Report of the Working Group on Seabird Ecology (WGSE)

23-27 March 2009

Bruges, Belgium

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Contents

Executive summary

Highlights:

- WGSE prepared a preliminary review of studies that have deployed various remote tracking techniques to gain better understanding of seabird dispersal and dispersion, and also to increase knowledge of seabird habitat preferences. The history of use of tracking methods is a fairly short and recent one. They include radio-tracking, satellite tracking, tracking using Global Positioning Systems, geolocators, and photography. The relative merits of these in various types of study are outlined and prospects for the future occasionally addressed. These prospects are improving rapidly with increasing miniaturization of devices that extends the scope of such studies as well as the suite of species that can be studied. Falling costs also add to the likelihood of increased future deployment. Although such techniques compare favourably in practical terms with more conventional methods, such as transect surveys, the latter remain useful and appropriate in many circumstances.

- In view of recent progress in the identification of inshore areas that serve as key feeding areas for important bird species (a requirement for EU Member States under the Birds Directive), and the potential for conflict with offshore renewable energy objectives of many countries bordering the North Sea, WGSE considered possible methodologies for studying the foraging demands of birds that visit such areas. In assessing the degree of potential conflict, it must be emphasized that appropriate methods be applied to the question. For example, seaduck congregate over large, productive mussel beds in shallow water outside the breeding season, especially in the southern North Sea. It is important that *inter alia* the energetic requirements of mussel-eating birds in these areas be assessed. WGSE has reviewed methods for doing so, and advised on an individual-based model that should include certain key biological (species-specific) and environmental (site-specific) variables in parameterization of the model.

The Working Group on Seabird Ecology (WGSE) met for five days (23–27 March 2009), and was attended by ten persons from six countries (Annex 1). Nine were nominated members of the group and one was invited by the Working Group Chair to attend this year's meeting. During the meeting, WGSE addressed all Terms of Reference and also discussed issues related to the possible formulation of a management plan for the great cormorant (advice delivered separately). The results of the meeting are reported here.

In response to anticipated OSPAR interest WGSE considered the EcoQO relating to seabird populations with specific reference to Norwegian and UK populations. The likely performance of the EcoQO as currently constructed (it requires further development) was also placed in the context of recent recommendations by OSPAR for the QSR 2010 report. Some shortcomings in the (draft) QSR recommendations are described; the principal note of caution being that the performance and usefulness of the indicator reduces as species are aggregated into coarse ecological or taxonomic categories.

A preliminary review is presented of published and current studies of seabird movement patterns and marine habitat associations using a variety of remote tracking techniques. The history of these novel techniques, which include *inter alia* radio-

and satellite tracking, GPS use and geolocators, is briefly outlined, they are described, and their uses are compared with more conventional methods such as transect surveying. Conventional and novel tools each have their own advantages and disadvantages. A brief summary of some issues relating to the analysis of remotely collected data are presented.

Little progress with the compilation of a European Community Plan of Action to reduce the bycatch of seabirds in fishing gear is noted. The most significant development appears to be the design or adoption of a *pro forma* for recording fishing effort and bycatch incidents. Some observations are made on the content of the form for the attention of the EC

An updated summary of ecological issues related to the circulation of pathogens and parasites in seabird populations is presented, an account of the impacts of ectoparasites, endoparasites, and fungi having been added to previous iterations of this review. These macroparasites appear to impair the fitness of their seabird hosts by depleting host resources such as blood or nutrients, but it can be difficult to unravel such direct effects from indirect effects mediated through other microparasites.

Possible quality assurance arrangements for the delivery of the OSPAR EcoQO on oiled guillemots are suggested in the report. The EcoQO aims for not more than 10% of those guillemots found on beached bird surveys to be oiled. A customized database managed by a competent database manager responsible for data collation and checking and dissemination of information is the main recommendation.

A revised, updated account of the effects of climate change on seabirds is presented in Chapter 7. Although mostly material presented in the 2008 WGSE report a new section addressing possible sensitivity of marine ecosystems is added. Although climate change effects on seabirds are not likely to have major ecosystem effects, seabirds are good indicators of change in the marine ecosystem. For example, climate-induced changes in plankton communities, notably at high latitudes, can cause changes in the length of food chains and consequent variation in the relative numbers of piscivorous and planktivorous seabirds.

In response to a request by Denmark, methodologies for the study of the energetic requirements of mussel-eating birds in Danish waters are reviewed and summarized. The preferred approach is to build individual-based energetic models, and a good example of one is described. The importance of including certain key biological parameters as well as site-specific environmental ones is emphasized.

1 Introduction

1.1 Participation

The following members of the Working Group on Seabird Ecology (WGSE) attended and participated in the meeting (see Annex 1 for full details).

Tycho Anker-Nilssen	Norway
Rob Barrett	Norway
Mark Bolton	UK
Thierry Boulinier*	France
John Chardine	Canada
Francis Daunt	UK
Morten Frederiksen	Denmark
Arnthor Gardarsson*	Iceland
Stefan Garthe*	Germany
Bill Montevecchi*	Canada
Jim Reid (Chair)	UK
Eric Stienen	Belgium
Mark Tasker	UK
Richard Veit	USA

*contribution by correspondence

Eleven persons were nominated members of the group and two persons were invited by the WG Chair to attend this year's meeting. The authority to nominate persons not yet nominated by national delegates was again considered by the group to be an extremely useful tool.

1.2 Terms of Reference

The 2008 Statutory meeting of ICES gave the Working Group on Seabird Ecology [WGSE] the following Terms of Reference:

a) review the status of relevant seabird populations in relation to the OSPAR ecological quality objective (EcoQO) for seabird populations and its component indicators;

b) summarize the quality status of seabird populations in each of the OSPAR regions as a contribution to the QSR 2010;

c) review and report studies of the distribution and habitat association of seabirds in ICES waters based on remote tracking of individual birds;

d) review the extent to which bycatch in commercial fishery may affect seabirds in the North Atlantic, including the Mediterranean and Baltic Seas;

e) review the ecological roles of macroparasites such as ectoparasites (ticks, fleas, lice), fungi, and Protozoa in seabird populations;

f) review the quality assurance arrangements for the following ecological quality objective as set out in the EcoQO Handbook (OSPAR publication 2007/307) and make suggestions for their further development and/or improvement: (i) oiled guillemots. (OSPAR request no. 5, 2009);

g) prepare review papers for the chapters of the ICES position paper on Climate Change on:

- Changes in abundance, migration and distributions patterns;

- Sensitivity of marine ecosystems to climate variability and regime shifts

A further Term of Reference was added at the request of ICES:

h) to advise on methodologies for:

- Estimation of the energetic requirements of Eiders and other mussel eating bird species in the Danish part of the Wadden Sea, including assessment of the amount of blue mussel necessary for the eiders; and

Estimation of the energetic requirements of Eiders and other blue mussel eating bird species, in the NATURA 2000 sites outside the Wadden Sea.

All Terms of Reference were addressed by WGSE, although it was not possible to consider some of them in as much detail as it would have liked because of reduced numbers of members of the group attending this year.

1.3 Note on bird names

Throughout the text we use official English names for bird species; scientific and English names are listed in Annex 2.

1.4 Acknowledgements

The Working Group on Seabird Ecology wishes to thank the Vlaams Instituut voor de Zee (Flanders Marine Institute) for arranging the meeting logistics in Bruges and Ostend, especially Ingrid Dobbelaere for providing us with rooms and other facilities. WGSE also thanks Hotel Acacia for facilities on the final day of the meeting. The following persons and organizations provided information for the meeting: Tony Diamond (University of New Brunswick), Mardik Leopold (IBN/DLO), Mark Mallory (Canadian Wildlife Service), Matt Parsons, Roddy Mavor and Ian Mitchell (Joint Nature Conservation Committee), Rob Ronconi (Dalhousie University), Gina Shield and Debra Palka (National Oceanographic and Atmospheric Administration), Kasper Thorup (University of Copenhagen). Karen McCoy (Génétique et Evolution des Maladies Infectieuses, CNRS/IRD, Montpellier) contributed to Chapter 5 of the report.

2 The quality status of seabird populations within the OSPAR regions

WGSE was asked to address two very similar Terms of Reference relating to the status of seabird populations in the OSPAR Maritime Area. Seabird population data were not available (and the mechanism to ensure their availability in a timely fashion for most of the OSPAR countries does not exist) in order to allow a formal assessment of their status in relation to the Ecological Quality Objective on seabird populations (ICES 2008) In any case, the EcoQO requires further development. Potentially, the EcoQO could serve as a useful tool in the QSR 2010, and also in reporting under the EU Marine Strategy Framework Directive. An attempt is made in this chapter to place recent trends in some seabird populations in a similar context to that of the EcoQO, although at the same time highlighting some shortcomings of the approach.

2.1 The EcoQO on seabird population trends

To date, only data from OSPAR Region III have been analysed with regards the EcoQO on seabird population trends in OSPAR regions as proposed by the WKSE-QUIN workshop (ICES 2008). Although new census data for northern gannets and great cormorants from Iceland were made available to WGSE, no new annual moni-

toring data were forthcoming from any of the other OSPAR countries to test the EcoQO. WGSE concurs with the ICES *ad hoc* advice group (May 2008) that such data should be made available and analysed annually, and, as discussed in more detail below, also agree with their suggestion that OSPAR Region I should be subdivided to account for the huge variations in oceanographic and ecological features and trends in seabird populations among subareas.

2.2 Insufficiencies of method applied for the QSR 2010

Although qualitative, the method hitherto applied in the QSR 2010 process to assess the quality status of seabirds and other ecosystem components in the OSPAR areas (Robinson *et al*. 2009) is complex, and WGSE did not have time to review it in any detail at its meeting. We did, however, identify what we believe are very important shortcomings when using it for assessing the status of seabirds. These are primarily linked to the spatial and ecological resolution of the analysis.

2.2.1 Differences at the ecosystem level

One evident problem is linked to the ecological differences between several large marine ecosystems (LMEs) identified within some of the OSPAR regions (see e.g. Arctic Council Oil and Gas Assessment, in preparation). This is especially true when considering such a vast and highly variable area as OSPAR I, which, in this context, is better divided into four different ecoregions (ICES 2008, Figure 2.1).
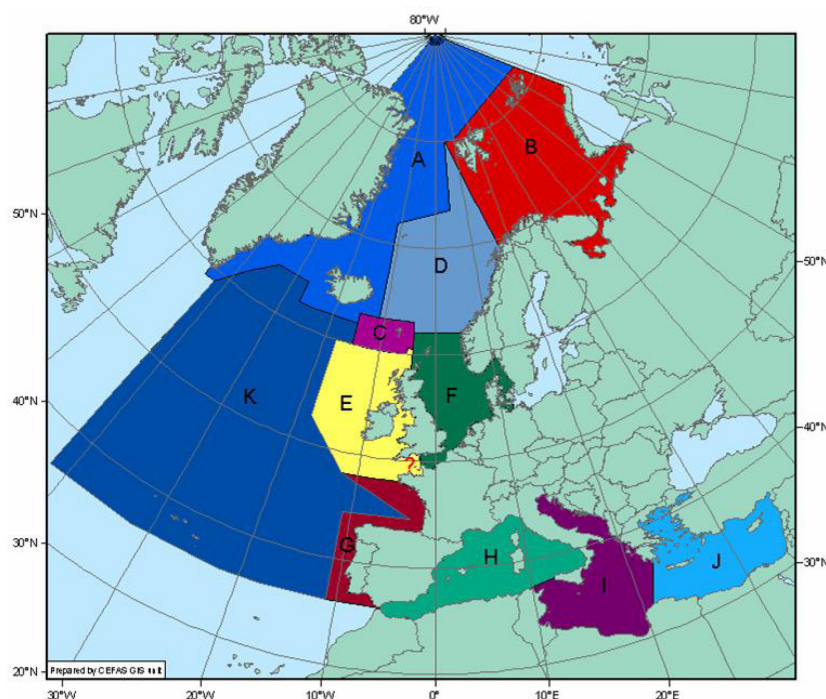
Figure 2.1. Proposed eco-regions for the implementation of the ecosystem approach in European waters (source ICES 2004). WKSEQUIN (ICES 2008) proposed that OSPAR Region I should be divided into eco-regions A-D for the purposes of an ECOQO on seabird population trends as an indicator of seabird community health. The eco-regions in OSPAR I are Greenland and Iceland Seas (A), Barents Sea (B), Faroes (C), Norwegian Sea (D).

The rationale for such subdivisions is illustrated by the fact that populations of the same seabird species in these areas do not necessarily respond equally to one of the main drivers of these systems; climate variation, as measured by the NAO or other indices (see e.g. Chapter 7 of this report). The reason for this is simple: most seabirds do not respond directly to small changes in climate (e.g. sea or air temperature) *per se*, but to the responses made by their main prey species. However, some of these prey species also interact among themselves, such that, for example, an increase in the population of one prey species may severely affect another.

One good example of this is the Norwegian spring-spawning (NSS) herring *Clupea harnegus*, which spawns in the Norwegian Sea but has its nursery areas in the Barents Sea where the young herrings are important predators of capelin *Mallotus villosus*, another key prey for seabirds. Thus, what benefits herring and birds feeding on herring has the opposite effect on capelin and birds feeding on capelin. If trends of seabird population from such different areas are averaged, there is a great risk that important responses become hidden. In other words, even if most populations of a seabird species are changing at rates beyond those considered being normal limits (cf. ICES 2008); the average estimate for their overall population might be well within the normal range.

The subdivisions shown in Figure 2.1 also reflect oceanographic differences that in turn more or less relate to observed differences among seabird populations. Although only a technical problem, splitting OSPAR I into several subregions also makes sense in terms of the state of current knowledge, which is equally variable across LMEs but tends to increase from west (east Greenland waters) to east (Barents Sea).

