume landed (in tonnes) by year. Fisheries landings were grouped into the following FAOSTAT fishing groups: *Demersal fish* (cods, haddocks, soles, rays, seabasses, mullets, among others), *Pelagic fish* (sardines, anchovies, herrings, tunas), *"Other" Marine fish* (miscellaneous, usually coastal species), and *Invertebrates* (prawns, shrimps, krill, crabs, molluscs). In the case of molluscs, only cephalopods were included. Data were grouped according to the information obtained by fishery, and condensed in graphs by area.

Landing areas by fishing groups were divided into the North-eastern Atlantic reported by European countries, African countries, and foreign countries fishing in Africa. Total landings from 1989 to 2008, for the four fishing groups, were analysed for the African landings (reported from African and non-African countries) by means of bar graphs. Similar comparisons were made between the two main wintering areas for seabirds, Iberia (including Bay of Biscay, Celtic Sea and Iberia) and NWA. Paired t-test analyses for annual catches between Iberian-Biscayan and NWA were applied by fishing group.

Discards

More detailed analyses were made of discard volumes, estimated from reported landings by country and type of fishery. To establish the percentage rate of discards by type of fishery is very difficult because the fishery of a single species often involves different kinds of fishing devices (nets, traps, lines), or technical implements (kind of ship, or boat). On the other hand, different discard rates can be related to the policies adopted by a country (such as net mesh regulations and market factors affecting the choice of target species) resulting in a wide range of discard percentages. Estimation of discards was made according to the reported rates of discarding by country and/or fishery (Kelleher, 2005), small pelagics from Mauritania (ter Hofstede and Dickey-Collas, 2006) and for Portuguese shrimp fishery (Monteiro *et al.* 2001). In cases where discard rate is not presented for a particular fishery, the overall discard percentage by country was applied (Kelleher, 2005).

Total discard mass by country was estimated from the percentages of discards by fishery and by country (Table 7-I) for fisheries recorded in the FishStat Plus database and FIGIS Database. In some cases discard percentage by fishery is reported as an interval, in these cases the bigger value was used as there has often been a tendency to under-report discarding (Kelleher, 2005). For Belgium, Denmark, Faroe Islands and Germany, discard percentage applied was the overall mean value for the EU (Kelleher, 2005). Results were grouped by fishing area: North-eastern Atlantic (including the North Sea), the Bay of Biscay (including the Celtic Sea and Iberia), and Eastern-central Atlantic (African countries). With the annual value of volume discarded, for the period between 1950 and 2007, trend graphs were made for each fishing area, applying time series analyses. Single linear or polynomial regression analyses were applied in order to detect statistical significance of observed trends.

Table 7-I. Percentage of discards by fishery and by country (after Monteiro *et al.* 2001; Kelleher, 2005; ter Hofstede and Dickey-Collas, 2006) for the three main distribution areas of gannets and skuas.

North-western Atlantic	Fishery	Percentage of discards
Iceland	All fisheries*	2.3
Faroe Islands	All fisheries**	40
United Kingdom	All fisheries*	37.9
	Invertebrates	83
	Pelagics	3
Belgium	All fisheries**	40
Denmark	All fisheries**	40
Netherlands	All fisheries*	11.8
	Invertebrates	83
	Pelagics	3
Germany	All fisheries*	40
	Invertebrates	83
	Pelagics	3
Norway	All fisheries*	3.9
	Invertebrates	83
	Pelagics	3
Celtic and Iberia	**Fishery**	**Percentage of discards**
Ireland	All fisheries*	12.1
Isle of Man and Channel Islands	All fisheries*	37.9
	Invertebrates	83
	Pelagics	3
	Pelagics	3
Spain	All fisheries*	3.9
	Pelagics	3
France	All fisheries**	21
	Demersal	28.1
	Pelagics	37.7
Portugal	All fisheries**	85
	Shrimp	90
North-western Africa	**Fishery**	**Percentage of discards**
Morocco	All fisheries**	19.4
	Cephalopods	30
	Demersal	30

Fisheries status and climate in the distributional area of Northern Gannet and Great Skua

Mauritania	All fisheries**	0.5
	Small pelagics	10
Senegal	All fisheries**	6.3
The Gambia	All fisheries**	11.6
Guinea-Bissau	All fisheries**	27
Cape Verde	All fisheries**	0.5
Foreign countries fishing in Africa		**Percentage of discards**
	All fisheries	12
	Demersal	30
	Invertebrates	85
	Shrimp	62
	Pelagics	3

*Excluding pelagics, **Including invertebrates

Sea surface temperature

Data related to climate change, in terms of sea surface temperature, were obtained from different points from the North-eastern Atlantic from the University of Columbia (http://iridl.ldeo.columbia.edu/SOURCES/.Indices/ensomonitor.html). Points are from the northern North Sea locations near the Bass Rock (55.5 N, 2.5 W) and Shetland (59.5 N, 20.5 W), from the southern Bay of Biscay near Bakio (43.5 N, 2.5 W), from western of Portugal near Porto (41.5 N, 8.5 W), and from North-western Africa in locations near Gibraltar (35.5 N, 5.5 W), Madeira (32.5 N, 16.5 W), Canaries (28.5 N, 14.5 W), Casablanca (33.5 N, 7.5 W in Morocco), Dahkla (23.5 N, 16.5 W in Western Sahara), Cape d' Arguin (20.5 N, 16.5 W in Mauritania), Dakar (14.5 N, 17.5 W in Senegal), the Bijagos Archipelagos (11.5 N, 16.5 W off the coast of Guinea-Bissau), and Praia (14.5 N, 23.5 W in Cape Verde).

Regression analyses of winter mean sea surface temperature (from December to March) against year were made for the period 1982-2008, for every selected point.

Finally, information and data related to the NAO (North Atlantic Oscillation) index (NAOI) were obtained from National Oceanographic and Atmospheric Agency, NOAA (ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/tele_index.nh) for the period 1990-2009 and trend graphs were made from mean annual NAOI and mean winter NAOI values. Regression analyses were made of the relationship of the relationship between the annual fishing landings and winter NAOI (December-March) by fishing group and region.

Results

Fisheries

The main fisheries in the North-eastern Atlantic are for demersal and pelagic fish groups, with an increase of invertebrate fishery landings in the North Sea and crabs in the Isle of Man in recent years. Crabs fishery have most important fishery in the Channel Islands, but this has been replaced by a fishery targeting demersal fish in recent years. Pelagic and demersal landings have been steady along the entire period, except "other marine fish" declining to 2004 and recovering in recent years (fig. 7-5). The same situation is observed in the North Sea fishing landings, with a noticeable decrease in recent years for "other marine fish" (fig 7-6).
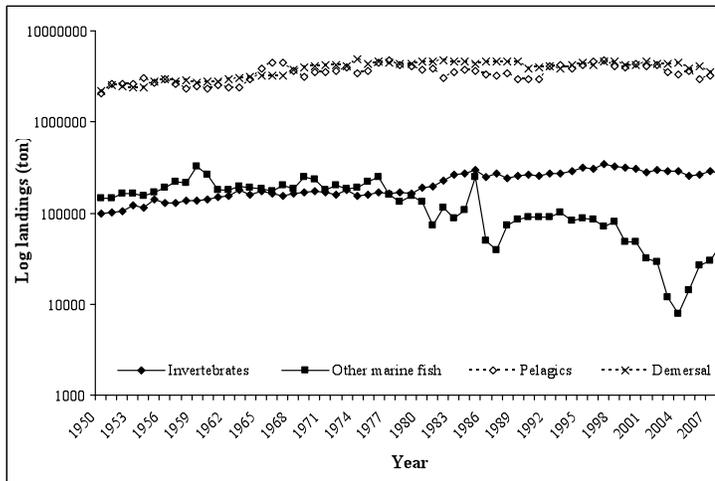

Figure 7-5. Landings by fishing group for all European countries in the North-eastern Atlantic by year.
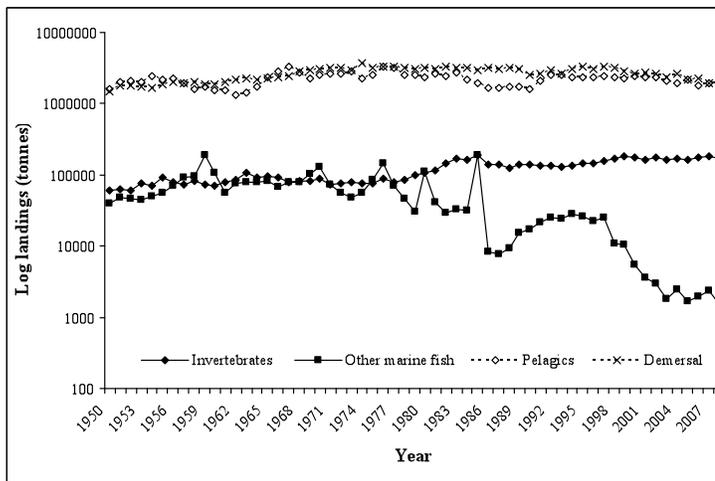

Figure 7-6. Landings by fishing group for the North Sea countries by year.

Fisheries around Iberia are showing a decreasing trend for demersal and pelagic groups in recent years, with a slight recovery for "other marine fish" after a collapse during 2003-2004 (fig. 7-7).

Fisheries in the North-western African countries were scarce during the decade of the 1950s, with some reports of "other marine fish". Fisheries become more diverse from the 1970s and are dominated by pelagics and demersal fish nowadays. Foreign fleet fishing in the Central-eastern Atlantic (from Spain, Russia, Netherlands, China, among others) are operating in the area at an industrial level. Fishing boats from American countries are fishing on pelagics since 1963; Asian countries have been fishing cephalopods since 1950 but with pelagic and demersal species the most important current fisheries. European countries have been fishing along the coasts of Africa since 1950 in a more diverse way, with pelagics and demersal dominating recent landings. Landings are decreasing in Central-eastern Atlantic for all fishing groups, except pelagics where landings have increased considerably (fig. 7-8), with similar pattern shown in landings from non-African countries only (fig. 7-9).

North-western African countries are landing an increasing volume for all fishing groups (fig. 7-10), but non-African countries dominate historic fisheries along the Central-eastern Atlantic (fig. 7-11). Historic total landings in the Central-eastern Atlantic are higher than landings around Iberia, with the exception of demersal (fig.7-12), but landings reported from Iberia exceed landings from African countries for all fishing groups (fig. 7-13). Total landings reported in the last 20 years are higher from the Central-eastern Atlantic (50,373,007 tonnes) than landings from Iberia (23,064,604 tonnes) for the same period.
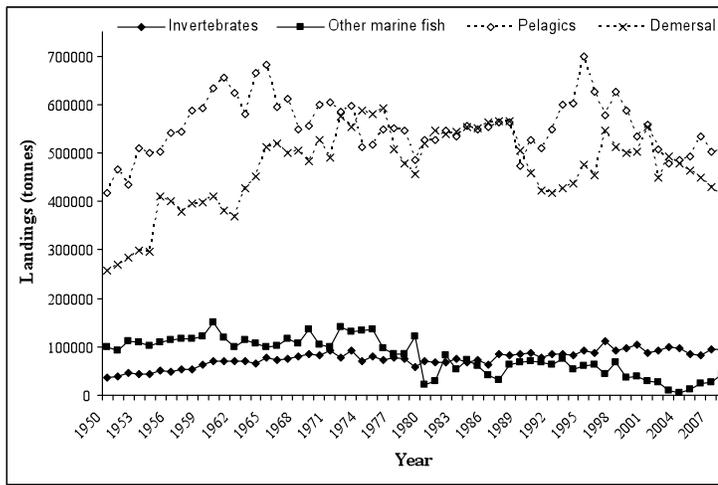
Figure 7-7. Landings by fishing group for the Iberia reports by year.
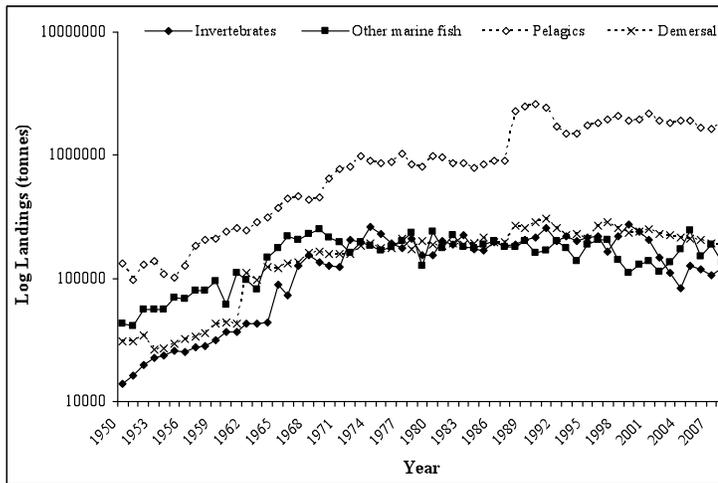
Figure 7-8. Landings by fishing group in the Central-eastern Atlantic by year.
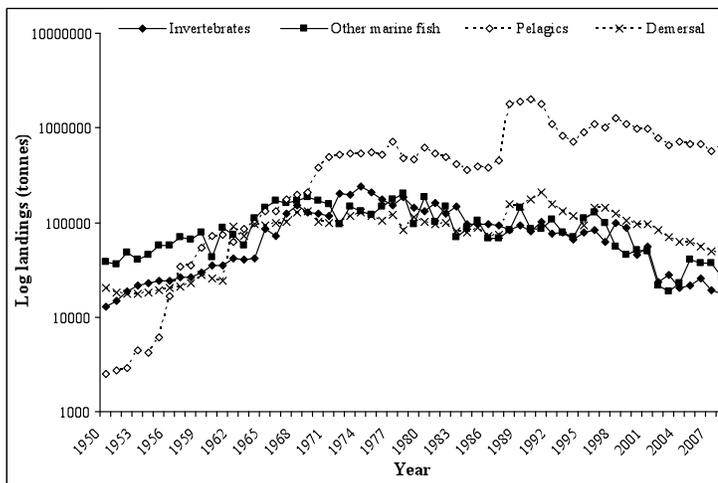
Figure 7-9. Landings by fishing group in the coasts off NWA, reported for non-African countries.
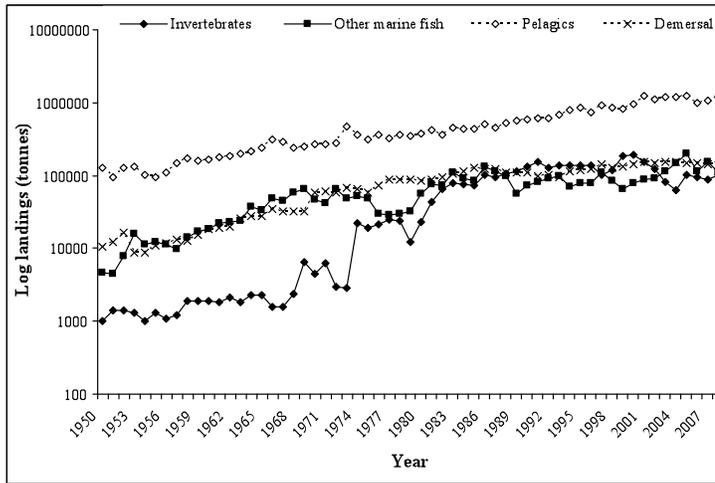
Figure 7-10. Landings by fishing group from NWA countries by year.
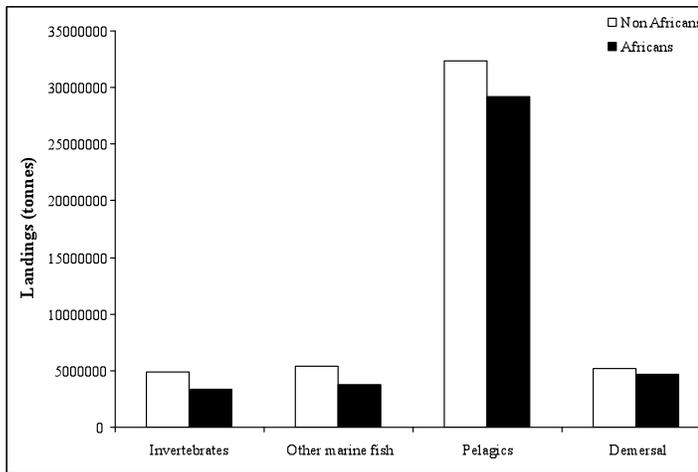
Figure 7-11. Total landings in the Central-eastern Atlantic, by fishing group, between NWA and non-African countries.
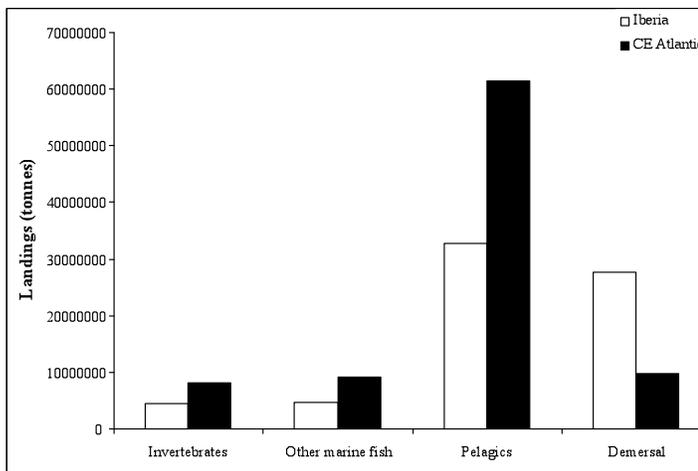
Figure 7-12. Total landings by fishing group between the Central-eastern Atlantic and Iberia.
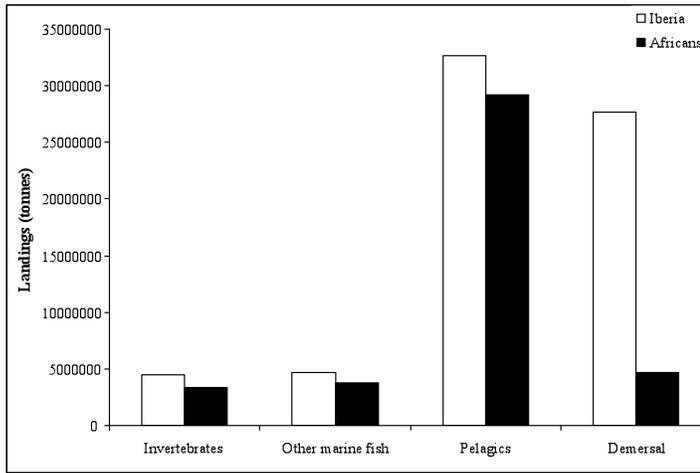
Figure 7-13. Total landings by fishing group from NWA countries and Iberia.

Differences in captures between Iberia-Biscay and NWA are significant in the case of demersal fish (t = -24.46, p < 0.001), marine fish (t = -36.59, p < 0.001) and invertebrates (t = -2.09, p = 0.041), but not in the case of pelagics (t = -1.23, p = 0.223).