2.2.2 Differences between populations, species and ecotypes of seabirds

Another important problem arises when treating all seabirds as a uniform group. Even if the average trend in population numbers indicates no significant change within a region, this does not automatically imply that only a few species are changing at rates outside what is considered normal limits. Furthermore, variation at the population level may be obscured when populations are lumped together within a species. These arguments are very well illustrated by the population trends recorded for different populations, species, and ecological groups of seabirds in the Barents and Norwegian Seas over the last decade (Figure 2.2a-d). When treated as one group ("seabirds"), there is seemingly no change in numbers in these areas (Figure 2.2d). However, very different pictures emerge from analysis at the population, species or ecotype levels (Figure 2.2a-c). Analysis at each of these finer scales reveals potentially informative patterns. For example, nine (82%) of the 11 ecotype by area groups have changed more than 30% in numbers within the last 10 years, and the corresponding numbers at the species and the local species-population levels were 72% and 71%, respectively. Moreover, the trend for most of these populations has been following the same direction for much longer. Consequently, there is no doubt that most seabird populations breeding in Norwegian waters are now well outside 70–130% of any reference level that could be assigned by applying the recommendations for the EcoQO on seabird population trends (ICES 2008). Thus, the overall target that at least 75% of the species should be within 70–130% of reference levels (ICES 2008) is clearly not met for seabirds in these areas. Nevertheless, the methods now being applied to produce the QSR 2010 fail to recognize this.
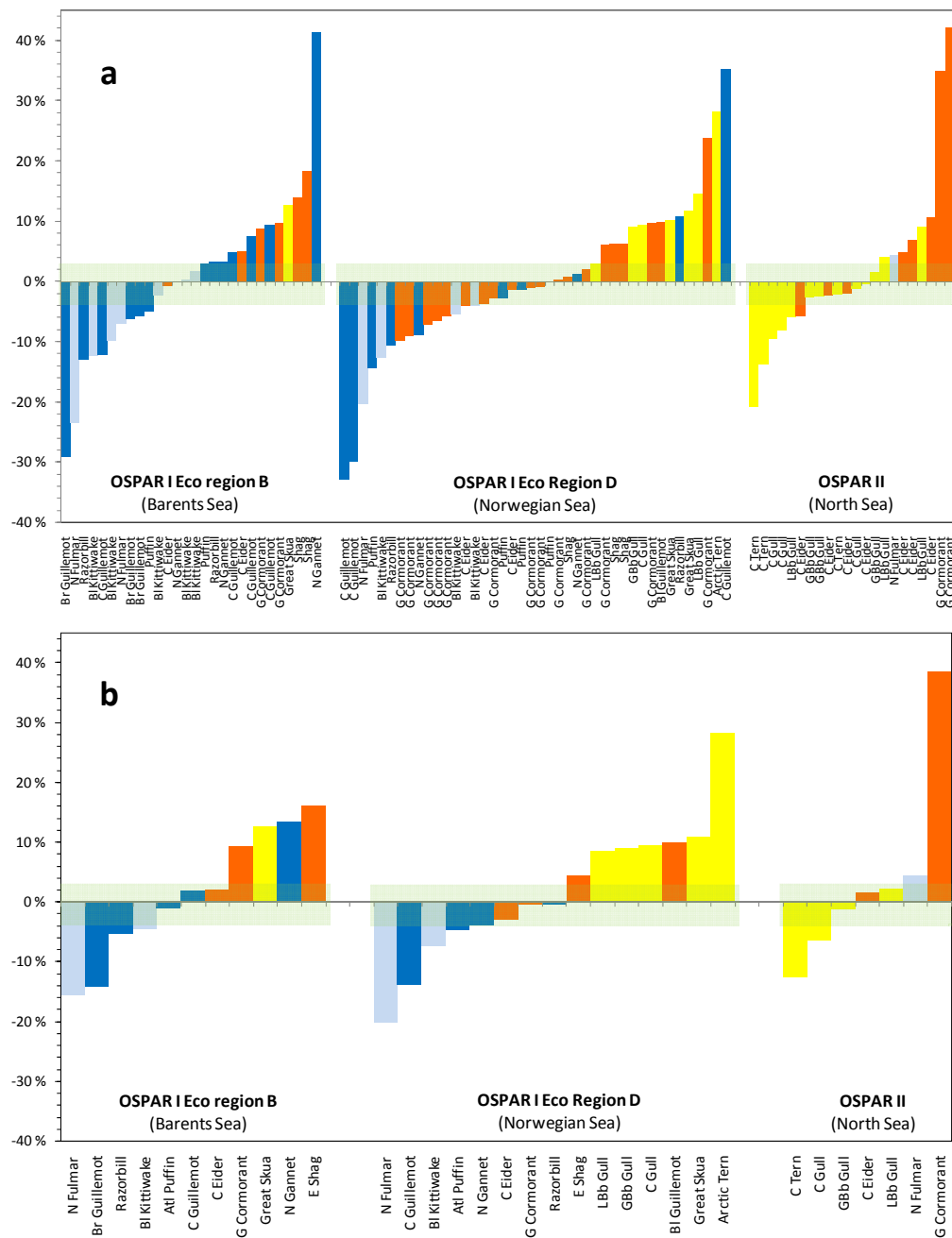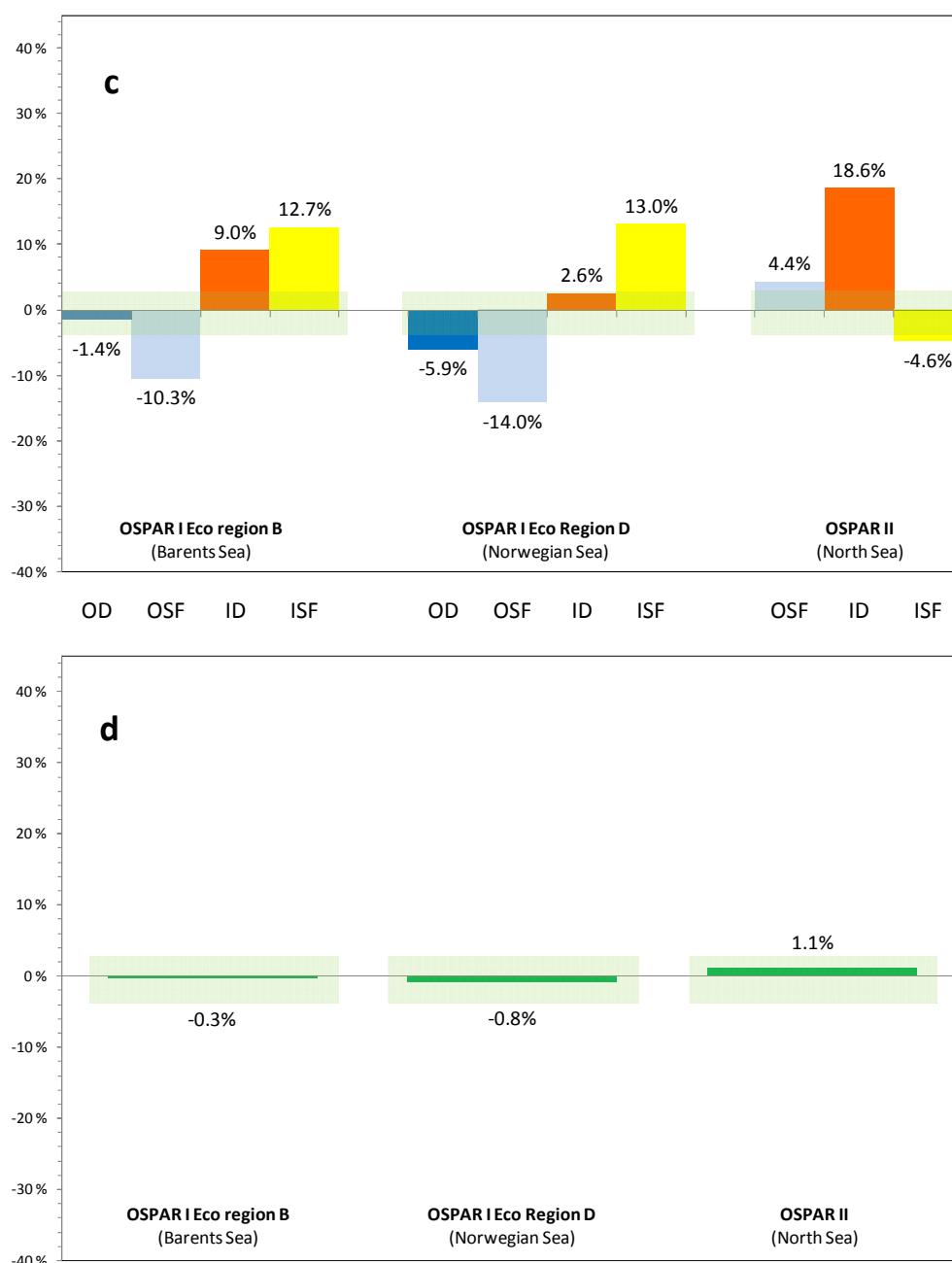
Figure 2.2. Four different ways of presenting the mean annual rates of change in breeding numbers of Norwegian seabirds during the last decade (1998–2007). The results are first split by three different ecoregions as indicated in each graph (cf. Figure 2.1), then either divided further at the population level (a), species level (b), or ecotype level (c), or treated as a uniform group (d). The ecotypes distinguish between four different feeding niches of seabirds, defined as offshore divers (OD, dark blue), offshore surface-feeders (OSF, light blue), inshore divers (ID, orange) and inshore surface-feeders (ISF, yellow). Within each region, all values are sorted from the lowest to the highest rates of change. Note that only rates within the green zone (-3.9% to +3.0% _p.a._) will maintain population numbers within 70–130% of initial numbers over the 10–year period, i.e. comparable with the proposed trigger limits relative to the EcoQO target levels (ICES 2008). (Data from the Norwegian National monitoring programme for seabirds, Lorentsen, 2007)

As a comparison, we applied a similar approach to published data for population trends of Scottish seabirds in 1986–2004 (Parsons _et al.,_ 2006). The results show that over the full 19-year period, only three (23%) of 13 species and none of the four eco-

types fell outside the 70–130% range, whereas when the last 5 years of the same period are examined, eight (62%) of the species and three (75%) of the ecotype groups did (Figure 2.3). Thus, not only does the time frame taken into consideration matter, but there is a clear tendency for a radical change for the worse took place between 2000 and 2004.
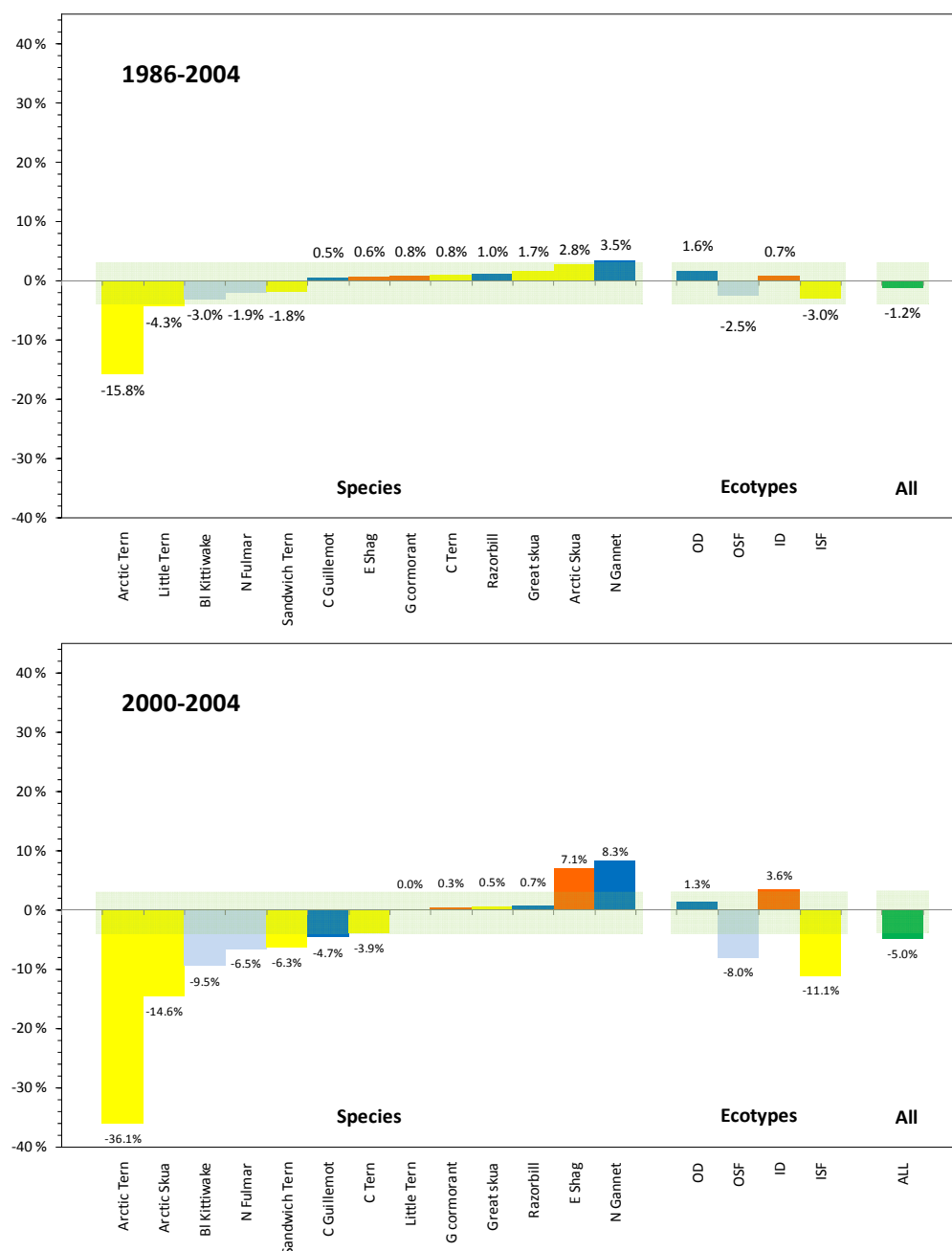
Figure 2.3: Three different ways of presenting the mean annual rates of change in breeding numbers of Scottish seabirds over the 19-year period 1986–2004 (upper panel) and during the last 5 years of the same period (lower panel; Parsons *et al.*, 2006). The results are either split by species level (left), ecotype level (centre), or treated as a uniform group (right). Codes and colours are otherwise as in Figure 2.2: offshore divers (OD, dark blue), offshore surface-feeders (OSF, light blue), inshore divers (ID, orange) and inshore surface-feeders (ISF, yellow). Within each region, all values are sorted from the lowest to the highest rates of change, and the green zone (-3.9% to +3.0% *p.a.*) indicates the rates that will maintain population numbers within 70–130% of initial numbers over a 10-year period (as applied in the Norwegian example in Figure 2.2), i.e. comparable with the proposed trigger limits relative to the EcoQO target levels (ICES 2008).

When compared with the results from the Norwegian part of the North Sea (Figure 2.2) it is interesting that inshore surface-feeding species are the ones experiencing the most severe declines on both sides of the North Sea (but be aware of the different lengths of time periods analysed). Note also that the positive trend for offshore surface-feeders on the Norwegian side reflects only an increase in numbers of northern fulmars in a relatively small area in the southeast of the country, although no colonies of black-legged kittiwakes are monitored in the North Sea part of Norway. Of the offshore surface-feeders on the Scottish side, the kittiwake clearly declined most from 2000–2004.

As a final comment, it should be borne in mind that in most areas only a fraction of the true populations are monitored, and that breeding numbers at the sampled localities (usually colonies) are very different. Given the coarse scale of the analysis applied and the insufficient data from many areas, it is not possible to readily adjust the monitoring results to reflect the overall changes in breeding numbers across regions.

2.3   References

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3   Tracking studies of seabirds in ICES waters

At its 2008 meeting, WGSE formulated a Term of Reference aimed at summarizing the results of studies of the distribution and habitat associations of seabirds in ICES waters as revealed by remote tracking of individual birds. This is a very large subject, and it was not possible to cover it exhaustively at the 2009 meeting. Here, we present a preliminary review of published and ongoing studies using a variety of techniques to track the movements of individual birds and evaluate their habitat preferences at sea, followed by a brief summary of data analysis issues.

3.1   Introduction

Species distributions and habitat associations are central components of their ecology, and provide crucial underpinning data for their conservation and for the identification of protected areas. Two main methods have been employed to ascertain distribution – surveying (principally transect surveying) and individual animal tracking. Both methods have proven invaluable and have complementary advantages (Table 3.1; from ICES 2007).

One important goal of animal tracking is to record an animal's location, from which population distribution is inferred. Habitat association is typically then inferred by comparing distribution with available habitat within the animal's potential range, the habitat data having been collected by other methods (e.g. remote sensing, habitat mapping). Alternatively, habitat association may be inferred directly by a data logger (e.g. by cameras photographing habitat directly, or loggers recording temperature, from which oceanographic water type can be inferred). However, in such cases there is no provision of equivalent data on where the birds are not distributed, which is important because habitat association is ideally analysed in the context of habitat availability.