Discards

Discards from the North-eastern Atlantic show an increasing trend from 1950 to 1976. Since then, discards have been decreasing until 2008 except for a high period during 1980-1988 (fig. 7-14). The trend between 1950 and 1976 represents a positive significant relationship (F = 273.49, p < 0.001, r^2 = 91.3; fig. 14), and the trend during 1976-2008 has a negative significant relationship (F = 49.70, p < 0.001, r^2 = 60.3; fig. 7-15).
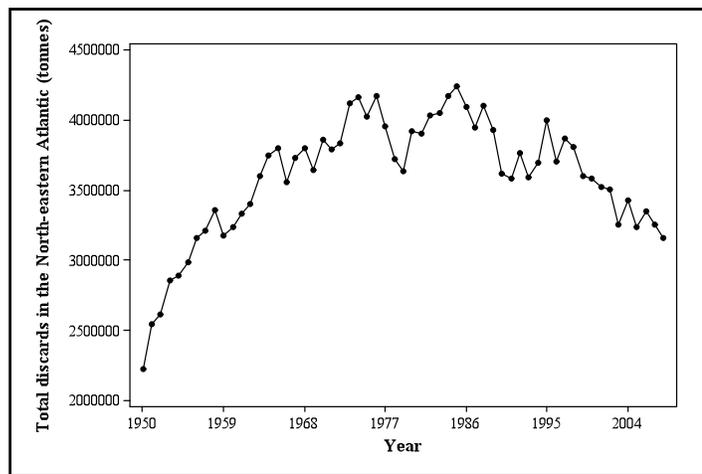
Figure 7-14. Time series plot from total discards recorded from the North-eastern Atlantic.

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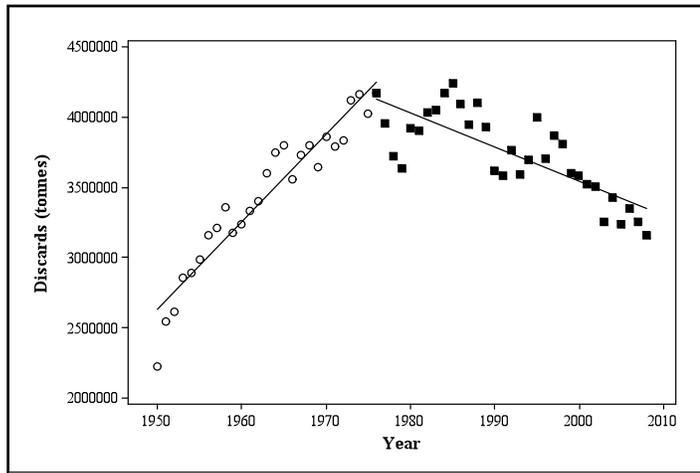
Figure 7-15. Linear regression for North-eastern Atlantic discards during 1950-1976 (open circles) and during 1976-2008 (solid squares).

The discards time series graph for the North Sea fisheries shows an increasing discard mass from 1950, with a peak in 1982-1983. Since then, the tendency has been a decreasing trend (fig. 7-16). Regression analyses indicate a significant positive trend during the period from 1950 to 1983 (F = 327.61, p < 0.001, r^2 = 90.8; fig. 7-17), and a significant negative trend during the period from 1983 to 2008 (F = 56.56, p < 0.001, r^2 = 69.0; fig 7-17), these trends being even stronger than in the North-eastern Atlantic area, though closely similar qualitatively.
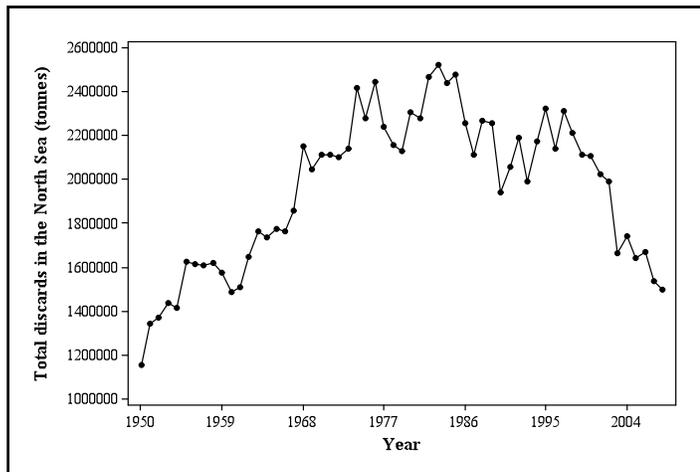
Figure 7-16. Total discards estimated from the North Sea by year.

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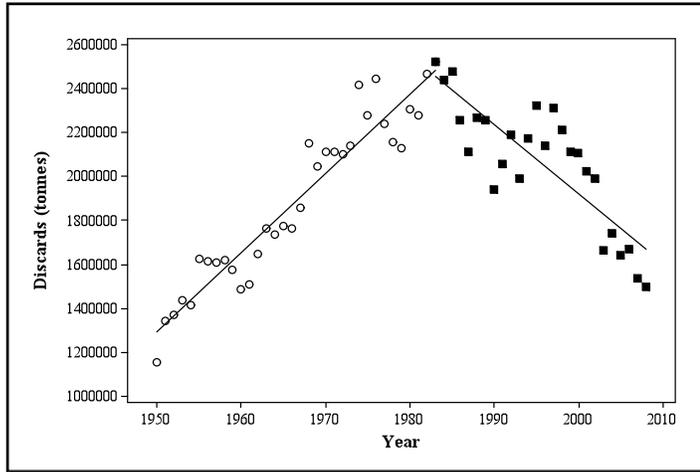
Figure 7-17. Linear regression for the North Sea discards during 1950-1983 (open circles) and during 1983-2008 (solid squares).

In the Iberia-Biscay-Celtic Sea area total discards showed a rapid increase from 1950 with a peak in 1965. Since then there has been a decreasing trend though with fluctuations (fig. 7-18). Regression analyses indicate a very positive trend during the period from 1950 to 1965 (F = 212.52, p < 0.001, r^2 = 93.4; fig. 7-19), and a negative one during the period from 1965 to 2008 (F = 81.99, p < 0.001, r^2 = 65.3; fig 7-19).
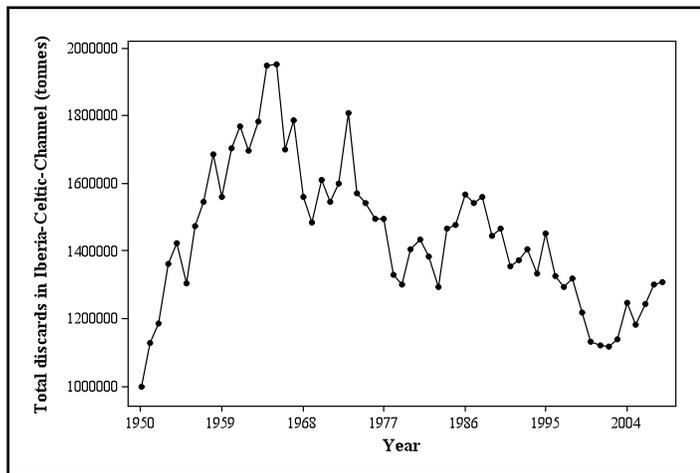
Figure 7-18. Total discards estimated from the Iberia, Biscay and Celtic area by year.
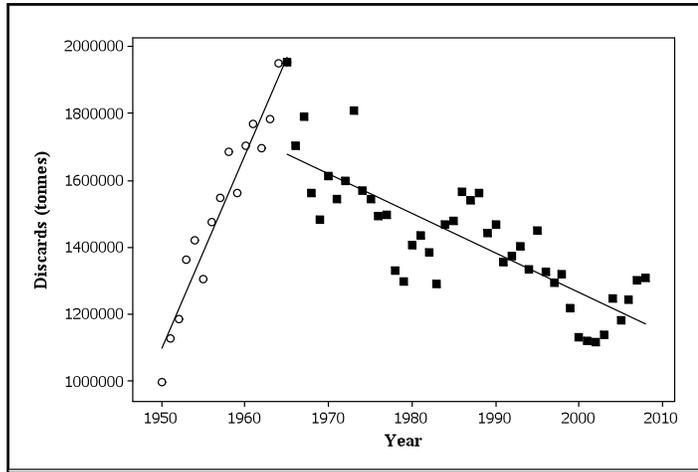
Figure 7-19. Linear regression for the Iberia, Biscay and Celtic discards during 1950-1965 (open circles) and during 1965-2008 (solid squares).

Total discards from the Central-eastern Atlantic present a slight increasing trend during 1950-1964. A more rapid increasing trend continues up to 1974. Since then, a decreasing trend is observed (fig. 7-20). Regression analyses show a very positive, but nonlinear, trend during the period 1950-1974 (F = 201.46, p < 0.001, r^2 = 94.4; fig. 7-21), followed by a negative trend (again non-linear) during the period from 1974 to 2008 (F = 104.20, p < 0.001, r^2 = 77.1; fig 7-21).

A closely similar pattern is observed in fisheries from the foreigner fleet landings from Central-eastern Atlantic (fig 7-22), with a positive non-linear relationship during the period 1950-1974 (F = 182.29, p < 0.001, r^2 = 93.8; fig. 7-23), and a negative non-linear relationship during the period from 1974 to 2008 (F = 114.87, p < 0.001, r^2 = 87.0; fig 7-23).
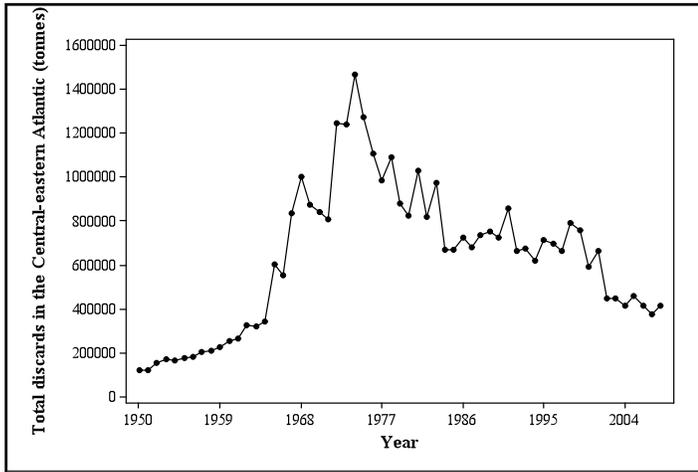
Figure 7-20. Total discards estimated from the Central-eastern Atlantic, by year.
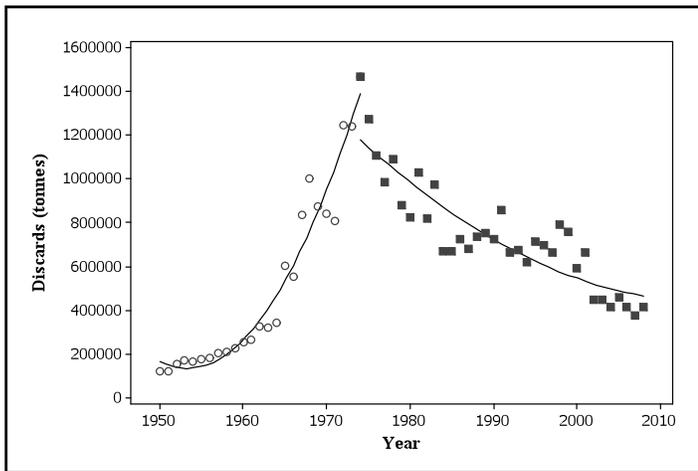
Figure 7-21. Polynomial (quadratic) regression for the Central-eastern Atlantic discards during 1950-1974 (open circles) and during 1974-2008 (solid squares).
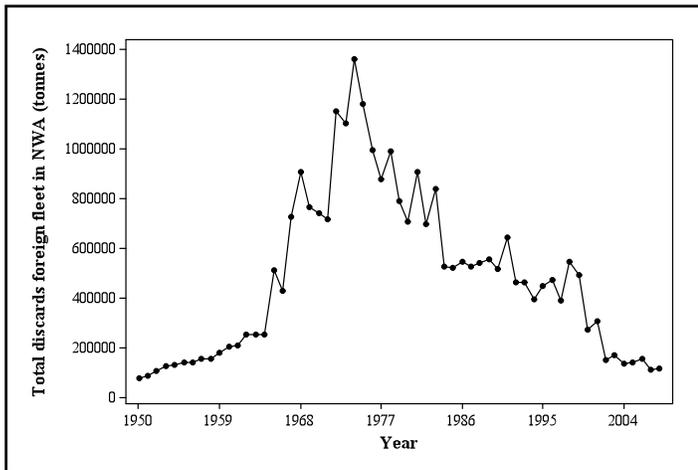
Figure 7-22. Total discards estimated from the foreigner fleet in the Central-eastern Atlantic, by year.
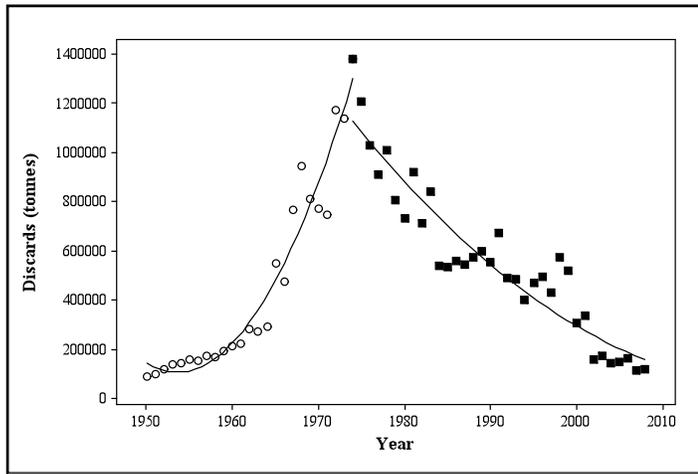
Figure 7-23. Polynomial (quadratic) regression for the foreigner fleet discards in the Central-eastern Atlantic during 1950-1974 (open circles) and during 1974-2008 (solid squares).

In contrast to all of the previous results, it is clear that discards from African countries have increased since 1950 (fig. 7-24), with a very positive relationship during the entire period 1950-2008 (F = 432.26, p < 0.001, r^2 = 95.7; fig. 7-25).
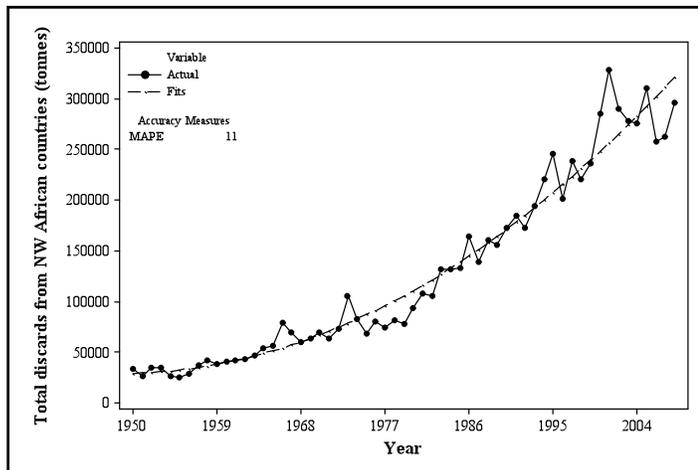
Figure 7-24. Total discards estimated from NW Africa by year.
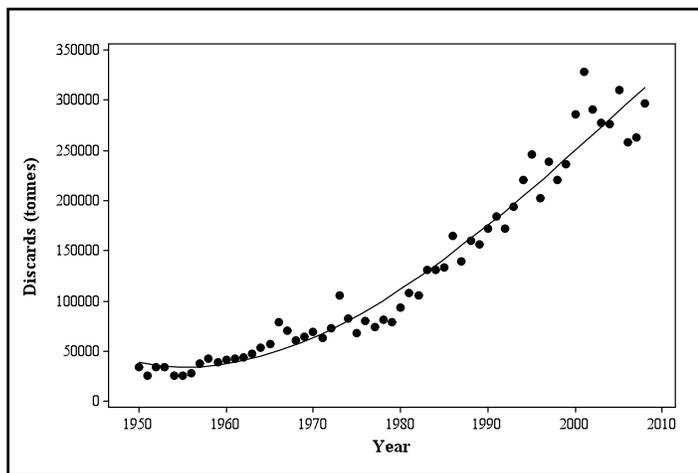
Figure 7-25. Polynomial (quadratic) regression for NW Africa discards during 1950-2008.

Despite the strongly divergent trends in NWA (Figs 7-24 and 7-25) and Iberia-Biscay-Celtic Sea (Figs 7-18 and 7-19), the discard mass in the latter has remained much higher than in NWA (fig. 7-26).
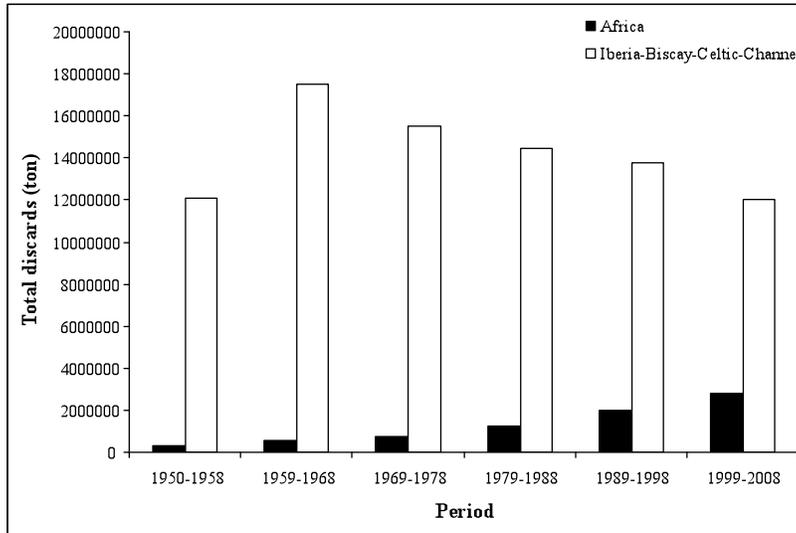
Figure 7-26. Trends in total discards between NWA and Iberia fisheries by period of time.

Winter sea surface temperature

A summary of the regression analyses of the temporal trend of mean winter sea surface temperature by location is presented in the Table 7-II. In general, sea surface temperatures from December to March have been increasing significantly in the last 28 years in the North Sea (fig. 7-27), with no significant change in the Iberia-Biscay area (fig. 7-28).
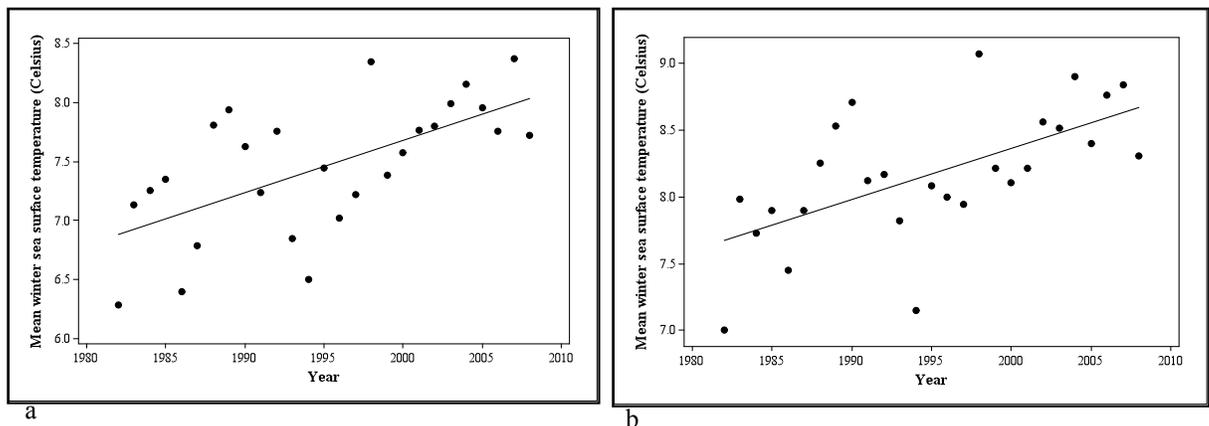
Figure 7-27. Regression analyses for the North Sea locations, a) The Bass Rock and b) Shetland).