In the marine environment, there has been a particularly wide adoption of individual animal tracking as a technique for estimating distribution, because direct surveying tends to be expensive and logistically difficult. With identification of important seabird habitats being critically important for spatial planning, and helping to identify both Special Protection Areas (required under the EU Birds Directive) and areas of common usage by seabirds and fishery, tracking of individual birds using electronic devices is one of the most important sources of information available for these purposes. As summarized in Table 3.1, this method has some important advantages over surveying methods, in particular the quality of information that is obtained on individuals. This includes high quality data on where an individual carries out different activities such as feeding and resting at sea, which is important in interpreting habitat associations. Animal tracking also provides invaluable information on the individual's status, including its provenance, breeding status and gender. These are all important variables in understanding the constraints under which the individual is operating, which in turn aids in the interpretation of distribution and habitat association. Set against this, animal tracking is typically based on small sample sizes, and the behaviour or distribution of animals may be adversely impacted by the logger. Given the importance of animal tracking in identifying Important Bird Areas in the ICES region, there is a need for a review and report on the distribution and habitat association of seabirds based on remote tracking of individual birds.

Table 3.1. Comparison between transect surveys and individual bird tracking.

	TRANSECT SURVEYS	BIRD TRACKING
Approach	Population	Individual
Representativity of population	Good (potential biases)	Restricted to a fraction of the population (e.g. breeding birds)
Bird information	Very limited	Good
Behaviour and interactions with environment	Direct information	Inferred information
Spatial coverage	Good (limited by survey constrains)	Good (within range of species and technical limitations of the devices)
Temporal coverage	Limited (or high effort required)	Good (limited by device lifespan)
Activity rythms	Lack of nocturnal data	Day-round information
Cost	Low (if "opportunistic" base)	Médium to High
Sample size	High	Low

Potential biases due to:	Temporal changes (at different scales)	Significant fraction of population disregarded Sample size
	Lack of any information of the birds observed: breeders vs. non-breeders, colony location, etc.	Device autonomy and accuracy
	Type of boat used (commercial, research vessel etc)	

In this chapter, after a short discussion on distribution and habitat association, a brief history of animal tracking is presented, followed by a description of the application of these methods in seabird studies in the ICES region, including a summary of their advantages and disadvantages. Future research priorities are also highlighted.

3.2 A brief history of animal tracking

3.2.1 Radio-tracking

The earliest method used to obtain distributions using animal tracking was radio-tracking (Kenward, 2000). The first full operational radio tag was described in Cohran and Lord (1963), and one of the earliest applications was in ruffed grouse (Marshall and Kupa, 1963). Over the last 45 years, radio-tracking has been used in a vast number of studies in a large range of animal groups, including terrestrial vertebrates, terrestrial invertebrates and marine vertebrates (reviewed in Kenward, 2000). It is much the most widely used method of obtaining animal locations because it has been available for the longest time, over a period which included a rapid and substantial miniaturisation that opened up opportunities for working on small species over 20 years ago, and is comparatively inexpensive.

3.2.2 Satellite tracking

Satellite-tracking was first used as early as the 1970s on wapiti *Cervus elaphus* (Buechner *et al.*, 1971), polar bears *Ursus maritimus* (Kolz *et al.*, 1980), turtles (Timko and Kolz 1982) and basking sharks *Cetorhinus maximus* (Priede 1980). The earliest tags weighed >5 kg so could be used only on the largest terrestrial and marine species. The Argos system was made available to animal tracking in 1978, and together with considerable miniaturisation over the same period the number of species on which satellite tracking was employed expanded rapidly, with the first deployments on volant birds in the early 1980s (bald eagles and giant petrels carrying 160g tags; Fuller *et al.*, 1984). Since then, miniaturisation has continued apace with solar-powered satellite tags available at approximately 10 g. The technique is now widely used in many species, in particular marine vertebrates.

3.2.3 Dead reckoning

Dead reckoning is based on the idea that your next location can be calculated from your current location if you know the direction you are heading, at what speed, and for how long. Thus, an animal track can be built up as a series of vectors starting at the deployment site, based on each heading an animal takes, and duration spent on that heading, and finally using average flight speeds for a species (or better still, measured flight speeds of the individual, although this was not possible in the early employment of this technique) to build the vector. By piecing the vectors together the track is estimated (Wilson and Wilson 1988). Loggers used in this method have consistently been smaller than satellite tags, less expensive, and give accurate three-dimensional movements at small scales. It has been used on a range of species, including whales, porpoises, seals (Mitani *et al.*, 2003), and seabirds (see next section).

The data are recorded on the logger, not transmitted, so in contrast to radio tags and satellite tags the logger must be recovered.

3.2.4 GPS

The emergence of GPS (Global positioning System) as a method of animal tracking has transformed this field because this technology improved the accuracy of locations by orders of magnitude. As with other animal tracking methods, its initial application was hindered by the size of logger, meaning that much of the early work was carried out on large, terrestrial mammals (e.g. Rempel *et al.*, 1996). However, substantial miniaturisation has occurred in recent years and GPS loggers have been attached to a large range of species, including birds (Weimerskirch *et al.*, 2002). With loggers now as small as 10 g, opportunities are opening up for numerous applications where loggers can be recovered.

3.2.5 Transmitter/GPS

A recent development has been the integration of transmitting and GPS technologies into one device (McConnell *et al.*, 2004). Two main methods are available – satellite/GPS loggers and GSM (mobile phone)/GPS technology. A third, bluetooth/GPS is being developed. The great appeal of these loggers is that they combine some of the most important advantages of the two logger types, namely very accurate locations without the need to recover the device. These techniques have been used on several species, notably marine mammals and several bird species (e.g. bald eagle, American white pelican).

3.2.6 Geolocation

Geolocation uses daylight data to determine location. Timing of dawn and dusk are estimated from thresholds in the light data. Latitude is then derived from daylength and longitude from the timing of local midday in relation to GMT and Julian day. This procedure produces two locations per day, except during the equinoxes in March and September when daylength is uniform from equator to pole. Geolocators were first developed in the early 1990s (DeLong *et al.*, 1992; Wilson *et al.*, 1992; Hill 1994) and have been used in a large number of species, with much of the pioneering work being carried out on fish (Block *et al.*, 2001). Currently, there are numerous studies carrying out long-term deployments particularly in the marine environment on fish, mammals, birds and reptiles, aided by the miniaturisation of this technology in recent years.

3.2.7 Photography

Cameras small and robust enough to be deployed on free-living animals have become available in recent years but they offer huge general appeal and have therefore been deployed on a large number of terrestrial and marine species (e.g. Madden *et al.*, 2008). Although their primary function is not to provide locational information, they can provide important insights into both distribution and habitat associations where external features are visible in the photographs.

3.3 Tracking techniques for seabirds in the ICES region

The principal methods of animal tracking for estimating distribution and habitat association on free-living animals have, with the exception of combined transmitter/GPS loggers, been deployed on seabirds. Here, the advantages and disadvantages

of each technique to seabird studies and a summary of applications in the ICES region described.

3.3.1   Radio-tracking

Radio tags were far too large to be considered for deployment on seabirds in the first two decades since they were devised. The first successful deployments were published in the late 1980s (Trivelpiece *et al.,* 1986; Anderson and Ricklefs 1987; Heath and Randall 1989) and deployments in the ICES region soon followed (Wanless *et al.,* 1990; 1991). As with animals as a whole, radio-tracking is the most widely used of the tracking techniques on seabirds in the ICES region (Table 3.1), because of the length of the time that they have been available, their small size and comparatively low cost. The latter two issues represent two of the most important advantages of radio-tracking over most other tracking methods for seabirds excluding geolocation, although GLS (global location sensor) loggers have reached these very small sizes only in recent years. Length of availability is also relevant – since they have been available for the longest period of time then continued use of radio-tracking could be advantageous if comparisons between the present and past data are being made. Another advantage of radio-tracking (along with satellite tracking – see next section), is that the bird needs to be caught only once for data to be obtained, which opens up possibilities where a second catch is not possible e.g. in situations where breeding seabirds are difficult to catch. Radio-tracking does, however, have some important disadvantages. The first of these is that the range at which radio tags can be detected by tracking receivers is limited – this may be just a few kms if the tracking receiver is close to sea level, although the range increases substantially with height (e.g. 150+ km at a height of 450m, Wanless *et al.,* 2005). Range is also dependent on signal strength, which can be increased by using more battery power but this has weight implications. However, if birds are operating out of radio range, distributions from radio-tracking will underestimate foraging range; furthermore, errors can be substantial and vary depending on the relative positions of triangulation points and the animal. These issues are all particularly relevant to seabird studies, since most receiving stations have to be positioned on land. A second major drawback of radio-tracking is that it is extremely labour intensive. Despite these drawbacks, it is still likely to be used in some situations, in particular with very small species such as terns (e.g. Perrow *et al.,* 2006) where alternatives for obtaining fine-scale location are still unavailable.

3.3.2   Satellite tracking

Satellite tags were also far too large to be considered for deployment on seabirds initially. The first deployments were on giant petrels (Fuller *et al.,* 1984), but the number of applications expanded rapidly after a classic paper on wandering albatrosses by Jouventin and Weimerskirch (1990), aided by substantial miniaturisation over the last 20 years, in particular among Southern Ocean species. In the ICES region, satellite tags have been employed on more than 10 species (see Table 3.2). As with radio tags, satellite tags have the advantage of not needing to recatch the animal to obtain the data, so they represent the only method of measuring fine scale natal dispersal (Kooyman *et al.,* 1996; Weimerskirch *et al.,* 2006). The main advantage of satellite tags over radio-tracking which is particularly pertinent to seabird studies is that there are no constraints on range, so wide ranging species can be followed. Satellite tracking is also considerably less labour intensive. On the down side, the cost is high, relatively few fixes are obtained per day (typically, fewer than 10), and a proportion of these are of poor quality. Thus, satellite tracking is generally not the most appropriate

choice for species with small ranges during the breeding season, where the error associated with the satellite can substantially bias distribution estimates, and where for half the fixes on average the individual will be at the breeding colony.

3.3.3   Dead reckoning

Dead-reckoning was first used on seabirds by Wilson *et al.* (1991). In the many situations where radio-tracking is not appropriate because animals are travelling out of range, dead reckoning has provided a useful alternative to satellite tracking since more fixes are obtained. It is also useful for species operating within small ranges during the breeding season, where satellite tracking is not sufficiently accurate. It has the additional advantage over satellite tracking of being cheaper. Accordingly, it has been deployed on several species in the ICES region (see Table 3.2). One of the main drawbacks of dead reckoning is that the logger has to be recovered to obtain the data, in contrast to the previous two methods. Another important drawback of dead reckoning loggers is that there are potential sources of inaccuracy when deployed on seabirds. Most notably, these are ground speed of the individual and the effects of wind on air speed, and it is difficult to incorporate these effects satisfactorily (individual ground speed is typically not known, so averages are used, and wind data may not be available at local scales and may be coarse in temporal scale e.g. hourly). Furthermore, because dead reckoning operates on the principle of building vectors, errors increase with increasing distance from the deployment site (Wilson *et al.*, 2002). However, a new logger is now available that incorporates activity and three-dimensional movement, allowing estimation of previously unknown variables with the aim of reducing location error (Wilson *et al.*, 2007). The ideal way to test the accuracy of a data logger is to attach it simultaneously to a more accurate logger (such as a satellite tag) to the same animal (as Phillips *et al.*, 2004 did to test accuracy of geolocators, see section below). However, to test the accuracy of dead reckoners in the smaller species for which it has primarily been used is not possible, because a combined deployment with e.g. a GPS logger would represent too great a weight burden on individual birds.

3.3.4   GPS

GPS loggers were first used on wandering albatrosses (Weimerskirch *et al.*, 2002). They have because been used in a number of species, but have overall been used much less widely than the previous methods. This is primarily because they have only been available for a few years, and until recently have been comparatively heavy. They have also been comparatively expensive. In the ICES region, they have only been used on northern fulmar, Manx shearwater, northern gannet and European shag (Table 3.2). One drawback of GPS loggers has been their restricted recording time, due to the large battery demands of the devices. However, the very high accuracy of position obtained means they offer a huge advantage over other locational loggers. Together with the substantial miniaturisation that has occurred in recent years, with some loggers now weighing <10 g, the number of applications of GPS loggers is expected to greatly expand.

3.3.5   Transmitter/GPS

Transmitter/GPS loggers have not been deployed as yet on seabirds, mainly because of their large size. However, because they combine accurate location without the need for recovery their appeal is obvious, so it is highly probable that deployments will be made when loggers become smaller.

3.3.6   Geolocation

Geolocation was first proposed as a potential method for obtaining seabird distributions by Wilson *et al.* (1992). However, because the accuracy was deemed to be low, and was affected by light interference that regularly occurs when seabirds are attending breeding colonies (especially burrow nesters), it was not widely employed over the following years. The potential for longer term deployments was recognized because power consumption is low compared with e.g. satellite telemetry or GPS, and one of the first studies to achieve long-term data were on wandering albatrosses (Weimerskirch and Wilson 2000). Loggers small enough to be deployed long-term on free-living seabirds have since become available in the last decade, with loggers now available at 1.5g. This has resulted in a huge increase in their use for year-round deployment on seabirds, and a large number of studies on more than 15 species are now underway in the ICES region with a primary goal to understand individual movements in winter (Table 3.2). Two studies have estimated the accuracy of geolocators to be in the order of 200 km (Phillips *et al.,* 2004; Shaffer *et al.,* 2005). Although this is a very large error, this should be seen in the context of the large distances many species travel outside the breeding season. Finally, accuracy of location can be improved in some regions by using temperature instead of latitude (Shaffer *et al.,* 2005). One important limitation of this technology is that its use is restricted at very high latitudes during periods of continuous daylight and/or darkness.

3.3.7   Photography

Cameras were first used on seabirds by Takahashi *et al.* (2004). In the ICES regions, cameras have been deployed only on European shags (Watanuki *et al.,* 2007, 2008). They have had limited use because they have become available only recently, are large and expensive, and for many seabird species they provide somewhat limited information on distribution and habitat association. However, for some species, such as those that feed on the seabed, they can provide high quality data on habitat association (Watanuki *et al.,* 2008). In addition, in a few specific cases, they may also provide location data e.g. coastal species where distinctive coastline features are photographed.

3.4   List of published and ongoing seabird tracking studies in ICES waters

Table 3.2 lists published and ongoing studies tracking seabirds using a variety of techniques in ICES waters (i.e. the North Atlantic and adjacent sectors of the Arctic). The list is unlikely to be exhaustive, but it is based on a wide-ranging literature search and also contains all ongoing studies.

Table 3.2. List of published and ongoing seabird tracking studies in ICES waters.