Table 7-II. Results from the regression analyses of temperature of year by location.

Location	F value	P value	r² value
The Bass Rock	16.31	<0.001*	37.1
Shetland	15.13	0.001*	35.2
Bay of Biscay	3.28	0.082	8.1
Bakio	4.04	0.055	10.5
Portugal	0.86	0.361	0
Porto	1.46	0.239	1.7
Gibraltar	1.06	0.313	0.2
Casablanca	0.33	0.570	0
Madeira	7.66	0.010*	20.4
Canaries	5.25	0.031*	14
Dakhla	0.38	0.546	0
Cape de Arguin	3.61	0.690	9.1
Dakar	6.59	0.017*	17.7
Guinea-Bissau	20.16	<0.001*	42.4
Praia	12	0.002	29.7

*Significant value
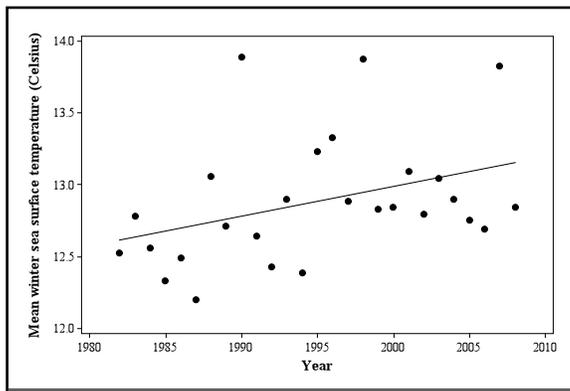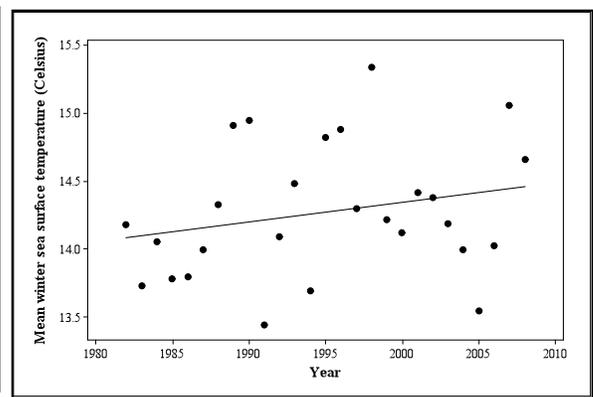
a) b)

Figure 7-28. Regression analyses for the Iberia, a), Bakio b), Porto.

On the other hand, temperatures have been increasing around the Canary Islands (fig. 7-29) and off Senegal-Guinea-Bissau, with no change in the coast from Morocco to Mauritania (fig. 7-30).
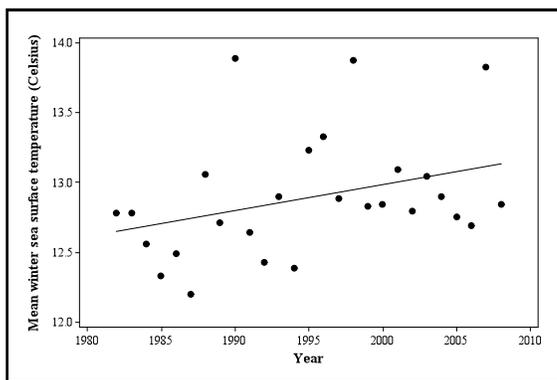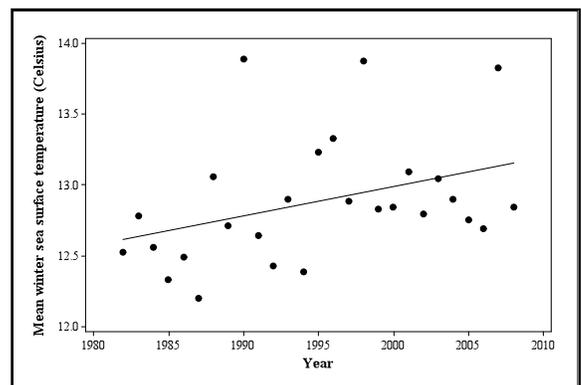
a) b)

Figure 7-29. Regression analyses for the Canarias Islands, a) Madeira and b) Canarias.

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Fisheries status and climate in the distributional area of Northern Gannet and Great Skua
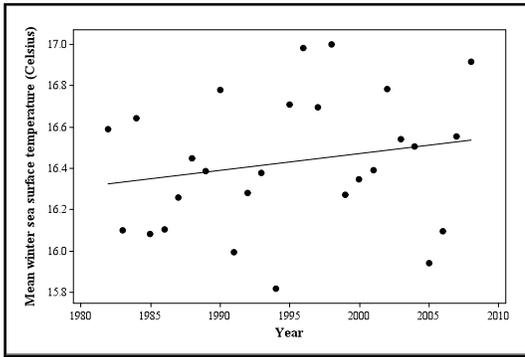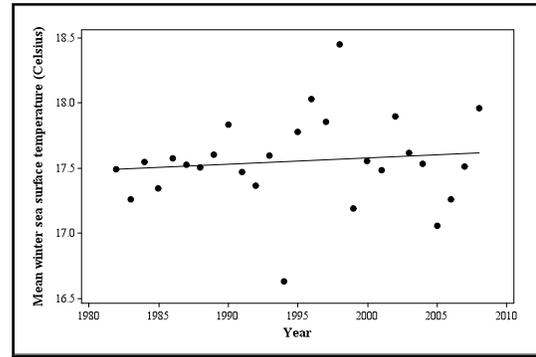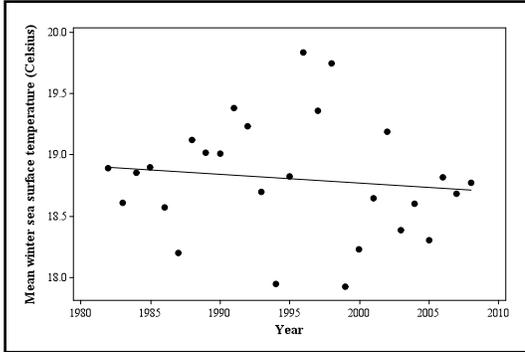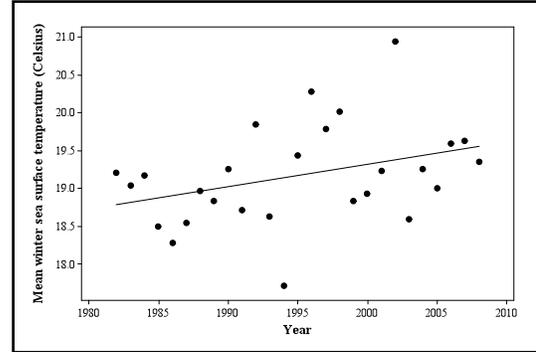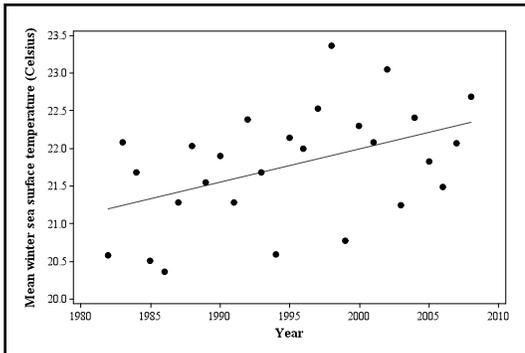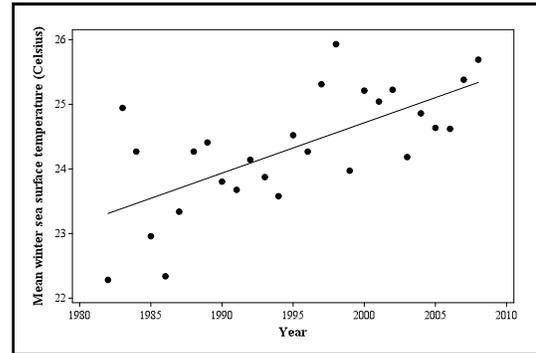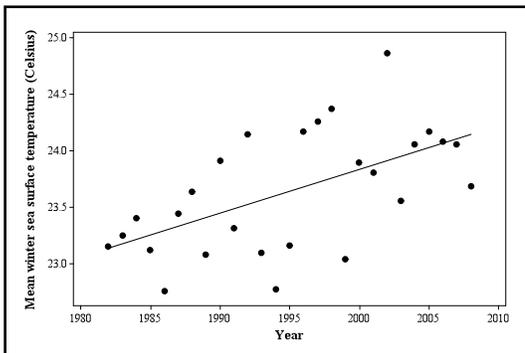
Figure 7-30. Regression analyses for NWA, a) Gibraltar, b) Casablanca, c) Dahkla, d) Cape de Arguin, e) Dakar, f) Guinea-Bissau and g) Praia.

Mean winter temperatures were particularly low during 1994 in the North Sea and around the Canary Islands, and almost all localities showed abnormal high temperatures during 1998.

The North Atlantic Oscillation Index has a typical oscillating shape, from positive values to negative ones. Annual mean NAOI shows the lowest values, or highest negatives, in 1998 followed by 2008. The graph has a trend to zero (fig. 7-31).
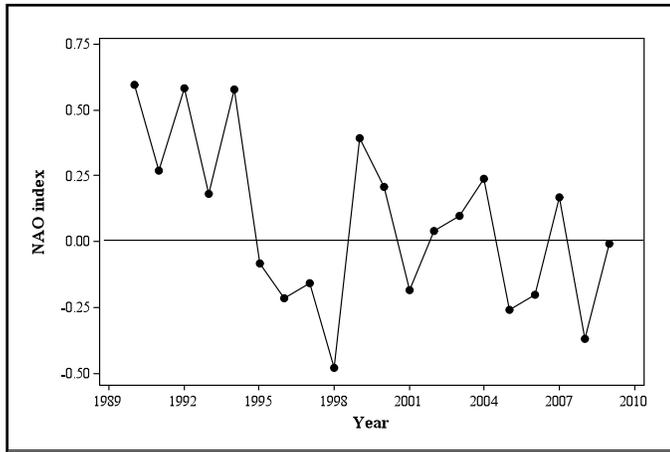
Figure 7-31. Annual mean North Atlantic Oscillation index.