SPECIES	SATELLITE TRACKING	GPS	GEOLOCATION	DEAD RECKONING	RADIO-TRACKING	PHOTOGRAPHY
Northern fulmar	Falk *et al.* 1995, Mallory *et al.* 2008	P.M. Thompson unpublished	P.M. Thompson unpublished			
Manx shearwater		Guilford *et al.* 2008	Guilford *et al.* 2009		Wilson *et al.* 2008	
Balearic shearwater				Aguilar *et al.* 2003		

Species	Satellite tracking	GPS	Geolocation	Dead reckoning	Radio-tracking	Photography
Cory's shearwater	Mougin & Jouanin 1997, Ristow *et al.* 2000, Magalhães *et al.* 2008		Gonzalez-Solis *et al.* 2007	Dall'Antonia *et al.* 1995, I. Ramirez unpublished, V. Paiva unpublished	Magalhães 2007	
Great shearwater	Ronconi 2007a, b, 2008					
Sooty shearwater	Ronconi 2007b, 2008					
Northern gannet	Hamer *et al.* 2000; 2001; 2007	Gremillet *et al.* 2006, Hamer *et al.* 2007, Garthe *et al.* 2007, Pettex *et al.* 2008; Skov *et al.*. 2008; S. Votier unpublished, F. Daunt unpublished, W.A. Montevecchi unpublished	R.W. Furness unpublished, D. Grémillet unpublished	F. Daunt unpublished; Montevecchi *et al.* in press		
Great cormorant			White unpublished		Gremillet *et al.* 1999; 2004	
European shag		Wanless *et al.*. 2005, Y. Watanuki unpublished	Daunt *et al.* 2006; D. Gremillet unpublished	Wanless *et al.* 2005	Wanless *et al.* 1991; 2005; Daunt 2000	Watanuki *et al.* 2007; 2008
Great skua				R.W. Furness unpublished	Votier *et al.* 2004	
Long-tailed skua			B. Sittler unpublished			
Herring gull	M.L. Mallory unpublished		M.L. Mallory & H.G. Gilchrist unpublished			
Audouin's gull					Manosa *et al.* 2004	
Lesser black-backed gull	Pütz *et al.* 2007, 2008		S. Votier unpublished			
Great black-backed gull	Weseloh 2008					

Species	Satellite tracking	GPS	Geolocation	Dead reckoning	Radio-tracking	Photography
Ivory gull	O. Gilg unpublished, H. Strøm unpublished					
Sabine's gull			I. Stenhouse & C. Egevang unpublished			
Black-legged kittiwake			F. Daunt unpublished, M. Frederiksen unpublished, M.L. Mallory unpublished, T. Anker-Nilssen unpublished	Wanless et al. 2005	Wanless and Harris 1992; Hamer et al. 1993, Humphreys 2002; Wanless et al.. 2005	
Sandwich tern					Stienen 2001	
Common tern			Nisbet et al. 2007		Becker et al. 1993, Black 2006, Rock et al. 2007a	
Arctic tern			C. Egevang and A. Petersen unpublished		Black 2006, Rock et al. 2007a	
Roseate tern			Nisbet et al. 2007		Rock et al. 2007b, I. Ramirez et al. unpubl	
Little tern					Perrow et al. 2006	
Common guillemot	W.A. Montevecchi and G.K. Davoren unpublished		F. Daunt unpubl, D. Grémillet unpublished, W.A. Montevecchi & D. Fifield unpubl	Wanless et al. 2005; Thaxter et al.. 2009	Wanless et al. 1990; Monaghan et al. 1994, 1996; Uttley et al. 1994, Olsson et al. 1999	
Brünnich's guillemot	Falk et al. 2001, A. Mosbech unpublished		A. Mosbech unpublished; D. Grémillet unpublished, Gaston & Fifield unpubl	Benvenuti et al. 1998		
Razorbill	Clark 2008		Clark 2008, F. Daunt unpublished	Dall'Antonia et al. 2001; Benvenuti et al.. 2001; Thaxter et al.. 2009	Wanless et al. 1990	

Species	Satellite tracking	GPS	Geolocation	Dead reckoning	Radio-tracking	Photography
Black guillemot					Sawyer 1998	
Atlantic puffin	T. Anker-Nilssen & T. Aarvak unpublished		F. Daunt unpublished		Wanless *et al.* 1990	
Little auk			A. Mosbech unpublished			

3.5 Use and analysis of tracking data

To date, most studies using animal tracking data, including seabirds, have concentrated on identifying areas used at various times of the year. Simple or more sophisticated mapping techniques (e.g. time of first passage) have been used to identify e.g. foraging areas during the breeding season or wintering areas. Locational data from tracking studies obviously also contain information about the habitat use and preferences of individuals, but so far few studies have attempted to use this information in more than a descriptive way. The main reason for this is that there are considerable analytical challenges associated with such an approach, linked to the specific characteristics of tracking data. Solutions to these challenges are currently being developed, but have mostly not yet been applied to real data.

Three of the main challenges are locational error, non-independence (autocorrelation) of individual fixes, and inferring population distributions from small sample sizes. Locational error varies strongly among tracking techniques, with GPS being the most accurate and geolocation the least accurate. For GPS, locational error is so small that it can in practice be ignored, but for other techniques some allowance has to be made for error. Satellite tracking data from the ARGOS system include an estimate of the quality and thus accuracy of each individual fix, and this information can be helpful in modelling distributions (e.g. Tougaard *et al.*, 2008).

Tracking data can be analysed using either an individual or a population perspective. From an individual perspective, the focus is on reconstructing the movement path of a bird in the highest possible detail and linking this to e.g. habitat data. An intuitively attractive approach to this type of problem is state-space modelling, which views the true path of an individual as unknown and models the observation process (including locational error) explicitly. Such an approach has been suggested for animal tracking by Patterson *et al.* (2008), and the first application has been undertaken (Patterson *et al.* in press).

When trying to model habitat preference of populations, it must be emphasized to take the non-independence of successive fixes and the often fairly low sample size in terms of individuals into consideration. Aarts *et al.* (2008) suggested an analytical framework for this type of question, but again this approach has not seen much practical use. It is anticipated that the use of this and related approaches to identify habitat preferences and develop predictive models of seabird distribution will increase quickly in the next few years, and an updated review of this subject will be considered in future versions of this chapter.

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4   Recent progress in addressing the problem of seabird bycatch in European Union waters

In response to a request by the European Commission, the problem of incidental catch of seabirds in fisheries in EU waters was reviewed by WGSE in 2008 (ICES 2008, chapters 3–5). The review concluded that although there were few data to indicate the true extent of seabird bycatch in EU waters, enough information existed to recognize that there is indeed a problem, and that the EU should develop and implement a Community Plan of Action aimed at reducing this bycatch, and investigating the issue further.

This work was used by ICES in providing advice on the issue to the European Commission.

This chapter provides an update on progress made in managing this important source of mortality for seabirds in EU waters and adds new information on the issue that has come to light since the publication of the WGSE 2008 report. Absence of comment can be taken to mean that no new information is available.

4.1 Recent changes to United Nations Fisheries and Agriculture Organization initiative to reduce seabird bycatch – International Plan of Action-Seabirds

Member States of the UN's Food and Agriculture Organization (FAO) adopted an international plan of action to reduce seabird bycatch on longlines in 1999 (IPOA-Seabirds). Under the international plan, individual Member States voluntarily undertake to draft and implement their own national plans of action (NPOA) once the extent of the problem has been evaluated. This long-standing initiative has had the positive result of highlighting seabird bycatch in long-line fisheries at the very high international level of the United Nations. Further, several FAO member countries or parts of member countries have drafted and are implementing NPOAs (Brazil, Canada, Falkland Islands, Japan, New Zealand, Uruguay and USA). The European Union is currently working towards the production of a Community Plan of Action which would apply to all EU states and is committed to producing this plan in 2009 (for a summary of progress, see below).

At the 27th Session of the FAO Committee on Fisheries (COFI) in 2007, considerable attention was focused on the NPOAs for seabirds and some important changes were agreed. These included: (1) the conclusion that best practice technical guidelines be developed to support the elaboration of NPOAs for seabirds, through continuing joint work between FAO and relevant bodies and organizations or an expert consultation; (2) an agreement that FAO should, in cooperation with relevant bodies, develop best practice guidelines to assist countries and RFMOs (Regional Fisheries Management Organizations) in implementing the IPOA-Seabirds; and, significantly (3) an agreement that the guidelines should be extended to other relevant fishing gears (e.g. trawl and gillnet fisheries).

In response to these directions and recommendations, FAO planned and organized an Expert Consultation to develop "Best Practice Technical Guidelines supporting the implementation of IPOA-Seabirds and elaboration of NPOA-Seabirds". The Expert Consultation was held in Bergen, Norway from 2–5 September 2008 and involved experts on NPOA-Seabirds, experts on the mitigation of the incidental catch of seabirds, and the RFMOs.

The FAO Best Practice Technical Guidelines for IPOA/NPOA-Seabirds were adopted by member states at the 28th Session of COFI on 2–6 March, 2009. This is considered by WGSE to be a very positive step in the direction of reducing seabird bycatch in all gear types. However, WGSE hopes that the FAO will now publish the guidelines in their Technical Series which would accord them formal status on the implementation of the Code of Conduct for Responsible Fisheries.

4.2 Progress towards completion of EU NPOA-Seabirds

WGSE notes that the European Commission has not yet implemented ICES advice on the Community Plan of Action on Seabirds as provided in 2008. ICES advised, based on available information, that development of the Community Plan of Action was

needed, and that there is an immediate and critical need for more systematic data collection of seabird bycatch data throughout EU waters.

ICES recommended a three step approach to establishing a Plan of Action:

- accessing fishing effort data;
- convening a special ICES meeting in autumn 2008 in order to assess the extent of bycatch; and
- organising a drafting meeting for the Plan of Action

WGSE understands that the European Commission is still considering a call for the specific fishing effort data that is required to assess the extent of seabird bycatch, and that this call may be combined with other separate calls for data from Member States. The special ICES meeting was not requested by the European Commission and it is understood that the European Commission intends to draft the Plan of Action in house.

4.3   New information/reviews of seabird bycatch in the EU waters

Very little new information has come to light since the publication of last year's WGSE report (ICES 2008). Žydelis *et al*. (in press) have reviewed information on waterbird bycatch in coastal gillnets in the Baltic and North Seas. They used the data published in 30 studies from the area, which together report bycatch of all groups of local waterbirds including divers, grebes, seaduck, diving ducks, auks and cormorants. In that sense the data are not new, but the treatment in the paper is. Estimates suggest that from 100,000–200,000 waterbirds are killed annually in fishing gear in this area. The authors assessed the impact of this mortality on populations using a technique called Potential Biological Removal (PBR; see Wade 1998), which calculates the limits to allowable human-caused mortality. This analysis showed that losses due to bycatch were likely to cause population declines for two of the three species surveyed.

In Norway, the Ministry of Environment is financing a nationwide study currently being launched and aimed at quantifying the bycatch of seabirds in commercial fisheries (Christensen-Dalsgaard *et al*. 2008). The selected approach is a combination of a broad-scale questionnaire directed at fishers when delivering their catch at fishing quays and a more detailed recording of bycatch aboard a small selection of vessels. These vessels are already established as a reference fleet for the Marine Research Institute in Bergen for the reporting of data on bycatch of fish and sea mammals. The study will address at least three "focus fisheries" identified to have special potential for seabird bycatch: the gillnetting of cod *Gadus morhua* (February-May) and lumpsucker *Cyclopterus lumpus* (May-August) in the northernmost parts of the country, and the driftnetting for mackerel *Scomber scombrus* south of 62°N in summer. The methods are described in more detail in the background document (Christensen-Dalsgaard *et al*. 2008), which also reviews the very limited existing knowledge concerning the extent of seabird bycatch in Norwegian commercial fisheries.

4.4   Assessing fishing effort and monitoring of seabird bycatch in EU waters

A major impediment to management of the problem of seabird bycatch in fishing gear is lack of detailed knowledge of how many of what species are being taken, where, when and in what gear types. In addition, and equally important, is the need for robust fishing effort data so that sampled bycatch rates can be scaled up to total bycatch. Although there are sample data on seabird bycatch for some EU fisheries, total fishing

effort data generally do not exist so there is a pressing need to fill this gap. Only then can the true impact of bycatch on seabird populations be assessed. WGSE understands that the European Commission is soon planning to put a call out to member states for fishing effort data and has adopted a draft *pro forma* for this purpose (see Appendix to this chapter below).

WGSE has reviewed the draft *pro forma* and offers comments here; WGSE hopes that these comments can be considered by the European Commission before of the call for fishing effort and bycatch data.

- The draft form contains questions/fields on both total fishing effort and seabird bycatch. WGSE recommends that an initial call for data should focus on the estimation of total fishing effort and that a separate form and data-call be developed for the ongoing observation and sampling of seabird bycatch. If it is felt that one call for data to cover both fishing effort and seabird bycatch is the preferred approach, there needs to be two forms, or levels of forms rather than a single form. The reasons for separating collection of the two types of data are:

  - the data come from different sources for total fishing effort (e.g. high-level, member states, fisheries management agencies), vs. seabird bycatch (e.g. fisheries observers, fishers);

  - the data "entities" differ radically (total fishing effort per time period, fishing area and fleet segment, vs. number of seabirds by species per net haul or set- of course including no birds);

  - it reduces the complexity in the single form. Currently the form does not request for the number of individuals by species or species group, which is an essential component of bycatch monitoring and assessment. Addition of these questions could over-complicate a single form which in turn might reduce response rates; and

  - collection of bycatch data according to seabird species or species group requires supporting infrastructure. This could consist of observer training in seabird identification (regular to cover observer turnover and need to refresh) and the production of seabird identification material to be used by observers and fishers. These may require some time to develop and launch.

- The current form requests data is collated within four, 3-month seasonal periods (March-May, June-August, September-November, and December-February). It is not clear why these periods were chosen and it may be more convenient to choose periods that does not straddle a calendar year (i.e. January-March, April-June, July-September, and October-December). An alternative would be to request fishing effort data by month, which would allow more flexibility in future collation and might be more convenient for respondents (thereby increasing response rate).

- If net dimensions differ between fisheries it may be useful to request Total net <u>area</u> as well as Total <u>length</u> of nets.

- The form needs provision to record year and EU Member State.

- An example of a bird bycatch form in use in the US, can be found at: http://www.nefsc.noaa.gov/femad/fishsamp/fsb/

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4.6 Appendix. Proposed *pro forma* to collect fisheries effort and seabird bycatch data in EU fisheries

EUROPEAN COMMISSION

DIRECTORATE-GENERAL FOR MARITIME AFFAIRS AND FISHERIES

Brussels, 2008

Proposed standard format to report on incidental catches of seabirds

Title

Table of contents

1. Fishing effort and incidental catches

Table 1a. Description of fishing effort and incidental catches in static gear – Reporting format.

| | FISHING AREA | FLEET SEGMENT | MAIN TARGET SPECIES | TOTAL FISHING EFFORT | | | | | | INCIDENTAL CAUGHT SPECIES | NO OF INCIDENTS | INCIDENTAL SPECIES CAUGHT | |
				No. of vessels	No. of trips	Days at sea	Total length of nets	Total soak time	Number of hooks set			With mitigation devices	Without mitigation devices
Mar/April/May	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Jun/Jul/Aug													
Sep/Oct/Nov													
Dec/Jan/Feb													

Table 1a. Description of fishing effort and incidental catches in static gear – Data format.

NAME OF FIELD	DEFINITION AND COMMENTS
(1) Fishing area	Indicate areas to level 3 according to Appendix I of Commission Decision 2008/949/EC.
(2) Code number for fleet segment (métier)	Indicate to level 4 according to Appendix IV of Commission Decision 2008/949/E (e.g. OTB; OTT)
(3) Main target species	Indicate the main target species. Minimum specification – group or common name; Maximum specification – scientific name of the species
(4) Number of vessels	Indicate the total number of vessels operating
(5) Number of trips	Indicate the overall number of trips
(6) Days at sea	Indicate the overall number of days at sea corresponding to fishing time*.
(7) Total length of nets	Indicate the total length of nets, in km
(8) Total soak time	Indicate the total soak time of nets, in km.h
(9) Number of hooks set	-
(10) Incidental caught species	Indicate the species caught incidentally. Minimum specification – group or common name; Maximum specification – scientific name of the species
(11) Number of incidents	Number of days (hauls?) when incidents occurred?
(12) Number of specimens incidentally caught with mitigation devices	-
(13) Number of specimens incidentally caught without mitigation devices	-

2. Fishing effort and incidental catches in towed gear

FISHING AREA	FLEET SEGMENT	MAIN TARGET	TOTAL FISHING EFFORT	INCIDENTAL CAUGHT	NUMBER OF	INCIDENTAL SPECIES CAUGHT

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* The activity of a vessel shall be measured in days present within a geographical area referred to fishing area. A day present within an area shall be calculated as any continuous period of 24 hours (or part thereof) during which a vessel is present within any geographical area defined in "fishing area" and absent from port. The time from which the continuous period is measured is at the discretion of the Member State whose flag is flown by the vessel concerned, provided that the Member State determines the start of the period in a consistent manner for each grouping of gears during a management period. In case that the vessel is present in the same area within a period of 24 hours for several times, the presence shall count as one day only.

			SPECIES	No. of vessels	No. of trips	Days at sea	No. of hauls	Total towing time	SPECIES	INCIDENTS	With mitigation devices	Without mitigation devices
Mar/April/May	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Jun/Jul/Aug												
Sep/Oct/Nov												
Dec/Jan/Feb												

Table 2a. Description of fishing effort and incidental catches in towed gear – Reporting format.

Table 2b. Description of fishing effort and incidental catches in towed gear – Data format.

NAME OF FIELD	DEFINITION AND COMMENTS
(1) Fishing area	Indicate areas to level 3 according to Appendix I of Commission Decision 2008/949/EC.
(2) Code number for fleet segment (métier)	Indicate to level 4 according to Appendix IV of Commission Decision 2008/949/EC (e.g. OTB; OTT)
(3) Main target species	Indicate the main target species. Minimum specification – group or common name; Maximum specification – scientific name of the species
(4) Number of vessels	Indicate the total number of vessels operating
(5) Number of trips	Indicate the overall number of trips
(6) Days at sea	Indicate the overall number of days at sea corresponding to fishing time*.
(7) No. of hauls	-
(8) Total towing time	Indicate the total towing time in hours (h)
(9) Incidental caught species	Indicate the species caught incidentally. Minimum specification – group or common name; Maximum specification – scientific name of the species
(10) Number of incidents	Number of days when incidents occurred?
(11) Number of specimens incidentally caught with mitigation devices	-
(12) Number of specimens incidentally caught without mitigation devices	-

3. Estimation of incidental catch rate

Table 3a. Incidental catch rate by fleet segment and target species – reporting format

FISHING AREA	FLEET SEGMENT	MAIN TARGET SPECIES	INCIDENTAL CAUGHT SPECIES	NUMBER OF SPECIMENS CAUGHT	INCIDENTAL CATCH RATE	TOTAL INCIDENTAL CATCH ESTIMATE
(1)	(2)	(3)	(4)	(5)	(6)	(7)

Table 3b. Incidental catch rate by fleet segment and target species – data format

NAME OF FIELD	DEFINITION AND COMMENTS
(1) Fishing area	Indicate areas to level 3 according to Appendix I of Commission Decision 2008/949/EC.
(2) Code number for fleet segment (métier)	Indicate to level 4 according to Appendix IV of Commission Decision 2008/949/EC (e.g. OTB; OTT)
(3) Main target species	Indicate the main target species. Minimum specification – group or common name; Maximum specification – scientific name of the species

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(4) Incidental caught species	Indicate the species caught incidentally. Minimum specification – group or common name; Maximum specification – scientific name of the species
(5) Number of specimens incidentally caught	-
(6) Incidental catch rate	To be indicate per unit of fishing effort. (e.g. specimens/day, /haul,/soak time x km, /hours x metres
(7) Total incidental catch estimate	-

4 Annexes

Recording of incidental catches

[A short description of how the incidental catches of seabirds was observed and recorded by the observer should be given (max.2 pages). This can include the circumstances of the observation of incidental catches (such as incidental catches observed during hauling or only animals taken on board the ship), and the collection of additional information from incidentally caught animals.]

Mitigation measures in use

[In case mitigation measures are already in place, provide information according to table I presented in this section. Please present a short description of the mitigation measures (max.6 pages)]

Table I. Description of mitigation measures – Reporting format

FLEET SEGMENT	FISHING AREA	MITIGATION MEASURES IN USE
(1)	(2)	(3)

Table I. Description of incidental catches of seabirds – Data format

NAME OF FIELD	DEFINITION AND COMMENTS
(1) Code number for fleet segment (métier)	Indicate to level 4 according to Appendix IV of Commission Decision 2008/949/EC (e.g. OTB; OTT)
(2) Fishing area	Indicate areas to level 3 according to Appendix I of Commission Decision 2008/949/EC.
(3) Other mitigation measures	Provide information of mitigation techniques/methods in use. Detail information can be attached as an annex to the report.

5   Ecological issues related to the circulation of pathogens and parasites in seabird populations

At the 2007 meeting, the group proposed a first version of a review on ecological issues related to the circulation of pathogens and parasites in seabird populations and this topic was listed as a term of reference for the 2008 and 2009 meetings. This chapter thus presents a second updated version of this synthesis.

5.1   Introduction

Recent outbreaks of avian influenza (Olsen *et al.* 2006) and West Nile viruses (Rappole and Hubalek 2003, Gerhardt 2006) have highlighted the role that birds can play in the ecology of zoonotic diseases. The large population sizes of seabirds, their high mobility and their wide geographic distribution make them significant potential players in the ecology and epidemiology of zoonotic diseases, and in several instances they have been involved in major outbreaks (e.g. Olsen *et al.* 2006, Herrmann *et al.* 2006). The highly social breeding habits of seabirds and their capacity for long distance movement (Furness and Monaghan 1987) make them unique hosts for micro- and macroparasites. The discrete distribution of seabirds among colonies and the large amount of existing knowledge of their breeding biology and at sea distribution also suggest that they could make good models to study the dynamics of host-pathogens interactions. Despite the recent active development of work on the ecology and evolution of host-parasite interactions (Grenfell and Dobson 1995, Hudson *et al.* 2002, Frank 2002, Thomas *et al.* 2006), relatively little information is available on seabird-parasite interactions and their epidemiological implications. We present here some elements on ecological issues related to the circulation of pathogens and parasites in seabird populations in order to identify gaps in our knowledge and potential avenues for research of basic and applied interest.

5.2   Seabirds as hosts for pathogens and parasites

Parasites can be defined in an ecological sense as organisms that live at the expense of others (Combes 2001). This definition encompasses both micro- (bacteria, viruses, protozoans etc.) and macro-parasites (nematodes, cestodes, insects, mites, ticks etc). Hosts and parasites are involved in intimate relationships that have implications at both ecological and evolutionary scales (Combes 2001). For instance, the costs associated with parasitism can lead to differential survival or breeding success of host individuals living in various ecological conditions on the short-term, but can also lead to the coevolution of host and parasite genomes on the long-term (Combes 2001). Hosts are mortal, so parasites face the dilemma of efficiently exploiting their hosts without reducing their probability of transmission. As efficiency at host exploitation is often assumed to be related to virulence, transmission rate and virulence are expected to be positively correlated. This is an important point to consider when investigating implications of the interactions between the life histories of hosts and parasites. Another important issue related to the intimate nature of the relationships between hosts and parasites is the fact that parasites can be more or less specialized in terms of the host species they can exploit. Some generalist parasites can exploit different hosts, which can have key epidemiological implications when some host species play the role of reservoirs for agents that can lead to diseases in others. In terms of ecological implications, generalist parasites could also be involved in apparent competition between seabird species living in sympatry.

As warm-blooded vertebrates, seabirds are hosts of a large suite of pathogens and parasites (Hubalek 1994, 2004). Numerous life-history and ecological characteristics of seabirds distinguish them as hosts compared to other vertebrates, especially regarding the probability that parasites are transmitted among hosts individuals within a given geographic area (Table 5.1).

Table 5.1. Seabirds as hosts for parasites: some implications of their life-history and ecology.

LIFE HISTORY PARTICULARITIES	IMPLICATIONS	EXAMPLES
Breeding site fidelity (High probability of returning to the same breeding site between year)	Spatial structure of host-parasite interactions (Holt and Boulinier 2005)	Patterns of infestation by nest dwelling parasites (ticks, fleas; Rothschild and Clay 1957, Boulinier *et al.*, 1996)
Long-lived	Temporal scale of host-parasite interactions (acquired immunity, maternal effects…)	Interannual persistence and maternal transfer of antibodies against Lyme disease agent Borrelia burgdorferi s.l. (Gasparini *et al.*, 2001, Staszewski *et al.*, 2007)
Colonial breeding	Increased transmission among individuals	Avian influenza in Common terns Sterna hirundo (Olsen *et al.*, 2006)
Interspecific colony structure (mixed colonies)	Increased potential for host shift and/or host sharing	Evidence of host races for the seabird tick Ixodes uriae (McCoy *et al.*, 2005b, Dunneau *et al.*, 2008)
Migratory and high dispersal capacity	Potential large-scale dissemination of parasites	Marine cycle of Lyme disease agent Borrelia burgdorferi (Olsen *et al.*, 1995)
Seasonal reproduction	Seasonality in the interactions with parasites (Altizer et al. 2006),	Seasonal exposure to nest dwelling parasites and associated microparasites (implication for selection on host phenology, time to recovery)
Piscivorous /scavengers	Trophic transmission of micro- and macro-parasites	Salmonella epidemiology (Monaghan *et al.*, 1985)

Detailed reviews of the micro-pathogenic organisms associated with free-living seabirds can be found in Hubalek (1994, 2004) and more specialized papers present reviews for seabird viruses (Chastel 1988) or parasites of auks (Muzaffar and Jones 2004). Here, we do not review this literature *in extenso*, but we highlight some information and references about pathogens and parasites of seabirds to illustrate potentially significant ecological issues. It should be noted that some specific host-parasite systems have been the subject of much work, although very little information is available on others, notably because they have been implicated in dramatic outbreaks. An illustration of this is the large amount of work performed in the 1970s and 1980s on seabird arboviruses (Nuttal 1984, Chastel *et al.*, 1988), although more recent work on seabird microparasites has focused on Lyme disease bacteria *Borrelia burgdorferi sensu lato* since its identification in seabirds in 1993 (Olsen *et al.*, 1993). Little is known about the circulation of other pathogens such as Avian influenza viruses (Olsen *et al.*, 2006). Also, the fact that some detailed studies were performed at a time when genetic approaches were not yet readily available increases the heteroge-

neity in the quality and quantity of information available on different host-parasite systems. In particular, genetic approaches are increasingly used to infer the evolution of pathogens and parasites, but their use with natural host-parasite systems is still limited (De Meeûs *et al.*, 2007).

5.2.1 Viruses

Many viruses are circulating in seabird populations (Hubalek 2004), but we will focus here on two groups: arboviruses (often transmitted among seabirds by nest dwelling parasites such as ticks) and influenza A viruses. Regarding other types of viruses, one of particular interest because of its known pathogenic effects on birds is Newcastle Disease Virus, which is known to circulate in cormorants and shags, but usually in inland areas. It should also be noted that recent investigations on coronaviruses in wild birds clearly emphasize that little is known about the presence of several viruses in wild populations (Monceyron-Jonassen *et al.*, 2005).

Many arboviruses have been identified in seabird species parasitized by soft and hard ticks (Clifford 1979, Nuttal 1984, Chastel 1988, Chastel *et al.*, 1990; Major *et al.*, 2009). These arboviruses are circulating at different latitudes, notably due to their associations with different ticks, such as *Ixodes uriae* in the North Atlantic (Main *et al.*, 1976, Spence *et al.*, 1985, Nunn *et al.*, 2006a). Where intensive work has been carried out, as for instance in Brittany, Western France, several of these arboviruses have been isolated in the same ectoparasite species parasitizing the same host species in the same area (e.g. *Ixodes uriae*, *Ornithodoros maritimus*), suggesting the natural exposure of some seabirds to a high diversity of viruses (Chastel *et al.*, 1981, 1987, 1990, Quillien *et al.*, 1986; Major *et al.*, 2009). In general, not much is known about the pathogenicity of these viruses, although evidence of massive failure of tern colonies have been associated with the detection of some viruses and other viruses have been reported to have pathogenic effects on humans (Converse *et al.*, 1975, Feare *et al.*, 1976, Clifford *et al.*, 1980).

Influenza viruses are circulating in seabird populations although knowledge is still limited. Strains of these viruses have been repeatedly isolated in gulls (*Larus* spp; Krauss *et al.*, 2007, Munster *et al.*, 2007, Lebarbenchon *et al.*, 2007), but also in a few other seabirds. A recent study showed for instance that three out of 26 Common guillemots *Uria aalge* banded in the Baltic Sea tested positive for influenza A virus using RT-PCR (Wallesten *et al.*, 2005). Phylogenetic analyses further showed that five gene segments belonged to the American avian lineage of influenza A viruses, whereas three gene segments belonged to the Eurasian lineage. This indicates that avian influenza viruses may have a taxonomically wider reservoir spectrum than previously known and that naturally occurring chimeric avian influenza A viruses can include genes of American and Eurasian origin in Europe. Influenza A viruses have been known for a long time to circulate in duck populations and the close contact occurring between waterbirds species in some area calls for attention to the potential circulation of such viruses in seabirds (Muzaffar *et al.*, 2006).

5.2.2 Bacteria

Many bacteria are circulating in seabird populations (Hubalek 2004). Among them, attention has especially been driven in recent years to Lyme disease agent *Borrelia burgdorferi sensu lato*, which was shown to circulate in seabirds only relatively recently (Olsen 1993). Lyme disease is the main human arthropod borne disease in the northern hemisphere. It is due to various genospecies within the *Borrelia burgdorferi* sensu lato which are transmitted by tick bites to humans, usually by 'terrestrial' ticks

such as *Ixodes ricinus* and *Ixodes scapularis*. Pathogenic genospecies of *Borrelia burgdorferi* sensu lato have been identified in seabirds (Olsen *et al.*, 1993, 1995, Gylfe *et al.*, 1998, Smith *et al.*, 2006, McCoy *et al.*, unpublished) and some of its epidemiological (Olsen, *et al.*, 1995, Gylfe *et al.*, 1998) and ecological implications have been investigated (Gasparini *et al.*, 2001, 2002, Staszewski *et al.*, in press).

5.2.3 Other parasites

Fungi and macroparasites, including ectoparasites and endoparasites (Rothschild and Clay 1957), are of importance for seabirds and they will be briefly reviewed here. There is evidence that these parasites impact seabird host fitness by the acquisition of costly host resources (e.g. blood or nutrients). However, it can be difficult to distinguish between such direct effects and the impact of micro-parasitic infections for which ectoparasites act as vectors.