The winter NAOI is dominated by positive periods, with negative values observed in 1996, 2001, 2005-06 and 2009. Like the annual NAOI, the trend is decreasing for the entire period (fig. 7-32).
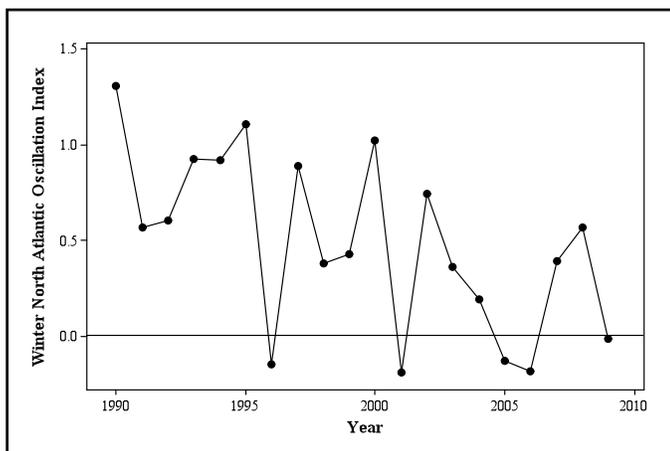
Figure 7-32. Winter mean North Atlantic Oscillation index by year.

In the North Sea, the winter NAOI has a negative relationship with demersal catches (F = 9.90, r^2 = 13.3, p = 0.003), a positive relationships with invertebrate catches (F = 14.88, r^2 =

19.3, p < 0.001) and other marine fish (F = 4.40, r^2 = 5.5, p = 0.040), and no relationship with pelagic captures (F = 0.71, r^2 = 0.2, p = 0.402; fig. 7-33).

a   b
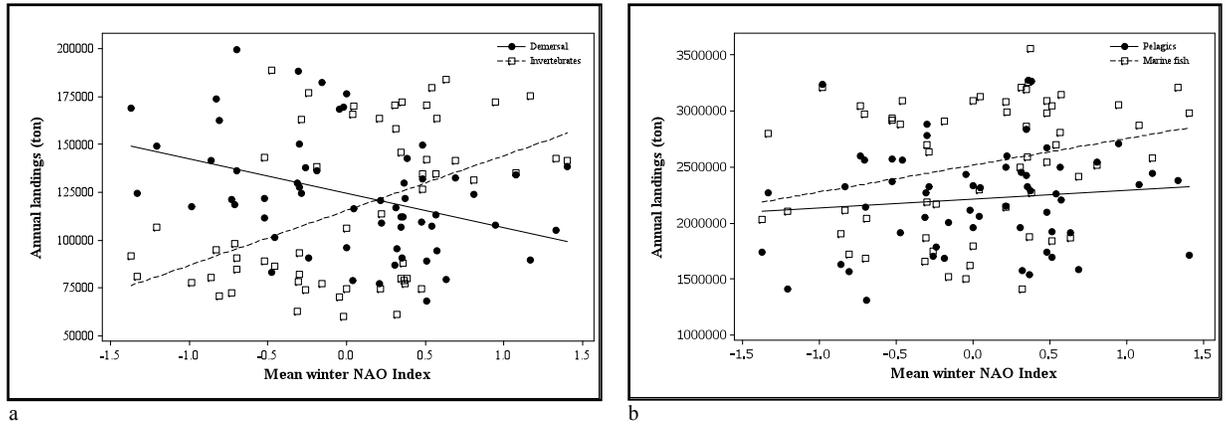
Figure 7-33. Regression analysis between the winter NAO Index and the landings of a) demersal fish and invertebrates and b) marine fish and pelagics, in the North Sea.

In Iberia and the Bay of Biscay, the NAOI has a positive relationship with demersal catches (F = 14.20, r^2 = 18.5, p < 0.001) and invertebrate catches (F = 5.94, r^2 = 7.8, p = 0.018), and no relationship with either pelagic (F = 1.71, r^2 = 1.2, p = 0.196) or other marine fish captures (F = 0.26, r^2 = 0.1, p = 0.613; fig. 7-34).

a   b
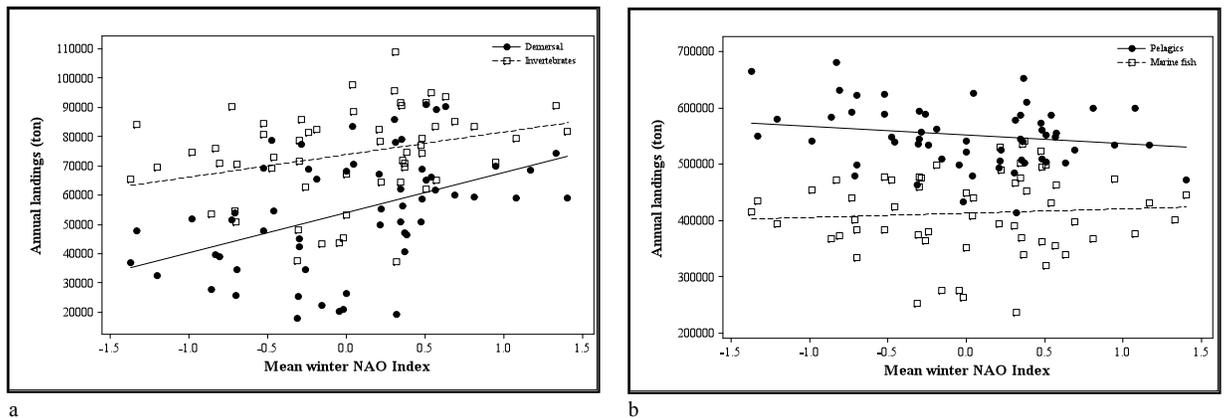
Figure 7-34. Regression analysis between the winter NAO Index and the landings of a) demersal fish and invertebrates and b) marine fish and pelagics, in Iberia and the Bay of Biscay.

In NWA, the NAOI has a positive relationship with demersal catches (F = 10.87, r^2 = 14.5, p < 0.002), invertebrate catches (F = 20.06, r^2 = 24.7, p < 0.001), pelagic (F = 25.39, r^2 = 29.6, p < 0.001) and other marine fish captures (F = 9.84, r^2 = 13.2, p = 0.003; fig. 7-35).

a

b
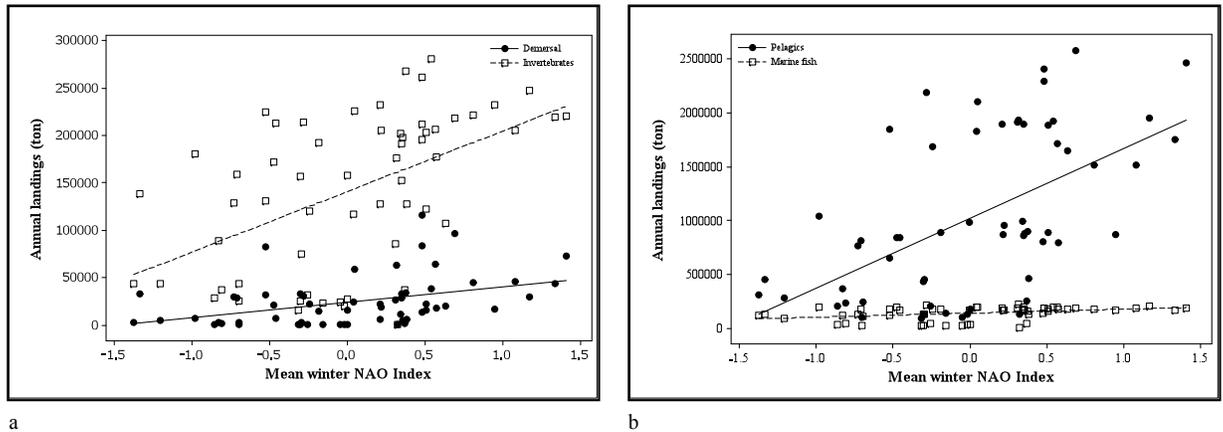
Figure 7-35. Regression analysis between the winter NAO Index and the landings of a) demersal fish and invertebrates and b) marine fish and pelagic fish in NWA.

Discussion

Fish landings are far higher from catches around Iberia than off Africa especially from demersal fisheries, except for pelagics. For this reason, theoretically there is more food for scavenging seabirds in the Bay of Biscay and Celtic Sea, suggesting that these may be more suitable areas for wintering gannets and skuas. However, several fish stocks like hake and anchovy have been depleted in the Bay of Biscay (Gil, 2008) and the fisheries in North-western African countries are increasing in the last years, resulting in a large and increasing amount of fish discards. Increased fishing in African waters in recent years could be attracting scavenging migrant seabirds. On the other hand, increases in pelagic catches in NW Africa (FAO, 2006; 2008) probably relate to increases in stocks of these small pelagic fish due to reduced predation by large demersal fish which have been reduced in abundance. Larger stocks of pelagics may also attract seabirds such as Skuas and Gannets.