5.2.3.1 Ectoparasites

It is clear that there are fitness costs associated with ectoparasites, and that mechanisms have evolved to reduce their prevalence and impact. For example, Douglas *et al.* (2004) found that volatile odorants produced by crested and whiskered auklets kill and repel ectoparasites. Seabirds, such as black noddies perform "sunning" behaviour to reduce louse loads, even when the ambient temperature is high and despite this being an energetically costly behaviour (Moyer and Wagenbach 1995).

Tick burdens have been linked to chick growth and mortality and nest desertions in a number of seabird species, including: sooty tern (Feare 1976); brown pelican (King *et al.*, 1997a and 1997b); Guanay cormorant, Peruvian booby and Peruvian pelican (Duffy 1983), roseate tern (Ramos *et al.*, 2001; Monticelli *et al.*, 2008), and black-browed albatross (Bergstrom *et al.* 1999). Heavy tick infestations have also been linked with adult mortality in king penguins (Gauthier-Clerc *et al.*, 1998). Moreover, tick prevalence has also been found to be correlated with seabird population dynamics and dispersal. Colonies of kittiwakes that were decreasing in population size had higher tick prevalence than colonies that were increasing in size (Boulinier and Danchin 1996). Moreover, there was a negative association between the proportion of breeding philopatric kittiwakes and local tick prevalence the previous year (Boulinier *et al.* 2001).

Feather mites are a common group of ectoparasites on seabirds (Proctor 2003). Due to their apparently benign nature, feeding on feathers and dead skin cells and not penetrating the host's skin, this group of parasites have not been extensively studied. There is very little information regarding prevalence levels or potential impacts on the host. However, a study of the feather mites on Caspian terns found that mite densities correlated negatively with host size and body condition (Bridge 2003).

Little is known about the impact of blood-feeding mites in seabird hosts. Gilardi *et al.* (2001) recorded mange caused by epidermoptid mites in fledgling Laysan albatrosses, and the severity of inflammation was such that it was suggested that this could be a significant cause of morbidity, or even mortality. Dobson (1952) recorded infestations of the blood-feeding mites *Dermanyssus gallinae* on Atlantic puffin chicks. Studies of the impacts of haemataphagous mites in passerines suggest that these ectoparasites have an impact on reproductive success (e.g. Moller 2002), and that further investigation of mites in seabirds would be worthwhile.

Lice have been recorded at high densities on seabirds (Choe and Kim 1987; Daunt *et al.* 2001; Muzaffar and Jones 2004; Gómez-Díaz *et al.*, 2007) but there is no evidence to

suggest that infections cause fitness costs to the host. This is despite the fact that lice have been shown to cause damage to plumage and hence might be predicted to have energetic costs (Booth *et al.*, 1993, Moyer and Wagenbach 1995).

Fleas have also been recorded in seabirds. For example, *Xenopsylla gratiosa* have been recorded on Cory's shearwater and Cape Verde shearwater (Gómez-Díaz *et al.*, 2007). Two species of flea, *Notiopsylla kerguelensis* and *Parapsyllus heardi*, parasitise the 35 species of seabird breeding on the Kerguelen islands (Chastel and Beaucournu 1992), *Ceratophyllus vagabundus* parasitise puffins, shags, cormorants, kittiwakes in Norway, and *Ceratophyllus garei* parasitise large gulls in Spitsbergen (Mehl 1992). However, the effects of these parasites on their seabird hosts are not understood.

5.2.3.2 Endoparasites

Seabirds are infected with a wide variety of endoparasites, including: platyhelminthes (digeneans and cestodes); Acanthocephala; and nematodes (Threlfell 1968). Infection by endoparasites can cause pathological damage and be costly to hosts, for example, nematode infections can cause lesions and ulcerations in the alimentary tracts of seabirds (Nagasawa *et al.*, 1998). However, experimental and observational evidence of impacts of infections on seabird fitness is poor, in part because it is difficult to quantify and monitor infection levels non-destructively. There is evidence that parasite infections can interact with levels of environmental pollutants. An experimental study found that male glaucous gulls treated with an anti-helminthic drug had no detrimental effects of organochloride blood residues on nesting success when compared with untreated males (Bustnes *et al.*, 2006).

5.2.3.3 Fungi

Candida albicans and *Candida tropicalis* have been isolated from the digestive tracts and faeces of gulls (Buck 1983, 1990). *Candida dubliensis* has been isolated from *Ixodes uriae* ticks isolated from an Irish seabird colony (Nunn *et al.* 2007). *Aspergillus* spp. has been recorded in tufted puffins (Monroe *et al.* 1993) and common guillemots (Petermann *et al.* 1989). However, the impacts of such fungal infections on their seabird hosts are unknown.

5.3 Factors affecting the circulation of parasites in seabird populations

5.3.1 Seabird population biology and parasites

As summarized in Table 5.1, a series of common characteristics of seabird species are likely to be important for their ecological and evolutionary interactions with parasites. The re-uses of nesting sites year after year and dense aggregations occurring at nesting colonies are obvious characteristics that are favourable for the maintenance of high parasite populations. Large numbers of ectoparasites can in particular be found on most seabird colonies (Guiguen, 1988).

Negative effects on reproductive success when parasite loads are high can be significant, with potential consequences for the local dispersal of breeders via mechanisms of differential dispersal and recruitment as a function of local breeding success (Boulinier and Danchin 1996, Boulinier *et al.*, 2001, Gauthier-Clerc *et al.*, 2003). Currently, there is nevertheless no evidence of negative effects on adult survival, but very few attempts have been made to investigate this issue.

Population genetic investigations using neutral markers (microsatellites) have shown that gene flows between populations of the seabird tick *Ixodes uriae* are much more restricted than gene flows between its host populations at the same geographic scales

(McCoy *et al.*, 2003, 2005a). An interesting result is also that the ecology and behaviour of the seabird host species may lead to different dispersal rates among colonies of the ticks; for instance, tick populations are much more structured between Black-legged kittiwake populations than between Atlantic puffins populations when investigated at the same geographical scale (McCoy *et al.* 2003), which could be due to a higher tendency for prospecting individuals to disperse ticks among colonies in puffins than kittiwakes. Another important finding was that several seabird populations breeding in mixed colonies (i.e. in sympatry) do not appear to share the same *Ixodes uriae* tick populations as revealed by population genetic analyses of the ticks collected on different host (McCoy *et al.*, 2001, 2005b). This suggests a specialization of the tick for its hosts, which should have implications for the circulation of microparasites such as *Borrelia* and arboviruses in seabird populations.

5.3.2 Global change and the circulation of pathogens and parasites in seabird populations

Human activities at various spatial scales can have dramatic consequences for the circulation of parasites in seabird populations and between free-ranging birds and humans and domesticated populations. Refuse dumps and fish factories have been identified as foci of bacteria transmission (e.g. *Salmonella*) involving gulls (Monaghan *et al.*, 1985, Nesse *et al.*, 2005). Concerns of exchange of parasites between intensive animal production facilities (notably of poultry) and free-ranging birds have been raised following the recent outbreaks of Avian influenza (Olsen *et al.*, 2006). Ecotourism to remote areas hosting large seabird colonies has the potential to lead to exchange of parasites (Wallensten *et al.*, 2006).

The effects of climate change on the circulation of parasites, notably via induced changes in the distribution of vectors, could be important. Much work is done on the potential effects of climate change on the distribution of tick species responsible for the terrestrial cycle of Lyme disease, such as *Ixodes scapularis* (Ogden *et al.*, 2005), and knowledge of the temperature and humidity tolerance of different ectoparasites could be important in this context. It should nevertheless be noted that species such as *Ixodes uriae* shows clear adaptation to dramatic variations in environmental conditions (Murray and Vestjens, 1967, Lee and Baust, 1982, Barton *et al.*, 1996, Benoit *et al.*, 2007).

5.4 Implications of the circulation of pathogens and parasites in seabird populations

5.4.1 Threats to seabird populations and biodiversity

The role of parasitism in the ecology of natural bird populations has attracted much interest in the last two decades, notably in the fields of behavioural and population biology (Lloye and Zuk 1991, Clayton and Moore 1997), but those factors have not often been clearly identified as major threats to seabird populations. This is not to say that parasites do not play a significant role in the ecology of seabirds, as for instance breeding failure and dispersal among sub-colonies have been attributed to high local levels of ectoparasites in various species (Boulinier *et al.*, 2001).

As pathogens and parasites have the potential to spread rapidly among dense populations, such as seabird colonies, and as they have the potential to lower dramatically a key demographic parameter such as adult survival (to which seabird populations are highly sensitive), they nevertheless represent a factor that has the potential to be important. Furthermore, the impacts of parasites can be difficult to predict. For ex-

ample, a recent experimental study by Reed *et al*. (2008) found that macroparasites constrained females' ability to produce offspring of the larger, more costly sex (males). Such an effect on the secondary sex ratio of offspring could have important implications for seabird population dynamics.

An interesting issue relates to the question of whether the circulation of parasites in seabird populations is more or less independent of the circulation of parasites in other animals and humans. *Borrelia burgdoferi* may have been circulating in seabird populations for thousands of years independently of the terrestrial cycle which involve most human cases (Olsen *et al*., 1995, Gauthier-Clerc *et al*., 1999), but alternatively the development of ecotourism in remote areas with large seabird colonies raised the question of the risk of exposure of seabirds to new parasites, such as for penguins in Antarctica (Wallensten *et al*., 2006). It is nevertheless often hard to know whether parasites were native or introduced (Gauthier-Clerc *et al*., 2002). As we have seen above, global change could lead to increased exposure of individuals and populations to parasites with which they have not evolved, which could have major ecological and epidemiological implications.

5.4.2   Seabird parasites and human disease

Seabirds are carriers of a few diseases that can transmit to humans (zoonoses), but as humans are rarely in close contact with them this poses relatively little health concern. On islands where humans are still exploiting seabirds for food, cases of exposure of humans to zoonotic agents have been reported, such as seropositivity of bird hunters against *Borrelia burgdoferi* in the Faroe Islands (Gylfe *et al*., 1998). Seemingly, biologists handling seabirds and working in areas infested by seabird ectoparasites may be at risk of exposure. The tick *Ixodes uriae* can for instance bite humans; although the fast detection and removal of feeding ticks is likely to often preclude the transmission of bacteria such as *Borrelia burgdoferi* to humans (transmission via a tick bite only occurs after several days of attachment to the host). One other instance that can lead to risks of exposure of humans to parasites carried by seabirds is in the context of rehabilitation programmes associated with the care for e.g. oiled birds (Steele *et al*., 2005).

Due to their high dispersive behaviour and colonial habits, seabirds have the potential to disperse microparasites at large-scales. Their role in the epidemiology of zoonoses and notably the emergence of infectious diseases, is nevertheless much constrained by the low contact between seabirds and wild terrestrial vertebrates (e.g. mammals, waterfowls, passerine birds), domesticated animals (livestock) or humans. As we have seen above, global changes may nevertheless increase the contact between host-parasite systems, which could lead to the rapid changes in their dynamics. A better knowledge of the dynamics of these complex systems is thus required.

5.5   Perspectives

5.5.1   Monitoring of pathogens and parasites

As for any monitoring programme of biodiversity, the why, what and how should be considered seriously before engaging in the gathering of information and samples (Yoccoz *et al*., 2001). Particular attention to the spatial variability expected at different spatial (e.g. within and among colonies) and temporal scales (seasonality and interyear variability) should be made. In particular, the small numbers of samples often screened in past published studies sometimes limit the inferences that can be made about factors potentially affecting parasite dynamics. Relatively descriptive studies

investigating evidence of the presence of various parasites are nevertheless useful to plan more extensive surveys (Gauthier-Clerc *et al.*, 2002, Uhart *et al.*, 2003).

As part of monitoring programmes of seabird populations involving the handling of seabirds for marking and/or diet sampling, samples could easily be taken to allow the tracking parasitic agents among populations at small and wide spatial scales. Such investigations can rely on molecular techniques (PCR methods) or the detection of antibodies in plasma or sera samples using immunological assays (ELISA, Western blots). It should be noted that as seabirds are long-lived, serological approaches, which rely on the detection of antibodies which may last for months and years in the host individuals after their exposure to an antigen, may provide only limited information about the timing of exposure of individuals to antigens (Staszewski *et al.*, 2007). If adults are difficult to capture, maternal antibodies can be detected in the egg yolk and the plasma of young chicks as these are available in an amount proportional to that circulating in the female plasma (Gasparini *et al.*, 2002). It should nevertheless be noted that the presence of antibodies in a 5 day old chick does not mean that the parasite is currently circulating in the host population as the mother may have been exposed to the parasites several years before, a sufficient exposure for a strong humoral immune response to be initiated.

The culture of micro-organisms or the sequencing of their DNA from can allow researchers to investigate phylodynamic issues (origin of the strain and relationship with other strains) provided there are enough samples available on the studied organism (Grenfell *et al.*, 2004). Such approaches should provide crucial elements for a better understanding of the processes responsible for the circulation of parasites in natural seabird populations. For vector-born parasite, such approaches can also be used on the vector to disentangle factors responsible for strain differentiation (De Meeûs *et al.*, 2007).

5.5.2 Perspective of research

As seen above, a lot of information is now available via classical parasitology studies as well as more recent work carried out in a more ecological and evolutionary framework. The use of population and evolutionary genetics should allow us to get a much better understanding of the circulation of parasitic agents. The current development of work at the interplay between immunology and ecology (immuno-ecology; Sheldon and Verhulst 1996, Viney *et al.*, 2005) could also provide interesting progress on some questions. For instance, the need to consider age-related effects and host immunity when undertaking quantitative studies of tick-borne pathogen transmission is becoming obvious (Gasparini *et al.*, 2001, Nunn *et al.*, 2006b). Interactions between host immunity and life-history issues such as emphasize involved with migration should also be considered (Gylfe *et al.*, 2000).

The development of these perspectives of research should thus rely on data from monitoring programmes and surveillance activities conducted at large-scales, but also on the development of specific case studies, which are necessary to complete our understanding of the ecology and epidemiology of seabird-parasite systems. Due to their relatively simple and spatially discrete structure, some seabird-parasite systems provide excellent opportunity for addressing questions of broad interest on the ecology and evolution of host-parasite interactions, as well on the effects of global changes on the risk of emerging infectious diseases.

5.6 References

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6 Quality assurance arrangements for the OSPAR ecological quality objective (EcoQO) relating to oiled guillemots

6.1 Introduction

Many contracting parties to OSPAR have established monitoring procedures or programmes for seabirds found dead on beaches in the seas around Europe (Table 6.1). These systematic Beached Bird Surveys (BBS) around the North Sea allow determination of species composition and oil rates (numbers and proportions of birds oiled of all birds found dead), and have been conducted since the early 1960s. The temporal and spatial trends in oil-related mortality in most countries bordering the North Sea have been studied. The common guillemot is the species most frequently found oiled on beaches surrounding the North Sea, and is therefore an appropriate choice for an EcoQO aimed at monitoring of chronic oil pollution. Spatial patterns in common guillemot oiling rates reflect different levels of chronic marine oil pollution around the North Sea, whereas temporal trends in oiling rates are indicative of changes in these levels over time. The results of these monitoring programmes were used by OSPAR to develop an Ecological Quality Objective for the common guillemot (OSPAR 2007). This EcoQO for oiled guillemots is:

The average proportion of oiled common guillemots in all winter months (November to April) should be 10% or less of the total found dead or dying in each of 15 areas of the North Sea over a period of at least 5 years.

Table 6.1. Current Beached Bird Surveys by European countries (adapted from OSPAR 2005).