Seabirds in the North-eastern Atlantic have benefited from the enormous amount of fish discarded, three times the volume from North-western Africa for the period 1992-2001 (Kelleher, 2005). It is possible that discards from the European waters attract such a huge number of seabirds, competition resulting in a low income of fish for seabirds wintering in the North Sea, Bay of Biscay and surrounded areas. If competition for food in the Bay of Biscay is great, due to the enormous fishing activities there, the increase of African fisheries and discards could attract an increasing number of birds. As a result, seabirds may be redistributing according to ideal free distribution. This means equally-competitive individuals

distribute between patches of food, such that the proportion of these resources equals the proportion of individuals by patch (Jackson *et al.* 2004) and all individuals obtain equal amount of food. Scavenging seabirds may be attracted in large numbers to fishing boats in the Bay of Biscay and Celtic Sea areas closest to the breeding areas, reducing their chances of obtain food as the number of birds is high. Thus, individuals migrating to Iberia early in the year could monopolize discards from fishing boats because they arrived first. As a result wintering Gannets and Skuas could gain from moving further south to waters off Africa in order to avoid competition for food around Iberia.

Fisheries from African countries have been increasing, but total fisheries landings from the entire Central-eastern Atlantic have been stable in recent years, unlike invertebrates and "other marine fish" landings, which have shown a decreasing trend. A similar situation is seen with discards; those from African countries are increasing, but not those from international fleets operating in other regions where decreased discarding has been evident after peaks in the 1970s.

Because of the lack of modern technology, the African fleet fishes near the coast, in waters on the continental shelf. These artisanal fisheries have increased significantly in Mauritania, Senegal, Guinea and Ghana, with a noticeable rise in the number of vessels and the level of motorization (Lenselink, 2002). A similar situation is observed in the Moroccan sardine fleet, which operates close to the ports in shallow waters not exceeding 100 m depth (FAO, 2006). So, wintering seabirds may be taking advantage of these coastal artisanal and semi-industrial fisheries developed by African countries, as well as extensive fisheries from the international fleet in the open ocean.

The increment in fishing landings and discards in North-western Africa is coupled with more stable climatic conditions, observed in the non-significant trend in the sea surface temperature during recent years in the coast off Africa from Morocco to Mauritania (fig. 7-33). Across the shelf off Mauritania, upwelling water is cold and this supports high concentrations of plankton reflected in high chlorophyll levels, with large numbers of seabirds congregated around fishing vessels (Brown, 1979; Leopold, 1993; Wynn and Knefelkamp, 2004). Fishing activities clearly influence the distribution of seabirds in the coast of Mauritania. However, seabird density inshore could be more related to the concentration of natural food, such as the

large stock of *S. aurita,* rather than the discards available (Wynn and Knefelkamp, 2004). It has been suggested that trawlers could affect the distribution of seabirds in the area, masking the effects of the oceanic conditions Leopold (1993).

Sardinella spp. do not spawn in the southern part of their distribution (see fig. 1-14) in the warm waters off Senegal, and spawn in the central and northern part of their distribution, in the coasts of Mauritania, Western Sahara and Morocco. They could be the key species attracting seabirds both as scavengers and natural feeders.

Observed sea surface temperature trends are in accord with previous observations, with slightly warmer temperatures around Canary Islands as well as in equatorial waters off Senegal, than the coastal waters of Western Sahara and Mauritania (Camphuysen and van der Meer, 2005). This means that gannets and skuas can find an increasing amount of food, being strongly attracted to trawlers (Wynn and Knefelkamp, 2004), in an environment with no noticeable effect of warming. Changes in climatic conditions, like sea surface temperature, may not affect seabirds directly, but the effects of sea warming on fish may be the key factor affecting seabird distribution. The upwelling area along the coast of Senegal supports a low density of seabirds, in comparison with other upwelling sites in the world, and higher densities of seabirds, mainly migrants, are found close to shore (Brown, 1979; Hunt and Scheider, 1987). In the case of the Northern Gannet this could be due to the behaviour of this species, because gannets seldom range far out to sea (Nelson, 2002).

Despite the Bay of Biscay showed no noticeable increase in temperatures during the period analyzed, an increasing trend was observed in previous analysis of the period 1972-1993 (Koutsikopoulos *et al.* 1998). If observed trends (summarized in the fig. 7-36) persist far in the future, the Eastern-central Atlantic will probably become the most important wintering area for gannets and skuas breeding in the northern North Sea.
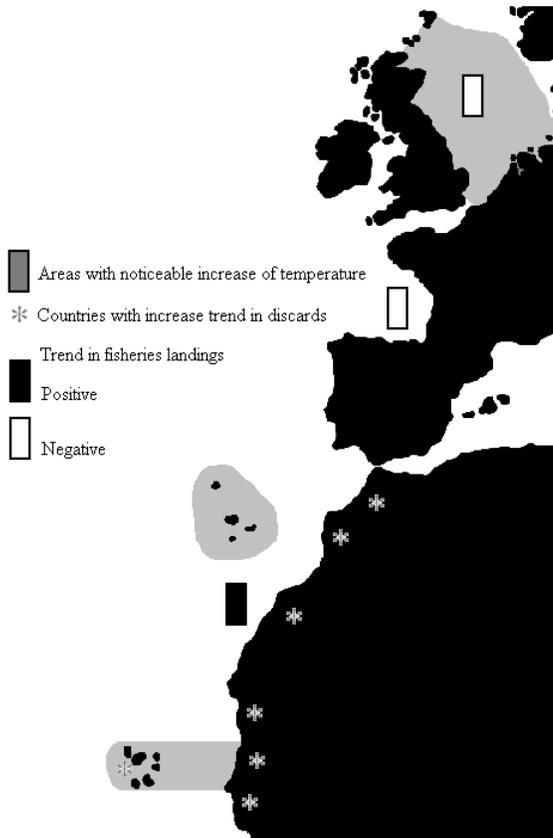
Figure 7-36. Eastern Atlantic Ocean showing the tendencies in fisheries landings, discards and temperature by area.

Oceanographic conditions along the northern coast off NWA are more stable, at least the sea surface temperature. At the same time, artisanal fisheries are increasing in the sub-area. This labour-intensive type of fishery involves a large number of vessels, with a limited volume of fish landed. Despite the fact that about 85% of fishing vessels in the world are artisanal, these account for only 20% of the total volume of catch (Lenselink, 2002). These particular conditions should be part of the answer as to why there are an increasing number of gannets and skuas wintering in African waters, because there are a large number of boats discarding food, and the stable temperatures are beneficial for local fish populations (mainly sardines). Some actions have been taken to stop overfishing in the North Sea, the Celtic Sea and Bay of Biscay, including the reduction of catch quotas, causing a north-south redistribution of fisheries (Worm *et al*. 2009). The logical response of scavenging seabirds is the movement to winter in southernmost waters. But the future is not clear because North-western African countries are likely to face severe overexploitation of their fishing resources (Kaczynski and Fluharty, 2002).

The all year NAOI lowest value was observed during 1998, unlike the winter NAOI, and mean winter temperatures were extremely high along the Eastern Atlantic in 1998 as well. A possible explanation of this is that winter temperatures could be related to atmospheric dynamics through the entire year, instead of only winter atmospheric dynamics. As a result, extreme high winter temperature in the Eastern Atlantic in 1998 was influenced by a negative NAOI, resulting in weak westerlies (Hurrell and van Loon, 1997), during the previous months. During negative NAOI the Western coast of Africa is warm with reduced upwelling (OSPAR, 2000; Hurrell and Dickson, 2004). Stable sea temperatures observed in this area could be related then to positive winter NAOI observed in the majority of the recent years.

Fisheries are positively related to the winter NAOI in the NWA, suggesting that higher fishing volumes are related to higher values in the index, when oceanic conditions are cold with strong upwelling. Local changes in the coast off NWA are strongly associated with wind trades and current direction, this association being less important in the Iberia-Bay of Biscay and North Sea areas, possibly because the coast of NWA is an open area whilst the Bay of Biscay and the North Sea are semi-closed seas. The winter NAOI is related also with demersal (negative) and invertebrate (positive) catches in the North Sea, and demersal (positive) around Iberia, suggesting that demersal and invertebrate species abundances are influenced by the North Atlantic Oscillation along the entire North-eastern Atlantic. Demersal and invertebrate species are associated with the bottom and possibly unable to respond to changes in the environment. Other marine fish captures are related to the NAOI in the North Sea and invertebrate captures are related to the NAOI in Iberia, but with a low values in the correlation coefficient showing a weak relationship.

Chapter 8

General Conclusions

Great Skuas from Shetland move to the North Sea before the autumn migration to the south (Furness, 2002a), possibly driving changes in wintering patterns and distribution. This movement to the North Sea could be related to the search of food and, in case of finding fish in high abundance, avoiding having to travel far south. When the number of birds in the North Sea is high, the competition for food could promote movement along the Atlantic coast of Europe. A similar situation could happen with the Northern Gannet, when individuals leave the breeding colony in the Bass Rock (or others in Scotland) to disperse around the North Sea, and even to the north.

New colonies have been formed in northern latitudes for both Northern Gannets (Wanless, 2002) and Great Skuas (Furness and Ratcliffe, 2004), indicating important changes in the distribution of these species. This colonization of new areas, resulting from an overflow of birds breeding in traditional colonies, clearly indicates that changed migration patterns are not related to failures in breeding success. Actually, the gannet colony from the Bass Rock has remained stable in recent years (Hamer *et al.* 2007). In this case, new colonies could be related to the northern movement of fish species, as a result of climate warming.

Recent numbers of Northern Gannets wintering in the North Sea are declining (ICES, 2007), which could be a convergence of negative effects of the warming of the sea on the fish food of seabirds during winter, although changes in fishery practices and in amounts of discards may be as, or more, important than influences of climate. The Bay of Biscay and the sea around Iberia has been a common wintering area for gannets and skuas, having a huge amount of food available as discards. Despite the fact that natural food is the primary target for breeding seabirds, scavengers like gannets and skuas tend to feed more on discards during winter (Furness, 2003). As a result, the number of fishing boats operating during the winter months in the wintering areas is an important aspect, just like the amount of discards.