COUNTRY	MONITORING DURING 20TH CENTURY	CURRENT MONITORING
Belgium	Regular surveys since 1950s	Ongoing programme
Denmark	Regular surveys since 1960s	Ongoing programme
Estonia	Regular surveys in 1990s	Unknown
Finland	Incidental reports	Unknown
France	Regular surveys since 1960s	Incidental surveys
Germany	Regular surveys since 1960s	Ongoing programme
Iceland	Unknown	Unknown
Ireland	Incidental reports since 1960s	Unknown
Latvia	Regular surveys in 1980s and 1990s	Unknown
Lithuania	Regular surveys in 1990s	Unknown
Netherlands	Regular surveys since 1940s	Ongoing programme
Norway	Regular surveys in 1980s and 1990s	Restarted monitoring in 2008
Poland	Regular surveys in 1970s, 1980s and 1990s	Unknown
Portugal	Regular surveys in 1980s and 1990s	Incidental surveys
Spain	Regular surveys in 1980s and 1990s	Incidental surveys

Sweden	Incidental reports since 1950s	Incidental surveys
Russia	Largely unknown	Unknown
UK	Regular surveys since 1960s	Ongoing programme

6.2   Quality Assurance

In this section we address actions that may be taken to ensure the highest probability of reaching the EcoQO. To date, quality assurance guidelines have not been established for the oiled guillemot EcoQO. WGSE herein proposes the application of some quality assurance in order to adequately assess trends in the oiled Guillemot EcoQO:

Oiled guillemot monitoring in Beached Bird Surveys should conform to established methodologies. Guidelines should be given by each contracting party on methodology of determining species and age and checking oil on plumages. WGSE noted that contracting parties should develop or sustain Beached Bird Survey programmes to ensure that the proportion of oiled guillemots can be evaluated for each subregion. Further, survey frequency and scale should be adjusted within each subregion to ensure that the minimum number of oiled corpses is achieved (25 complete corpses needed per subregion).

It is puzzling why the oiling rate of adult guillemots appears to be higher than that for juveniles (Camphuysen 2004). One might expect exactly the opposite, on the grounds that juveniles are less experienced and thus less likely to avoid oil slicks. It would be of interest to explore the reasons for this surprising pattern, other interesting results, and make suggestions for further research as part of the EcoQO reporting.

6.3   Remarks and Recommendations

There is inconsistency in the OSPAR EcoQO Handbook (OSPAR 2007) about whether or not to include beached guillemots that are still alive. There is mention of living birds in some parts and of corpses only, in other parts of the document. The EcoQO refers to both dead and dying birds. WGSE recommends that birds that are still alive should not be included in the sample of oiled birds. Living birds could escape, and therefore not be available for determination of age or oiling status, thereby biasing the ratio of oiled to unoiled birds. So data from Beached Bird Surveys should derive exclusively from dead birds; this might mean altering the wording of the EcoQO.

Ageing of guillemots is not always straightforward. Some adults have very faint white tips or silvery fringes to the greater wing coverts, whereas other birds that were in active moult at the time of oiling may have shed all greater wing coverts. WGSE suggests that each country should ensure that surveyors are appropriately trained in the relevant identification techniques and where necessary to   organize training sessions for volunteers to judge on acceptability (in terms of freshness) and age of the corpses, proper detection of oil on bird plumages, and other information that is to be recorded. A photographic guide should be provided to all volunteers showing both typical and aberrant plumage patterns.

The number of birds found oiled on beaches varies by season, with larger numbers in winter. OSPAR suggests collecting all data in November-April. However, WGSE recommends that as far as possible data within a region should be collected on the same dates each year. As there is already a regionwide survey during February, this effort should eliminate bias due to seasonality. Analysis of seasonal fluctuations by subregions is recommended.

While it is recognized that the EcoQO is for the proportion of birds that are oiled, we also recommend that data on numbers of birds found should be retained. Numbers of birds found will be useful when combined with the proportion that is oiled, to distinguish between major oiling events and mortality events due to other factors such as episodic food shortage.

A centralized or web-based, bespoke database for storage of all beached bird data should be established. An experienced database manager should be appointed for the collation of all data and the application of established protocols for their accuracy, veracity and other quality attributes. Consideration should also be given to possible web-based submission of all data to the database (manager). Data should be made available to all participants in the scheme partly in order to serve as an additional quality check (but also to facilitate region-wide collaboration in the venture.

Once determination has been made that the EcoQO has been met (or otherwise) a report by the database/project manager should be written, peer-reviewed by at least two independent reviewers, and disseminated widely.

6.4 References

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7 Climate change and seabirds in the OSPAR Maritime Region

ICES requested of WGSE, erroneously as it happens, that it prepares review papers for the chapters of the ICES position paper on climate change on:

- changes in abundance, migration and distributions patterns; and
- sensitivity of marine ecosystems to climate variability and regime shifts.

However, WGSE worked on this request in view of how much evidence of climate-related changes exists for seabirds in the ICES Region, and also of the fact that WGSE has addressed the issue previously. The following text relies heavily on chapter 7 in the 2007 WGSE report (ICES, 2007) and chapter 2 in the 2008 WGSE report (ICES 2008), with additional text and revisions. A relatively complete summary of documented links between seabirds and climate variation is presented in Table 7.1, and a selection of the studies are presented in more detail below to illustrate the variety of mechanisms involved.

Table 7.1. Links between climate change and seabirds.

SEABIRD PARAMETER	SPECIES	REGION	CLIMATE VARIABLE	SIGN OF CORRELATION WITH WARMING	SOURCES
Breeding range	Lesser black-backed gull	UK	Sea temperature	Positive	Mitchell *et al.,* 2004
	Northern gannet	UK	Sea temperature	Positive	Mitchell *et al.,* 2004
Non-breeding range	Lesser black-backed gull	UK		Positive	Wernham *et al.,* 2002, Mitchell *et al.,* 2004
	Common guillemot	Shetland	Sea temperature, sandeels		Heubeck *et al.,* 1991
Reproductive success	Northern fulmar	Orkney (North Sea)	NAO index	Negative (hatching); positive (fledging)	Thompson and Ollason 2001
	Atlantic puffin	Røst Norwegian Sea	Sea temperature	Positive	Durant *et al.,* 2003
	Atlantic puffin	Røst Norwegian Sea	Salinity	Negative	Durant *et al.,* 2006
	Great black-backed gull	Newfoundland	Sea temperature	Positive	Regehr and Rodway 1999
	Herring gull	Newfoundland	Sea temperature	Positive	Regehr and Rodway 1999
	Black-legged kittiwake	Newfoundland	Sea temperature	Positive	Regehr and Rodway 1999
	Leach's storm-petrel	Newfoundland	Sea temperature	Positive	Regehr and Rodway 1999
	Black-legged kittiwake	Isle of May (North Sea)	Sea temperature	Negative	Frederiksen *et al.,* 2004b
	Black-legged kittiwake	UK	Sea temperature	Negative	Frederiksen *et al.,* 2007
Annual survival	Northern fulmar	Orkney (North Sea)	NAO index	Negative	Grosbois and Thompson 2005
	European shag	Isle of May (North Sea)	Onshore wind, precipitation	Negative	Frederiksen *et al.,* 2008a
	Black-legged kittiwake	Isle of May (North Sea)	Sea temperature	Negative	Frederiksen *et al.,* 2004b

	Atlantic puffin	North Sea, Irish Sea	Sea temperature	Negative	Harris *et al.*, 2005
	Atlantic puffin	Røst Norwegian Sea	Sea temperature	Positive	Harris *et al.*, 2005
	Atlantic puffin	Norway (Barents Sea)	Sea temperature	Negative	Sandvik *et al.*, 2005
	Common guillemot	Norway (Barents Sea)	Sea temperature	Negative	Sandvik *et al.*, 2005
	Black-legged kittiwake	Norway (Barents Sea)	Sea temperature	Positive	Sandvik *et al.*, 2005
Population change	Common guillemot	Circumpolar	Sea temperature	For both species: populations increase with small changes and decrease with large changes	Irons *et al.*, 2008
	Brünnich's guillemot	Circumpolar	Sea temperature		Irons *et al.*, 2008
	Black-legged kittiwake	Isle of May (North Sea)	Sea temperature	Negative	Frederiksen *et al.*, 2004b
	Northern gannet	Newfoundland	Sea temperature	Positive	Montevecchi and Myers 1997
Nesting (laying or hatching) date	Black-legged kittiwake	Isle of May	NAO index	Positive	Frederiksen *et al.*, 2004a
	Common guillemot	Isle of May	NAO index	Positive	Frederiksen *et al.*, 2004a, Reed *et al.*, 2006
	Atlantic puffin	St. Kilda	Sea temperature	Positive	Harris *et al.*, 1998
	Atlantic puffin	Røst (Norwegian Sea)	NAO winter index	Negative	Durant *et al.*, 2004b
	European shag	Isle of May (North Sea)	Wind	Negative	Aebischer and Wanless 1992
	Black-legged kittiwake, common guillemot, razorbill, Atlantic puffin	Isle of May and Farne Islands (North Sea)	NAO winter index	Negative	Wanless *et al.*, 2009
Fledging date	Common guillemot	Baltic Sea	Air temperature	Negative	Hedgren 1979
Foraging cost	Common guillemot	Isle of May (North Sea)	Stormy weather	Positive	Finney *et al.*, 1999
	Northern fulmar	Shetland (North Sea)	Wind speed	Negative	Furness and Bryant 1996

7.1 Changes in abundance, migration and distribution patterns

7.1.1 Overview

Seabirds are almost without exception colonial breeders, which means that it is reasonably easy to collect data on a wide variety of aspects of their biology. The population size and demography of many seabird species are monitored in detail at several colonies throughout the ICES region, although these colonies constitute a small fraction of the total population. Lower intensity monitoring of population size occurs at a larger number of colonies. It is important to note that generally only the size of the actively breeding segment of the population can be monitored accurately, and that the size of the non-breeding segment is poorly known. This has important implications for the detection of effects of environmental change. At-sea surveys can also be used to monitor trends in abundance for entire populations, but need to be standardized, sustained and of sufficient spatial coverage.

Several aspects of seabird ecology make the detection of climate-related changes in abundance and distribution difficult. Seabirds have long generation times (usually 10–20 years) and raise few young per year, which recruit to the breeding population after several years, but adults can live for many years (Ashmole 1971, Jouventin and Mougin 1981). This life-history strategy implies that population growth rate is most sensitive to changes in year-to-year survival of adults, and consequently that natural selection will tend to make this demographic rate relatively insensitive to environmental variation ('environmental canalization', Gaillard and Yoccoz 2003). This means that breeding populations are able to 'integrate' environmental variation over many consecutive years, so that years in which resources are scarce may take some time to become evident in population trajectories, because resource scarcity mainly results in reduced production and survival of juveniles. Also, many seabirds seem to be able to sustain episodic, disastrous years, such as occur during El Niño conditions, but be more susceptible to longer-term trends in unfavourable conditions (Schreiber 2002, Veit and Montevecchi, 2006). It is thus in general much easier to detect environmental effects on demographic rates (fecundity and survival) than on abundance *per se*. When searching for responses by seabirds to climate change, it must be emphasized to include changes that occur as monotonic long-term trends as well as those that seem to cycle. In the sections that follow, we show how seabirds are impacted by changes in the North Atlantic Oscillation (NAO) index, which fluctuates periodically, and also how seabirds have responded to more monotonic long-term change.

In addition, seabirds are well-insulated, homoeothermic animals, and in most species individuals spend only a small fraction of their time immersed in seawater. Furthermore, climate-related changes in sea temperature are small relative to seasonal changes in the ICES region, and the breeding range of many species spans a wide temperature interval. Seabirds are therefore usually unlikely to be directly (physiologically) affected by changes in sea temperatures or salinity. However, most species rely completely on marine prey resources, and if key prey species are negatively affected by changes in ocean climate, this is likely to have serious implications. Bottom–up trophic effects are thus expected to be more important than direct physiological ones, and in many cases these effects may be lagged by several years because seabirds often depend on specific age classes of their fish prey. In accordance with this, most observed changes in seabird populations that have been linked to climate are thought to be mediated through seabird prey. Declines (or increases) are due to changing abundance of prey (Veit *et al.*, 1996, Montevecchi and Myers 1997, Thomp-

son and Ollason 2001, Frederiksen *et al.,* 2006), which in turn are driven by environmental change, such as changes in sea temperature. Usually, it has been difficult to establish the full chain of cause and effect from physical climate forcing through phytoplankton, zooplankton and fish to bird abundance. In the sections that follow we review published evidence from the ICES region and draw the appropriate conclusions.

The breeding distribution of many seabirds is also likely to change very slowly in response to environmental change. This is because seabirds are both long-lived and in most cases strongly site-faithful. Once established as breeders at a colony, adults of most species will only very rarely shift to a different location. In contrast, immature birds are much more likely to settle at a different location from their natal colony. This means that seabirds are more likely to occupy newly suitable areas more quickly than they are to leave areas that have newly become unsuitable. Non-breeding distributions are likely to change much more quickly than breeding distributions, but unfortunately extensive long-term data on non-breeding distributions are rare and difficult to collect. Possibly more abrupt changes to breeding distributions could arise as a result of rising sea levels. Seabirds nesting on barrier beaches and low-lying islands have lost substantial potential nest habitat in eastern North America and Bermuda (Nisbet *et al.* in press) as these habitats wash away, and the same may apply to gulls and terns nesting in EU waters.

7.1.2 Changes in breeding distribution

Few seabirds in the ICES region have changed their overall breeding range in the past 50 years, and for those that have, the role of climate change in such changes is unclear. Great skuas have increased in abundance within their traditional breeding range in Scotland, the Faeroes and Iceland, and have extended their breeding range north to northern Russia and Svalbard during the last 30 years (Mitchell *et al.,* 2004). Northern gannets have increased steadily on both sides of the North Atlantic from the late 19th century to the present, and during the last 20 years they have extended their breeding north along the Norwegian coast and into NW Russia. Population increase along the Norwegian coast has levelled off recently, probably due to other factors. Cormorants (subsp. *sinensis*) have expanded their breeding range into and in Norway over the past 20 years (Lorentsen and Christensen-Dalsgaard 2009). In Newfoundland, the major increase during the mid 20th century was related to a shift in diet to mackerel *Scomber scombrus*, which moved back into the region when surface waters warmed (Montevecchi and Myers 1997). Nevertheless, around the North Sea, the largest increase in gannet numbers, during the mid 20th century, did not correspond to the period of greatest temperature change, which is occurring now. Two species of gulls, lesser black-backed gull and Mediterranean gull have expanded their breeding range north during the past 30 years, so in theory these expansions could reflect changing climate. The expansion of lesser black-backed gulls incorporates colonization of, and population growth within, Iceland and greatly increased presence (but only very limited breeding) in North America (Nisbet *et al.* in press). The expansion of Mediterranean gulls to Britain is part of a broader scale range expansion from the vicinity of the Black Sea westwards. For each species, there are many factors that are influencing these range expansions and it is not clear that climate change is necessarily among these.

7.1.3   Changes in non-breeding distribution

Some seabirds in the ICES region have shown changes over recent decades in their migrations and winter distributions. As far as we know, most species have shown very little, or no, change in winter distribution or migration routes. A particular case is the distribution of seabirds that specialize in foraging at the ice-edge. Ivory gulls depend on ice edge habitats for foraging, and their recent steep population decline probably reflects diminishing ice coverage in the Arctic Ocean, among other factors (Gaston *et al*. 2005).