Nonetheless, there are an increasing number of reports of Northern Gannets and Great Skuas wintering in NWA in recent years. The lack of ring recovery records of these seabirds along the coasts off Northwestern Africa before 2006 (Furness *et al.* 2006), could be related to the poor effort in the search for wintering seabirds in the area or the high survival rate. If this last assumption is true, the high survival rate could be related to good conditions for wintering, in terms of food abundance.

But the important question remains: why Northern Gannets and Great Skuas are forming new colonies in the far north while there is a tendency to migrate further south in winter? New colonies at high latitudes could be explained by climate warming, but not the migration to lower latitudes. Actually, the climate warming explanation is contradicting in this case because it is difficult to interpret the movement of cold-adapted species to tropical areas when temperatures are rising.

On the other hand, it is important to stress that climate change could affect the seabirds indirectly. The negative effect of the increase in sea temperature on seabirds could be related to the effect of climate on fish, the food source for seabirds; and even more fundamentally, the effect of climate on plankton. This cascade-effect could be observed in the switch in the copepod species in the North Sea (Lindley *et al.* 1995), and reflected in a regime shift (Reid *et al.* 2001; Beaugrand, 2004). Changes in fish stocks in the area are associated mainly with fishing pressure which is intense and overexploiting most stocks at present, but there is a clear effect of the climate as well (Hilborn *et al.* 2003) In addition, the effect of the NAO is observed in changes of current and wind patterns (Edwards *et al.* 1999; Reid *et al.* 2003; Beaugrand, 2004). As a result, the oceanographic conditions in the North Sea are changing and the migration behaviour of both Northern Gannets and Great Skuas is apparently changing in recent years. The adaptation of seabirds to the new conditions depends on the ability to find new sources of food during winter, and the ability to reach distant wintering areas with enough fish available to survive.

Despite the increasing reports of wintering gannets and skuas in NWA, fisheries and fisheries discards in the Iberia-Bay of Biscay areas are still higher. Thus the advantage of wintering in NWA could possibly be explained by the following hypotheses:

- **Less competition in NWA in comparison with Iberia-Biscay**. Most of Northern Gannets and Great Skuas winter in the North Sea and the Bay of Biscay and Iberia coasts (Furness, 1987; Nelson, 2002; Kubetzki *et al.* 2009; Veron and Lawlor, 2010), with almost all ring recoveries of adult Great Skuas from Iberia (Furness *et al.* 2006). The increase of these seabird species wintering in NWA has been a surprise (Furness *et al.* 2006; Veron and Lawlor, 2010), and could be related to the lack of competition for food there. The first individuals arriving in Iberia find a huge amount of fishing boats discarding food, and as the number of migrant

seabirds is increased the discards begin to be difficult to obtain due to scramble competition behind fishing boats. When most of the migrants have reached the Iberian coasts, the amount of food per bird could be small, and competition strong. Under these circumstances moving southward appears an excellent alternative in the search of food. The theory of ideal free distribution could thus explain this idea.

- **Wider wintering area in the NWA because it is an open sea.** Gannets and skuas migrate close to the coast, but occasionally can move to pelagic waters (Camphuysen and van der Meer [2005] reported Northern Gannets and Great Skuas in deep ocean and shelf edge waters off Western Sahara and Mauritania). Because of this, it is important to consider the extension of the coastline and surrounding marine area to evaluate the available area for wintering. The wintering area off NWA is noticeably bigger than the coast around Iberia, and could attract an increasing number of migrant seabirds.

- **The high abundance of natural food in NWA.** Along the continental coast of NWA discards have been increasing in recent years, but the pelagic fish available is abundant as well. *Sardinella* species is the most notable fish in the area, being suitable for seabirds. Sandeels *Gymnammodytes cicerelus* are common in this area (Froese and Pauly, 2010) and are the kind of fish usually targeted by Northern Gannets and Great Skuas during breeding. The abundance of fish in the area is high; actually the Saharan Bank, from the South of Morocco to the North of Mauritania (including the entire coast off Western Sahara) is one of the richest fishing grounds in the world (Balguerias *et al*. 2000). Although pelagic fish are harvested, the pelagic fishery does not discard much if any of the catch so it does not make pelagic fish available as discards. But it is believed that the depletion of predatory demersal fish in this region may be causing an increase in abundance of the small pelagic fish and so may contribute to increased availability of this natural food for seabirds.

- **Major number of boats fishing in NWA.** Fisheries in NWA are driven mostly by small and artisanal vessels. In addition, limited surveillance leads to illegal fishing (and maybe overfishing) conducted by an unrestricted number of boats. In the same way, the lack of controls could promote the discarding of a huge amount of undersized, untargeted and bycatch fish, and offal. Fishermen could be using illegal type of fishing gear, usually associated with the fishing of undesired species. In fact there is no regular government in Western Sahara. In

addition, some countries are unable to regulate the number of foreign boats. As a result, the increasing numbers of unrecorded fishing boats may be an important source of food for scavenging seabirds.

- **More predictable and stable conditions in NWA.** Results of this research show a strong positive relationship between the NWA fisheries and the winter NAO Index. Whether seabirds are able to asses the abundance of fish using changes in the NAO conditions is something to be proved, but it is possible that sea surface temperature or wind direction during the autumn migration could indicate the conditions prevailing in African waters. The data on this thesis show that waters around Canary Islands, Cape Verde Archipelago and the coast of Senegal, have undergone a noticeable increase in sea surface temperature. These results coincide with previous reports from Camphuysen and van der Meer (2005), which found that subtropical waters off the Moroccan coast and around Canary Islands, as well as in equatorial waters off Senegal, are slightly warmer than the coastal waters of Western Sahara and Mauritania. With this information it is possible to establish the importance of the coast off Western Sahara and Mauritania as wintering area for Northern Gannets and Great Skuas. Unfortunately, there are no fishing data from Western Sahara.

- **The abundance of fish in NWA has been learnt and taught by increasing number of individual birds.** Living in colonies offers the opportunity to transmit information between individuals. Successful migrants could be followed by an increasing number of individuals on the lookout for food in following migrations. As a result, an increasing number of migrant seabirds in NWA may be related to birds following others newly discovered wintering grounds in southern latitudes in recent years. Results showed that age class 2 individuals, in both Great Skuas and Northern Gannets, showed no statistical differences in the finding latitudes of the rings between years (especially during non-breeding and winter months), indicating that major changes in migration patterns are observed in both age class 1 and age class 3. First fledglings in Great Skua and failed breeders migrate south at the same time (Furness, 1987) the failed breeders potentially being a source of information about new wintering grounds for juveniles. Late chicks could learn the route to NWA from successful breeders. If the idea of the free ideal distribution is correct, those late chicks and successful-breeding adults could be wintering in NWA because they are the last migrants, and this may

be explained by observed changes between years in the finding latitudes from age classes 1 and 3.

According to results obtained in this thesis, it is possible that climate warming is affecting the breeding distribution of seabirds in the north. Fisheries could have affected the breeding performance of seabirds; an example of that is the reduction in breeding numbers in Shetland associated with the depletion of sandeels (Furness, 2007). Changes in fisheries are apparently driving changes in the migratory patterns of seabirds. The depletion of fisheries in the North Sea has reduced the amount of fish discarded during winter (the main food supply for scavenging seabirds), forcing the migration to southern areas for an increasing number of seabirds. Results showed no Northern Gannets with data loggers wintering in the North Sea during the 2008-2009 winter, and around half of the individuals analyzed wintered in NWA. A similar situation occurred with Great Skuas carrying satellite transmitters (Furness *et al*. 2006). On the other hand, depletion of sandeels in the North Sea could affect other fish species as sandeel-predators. In this situation, larger fish species like Hake or cod will suffer as a result of the lack of food and, as a result, discards from these species will affect the scavenging seabirds.

It is important to note that Northern Gannets and Great Skuas are increasing in numbers. So, the search for new wintering areas in the south could be a consequence of the need to find food for a longer number of birds, whilst the formation of new colonies in the north is the solution to finding new food and space during breeding.

The Northern Gannet and Great Skua are species that live for a long period, and during their entire life span they learn and apply new strategies in their survivorship. This plasticity is observed when individuals ringed in Scottish colonies are found breeding in newly formed colonies in Russia, Norway, Bear Island, Svalbard and Jan Mayen. Sudden changes in the numbers of individuals wintering in the North Sea or Iberia or NWA, between a few years, is another example of this ability to change strategies. Such switches in the migratory strategy are unlikely to be related to a genetically imposed behaviour. Newly-adopted strategies to survive include not only changes in migratory patterns, as with the increasing number of Northern Gannets or Great Skuas wintering in NWA in recent years, but also changes in time

budgets such as Northern Gannets flying more during autumn migration when they spend winter in NWA.

This scenario of more individuals wintering in Africa could give rise to problems. Fisheries in Africa have a pessimistic future because the race for fish is in full swing (Hilborn *et al.* 2003). Fortunately, the Archipelagos of Madeira, Canary Islands and Cape Verde, and some points along the coast of NWA like Cape de Arguin (Mauritania), are under some kind of protection and considered priority areas for conservation by BirdLife International. Hopefully, conservation efforts will benefit the wintering grounds for Palaearctic-breeding seabird species, including Northern Gannets and Great Skuas. In the same way, new policies in the European countries, imposed to allow the recovery of fish stocks, should increase the food available in the North Sea. Future application of programmes to stop climate warming would promote the recovery of the natural populations along the entire North-eastern Atlantic.

This research has indicated that the Northern Gannet and the Great Skua are changing their migratory patterns, with increasing numbers wintering in the coast off NWA and adapting their time budgets to cope with this change in migration. In the same way, human fishing activities have been strongly implicated in causing these migratory changes. More surveys are needed in African waters, in order to establish the main source of food for Northern Gannets and Great Skuas, detecting their main wintering grounds precisely, and investigate for the adoption of new strategies that has allowed them to survive during winter in tropical latitudes.

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