Common guillemots responded to reductions in sandeel *Ammodytes marinus* abundance at Shetland in the late 1980s by moving further east in winter to feed in the Skagerrak (Heubeck *et al.,* 1991, Wernham *et al.*, 2002).

Northern gannets have increased considerably in breeding numbers in the North Sea, but despite that, the numbers wintering in the North Sea have reduced slightly from the 1980s to 2000s (Garthe *et al.,* in prep). Shipboard transects in the North Sea in winter in the 1980s and early 1990s suggest that virtually as many adult gannets were in the North Sea in winter as in summer. Recent studies suggest that at least half of the gannets present in the North Sea in summer now move out of the North Sea to winter from the Celtic Sea to West Africa. These changes are unlikely to be related directly to climate change, but perhaps rather to food availability and in this case possibly to reductions in the amounts of discards from North Sea fisheries (Garthe *et al.* in prep).

Lesser black-backed gulls breeding in the UK have increasingly developed the habit of overwintering in the UK and North Sea rather than migrating to North Africa as they did in previous decades, and the recent massive increase of winterers in North America (Nisbet *et al*. in press) may be related to this change as well These progressive changes may be linked to milder winter weather and also to available food supplies in the UK (Wernham *et al.,* 2002, Mitchell *et al.,* 2004).

Data on at-sea distribution in the North Sea provides a quantitative basis from which to assess distributional shifts that might reflect climate. Counts of seabirds at sea have been carried out systematically in the North Sea since 1979. These data show that scavengers have declined whereas a second group of species that includes many non-scavengers have increased (Table 7.2). Large gulls and northern fulmars declined most strongly, matching what would be expected when fisheries effort and thus the availability of discards and offal decline.

Table 7.2. Overall trends of seabird abundance in the North Sea for the two periods (1979–1991 and 1992–2004) covered in the ESAS (European Seabirds at Sea) database 4.1 (Garthe *et al.* in prep.).

OVERALL NORTH SEA TREND	
Summer/breeding period	**Species**
>50% increase	Northern gannet, lesser black-backed gull, Atlantic puffin
20–50% increase	no species
<20% changes	European shag, great black-backed gull, black-legged kittiwake, common guillemot
20–50% decrease	Northern fulmar, common gull, herring gull
>50% decrease	no species
Winter	**Species**
>50% increase	Atlantic puffin
20–50% increase	no species
<20% changes	European shag, northern gannet, common gull, common guillemot
20–50% decrease	Northern fulmar
>50% decrease	Herring gull, great black-backed gull, black-legged kittiwake

Trends for the northern and southern North Sea were different. Fulmar, kittiwake and large gull declines were most obvious in the northern half of the North Sea, coinciding with a trend of declining fisheries in that area, whereas numbers in the southern North Sea did not decline. It thus seems that fisheries effects may have overridden any climatic effects on the at-sea distribution and abundance patterns of seabirds in the North Sea. More detailed investigations are underway to assess these phenomena (Garthe *et al.* in prep).

7.1.4 Changes in reproductive success

One of the best examples of climate-induced changes in reproductive success to date from the ICES region comes from the North Sea. Black-legged kittiwakes have declined by 50% since 1990 (Frederiksen *et al.*, 2004b) and several species experienced breeding failure and/or late breeding in 2004 and 2005 (Wanless *et al.*, 2005, ICES 2006). The decline in numbers was associated with poor breeding success and lower adult survival over several years (Frederiksen *et al.*, 2004b). The increasing trend in the NAO index to the mid-1990s and the associated warming of the Northeast Atlantic and the North Sea has caused major changes in plankton communities, in particular, a decline in the copepod *Calanus finmarchicus* (Fromentin and Planque 1996, Planque and Fromentin 1996). This copepod is often eaten by sandeels and other species of forage fish, which are in turn a major source of food for several seabird species in the eastern North Atlantic and North Sea (Frederiksen *et al.*, 2006). It is now thought that the bottom–up effect of changing ocean climate conditions causing reductions in forage fish food in the North Sea is a controlling factor in sandeel abundance and quality (Frederiksen *et al.*, 2004b, Wanless *et al.*, 2004, see also Wanless *et al.*, 2005, Frederiksen *et al.*, 2007.
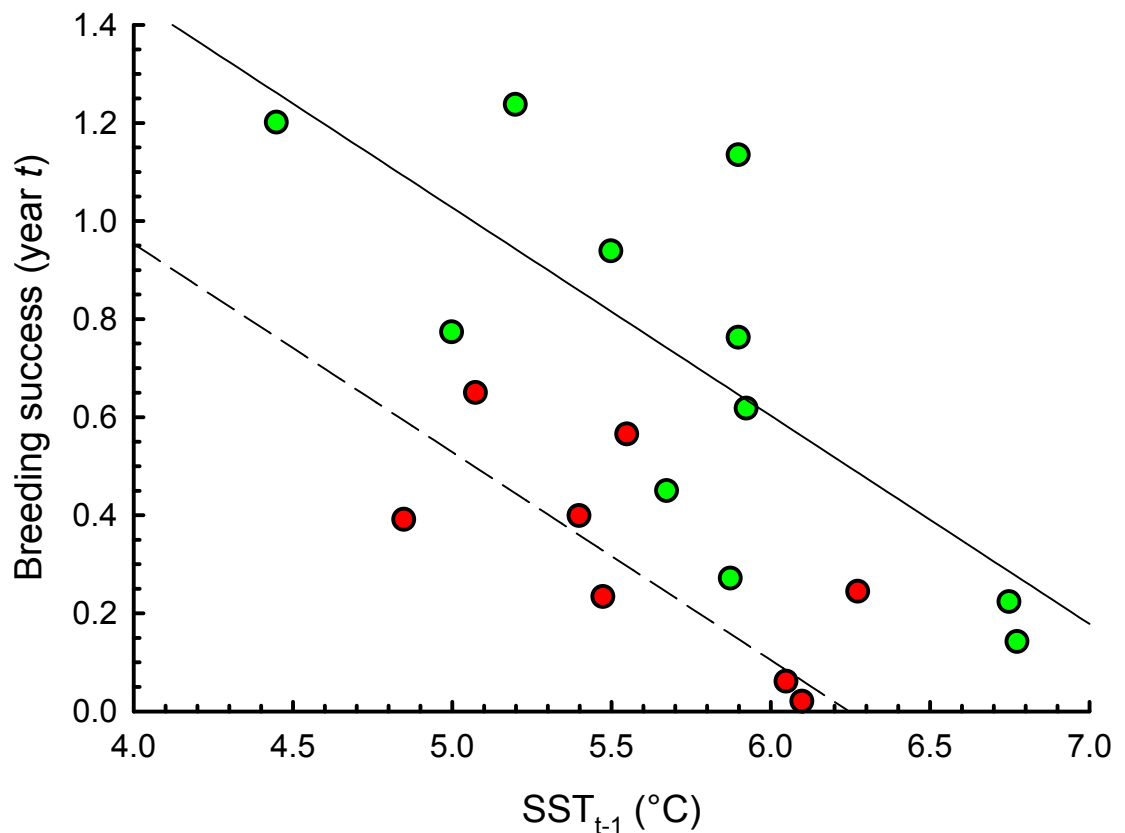
Figure 7.1. Figure adapted from Frederiksen *et al.* (2004b) showing additive effects of the local fishery for sandeels and climate change on kittiwake breeding success on the Isle of May, Firth of Forth, Scotland 1986–2004. Red symbols indicate years when the fishery was active, green symbols years when it was closed or inactive.

7.1.5   Changes in annual survival

Several studies show effects of climate on annual survival of adult seabirds in the ICES region. The survival of northern fulmars breeding on Eynhallow, Orkney, and common guillemots on Skomer, Wales, was negatively correlated with winter North Atlantic Oscillation index one year previously (Grosbois and Thompson 2005, Votier *et al.,* 2005). The survival of black-legged kittiwakes on the Isle of May, Scotland, declined with winter SST one year previously (Frederiksen *et al.,* 2004b). The survival of Atlantic puffins at three colonies in the UK was negatively correlated with local summer sea surface temperatures (SST), but at Røst, Norway, the relationship was positive (Harris *et al.,* 2005). At all these colonies, summer SST one year previously affected survival to the following year, except for the Isle of May where it was influenced by SST in the current year (Harris *et al.,* 2005). Using the same datasets for these colonies, Grosbois *et al.* (in press) showed that 67% of the interannual variance in adult survival was accounted for by a global spatial scale component, indicating there is substantial synchrony among colonies. The local sea surface temperature accounted for 40% of the global scale component, but also for an equally large fraction of the local scale component. SST thus acted at the same time as to synchronize and desynchronize survival rates, but the analysis also suggested some other unknown environmental factor(s) acted as synchronizing agents. On Hornøya, Norway,

the correlation between survival of four auk species and winter/autumn SST was negative, whereas that of black-legged kittiwake was positive (Sandvik *et al.*, 2005).

In all of these studies, the authors concluded that climate most likely affected seabird survival via indirect effects on prey availability. For Brünnich's guillemots on Hornøya this was established quantitatively, with survival increasing with the combined abundance of herring *Clupea harengus* and capelin *Mallotus villosus* prey which, in turn, declined with SST (Sandvik *et al.*, 2005). For the remainder of studies cited, indirect effects were inferred qualitatively from published literature on relationships between key prey species and climate. Such reasoning explains the contrasting trends of survival with SST for Atlantic puffins in the UK and Røst, since those in the UK feed on sandeels and those in Røst feed on herring, and abundance of these are negatively and positively affected by SST respectively (Toresen and Østvedt 2000, Arnott and Ruxton 2002). The negative relationship between capelin abundance and SST in the Barents Sea is, however, to a large extent explained by a parallel change in the balance between the stocks of capelin and that of young herring which is one of their main predators (Hjermann *et al.*, 2004). In the southwest Barents Sea, an ongoing study has shown a close positive relationship between the Barents Sea capelin stocks and the survival rates of adult kittiwakes (Erikstad and Barrett in prep.). This corroborates Barrett's (2007) suggestion that variations in capelin availability may have contributed to the steep decline in the kittiwake population in the Barents Sea region.

The corollary of this conclusion is that links between climate and survival may be inferred from studies where seabird survival has been related to abundance of a prey species known to be sensitive to environmental change. For example, the survival of great skuas, arctic skuas and black-legged kittiwakes on Shetland varied with the availability of sandeels (Oro and Furness 2002, Ratcliffe *et al.*, 2002, Davis *et al.*, 2005) and, since sandeel stocks are related to ocean currents and SST (Wright 1996, Arnott and Ruxton 2002), variability of their survival could ultimately be caused by climatic fluctuations.

In contrast to the above-mentioned studies, which all indicate or assume indirect effects of climate on seabird survival, the survival of European shags on the Isle of May was shown to be strongly related to winter weather, being particularly low when precipitation was high and onshore winds frequent (Frederiksen *et al.*, 2008a). Because of their only partially waterproof plumage, shags and other cormorants are likely to be unusually sensitive to this type of weather, and it is unlikely that such effects are common among other taxonomic groups.

7.1.6   Changes in abundance

Common and Brünnich's guillemots provide a good example of global-scale population growth in response to climate change (Irons *et al.*, 2008). The two species reacted somewhat differently to SST shifts. The Arctic-adapted Brünnich's guillemot performed best when the SST increased slightly, whereas the more temperate common guillemot did best when the SST decreased slightly. Both species reacted negatively following the stronger changes in SST (mean SST differing more than 0.5°C from that in the previous regime), regardless of whether the temperatures changes were positive or negative. This response, with the magnitude of the shift being more important than its direction, suggests that the largest shifts were causing the most severe and long-lasting changes to the foodwebs these birds rely on. This illustrates the complexity of how climate change will impact seabird populations, and emphasizes that ex-

treme care is needed when projecting observed, short-term trends to the longer-term climate change scenario.

Few other studies have analysed changes in abundance of seabirds in relation to climate change, largely because the lags inherent in seabird life histories necessitate the use of mathematical population models based on detailed demographic information. For black-legged kittiwakes, Frederiksen *et al.* (2004b) showed that if mean sea surface temperatures in the North Sea were to increase further, this would lead to population declines whether the sandeel fishery was reopened or not (Figure 7.2). In section 7.1.9 below, relationships between changes in seabird abundance and climate are explored further.
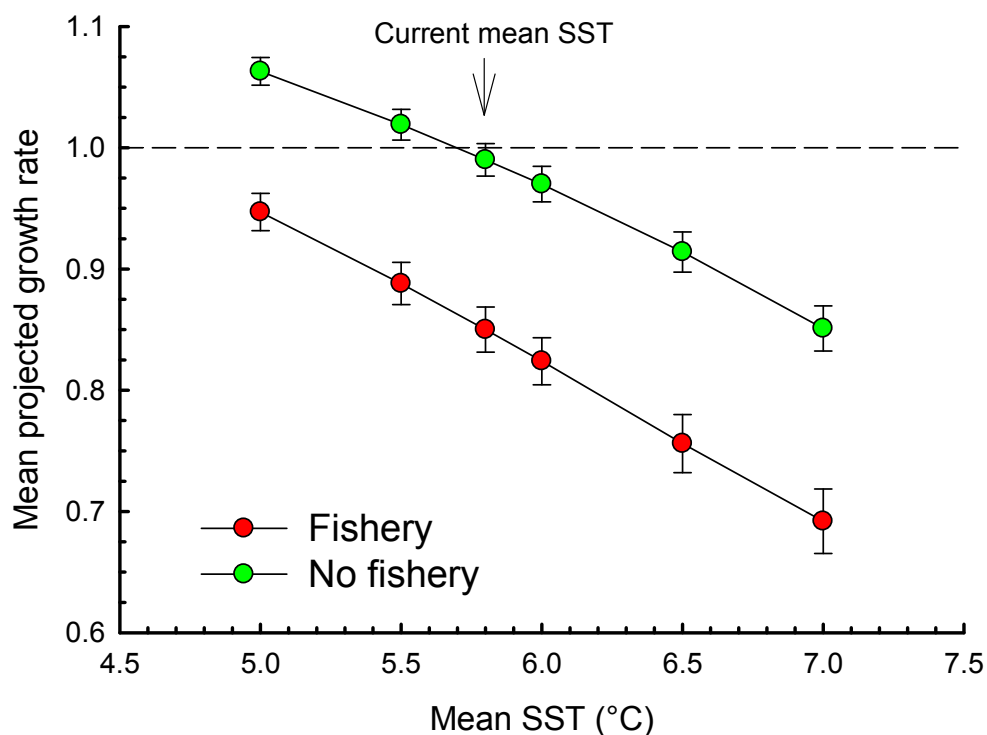

Figure 7.2. Figure adapted from Frederiksen *et al.* (2004b) showing additive effects of the local fishery for sandeels and climate change on projected kittiwake population growth on the Isle of May, Firth of Forth, Scotland.

7.1.7   Changes in migratory schedule

Among seabirds, few examples of changes in migration phenology are available. Data from a Dutch seawatching project showed that little gulls along the Dutch mainland coast passed gradually earlier in spring over the last three decades (Figure 7.3). Nowadays, the median numbers are counted almost three weeks earlier than in the 1970s. Surprisingly, there is no evidence of a similar pattern with tern species (NZG/Club van Zeetrekwaarnemers unpublished data; C. J. Camphuysen, pers. comm.).
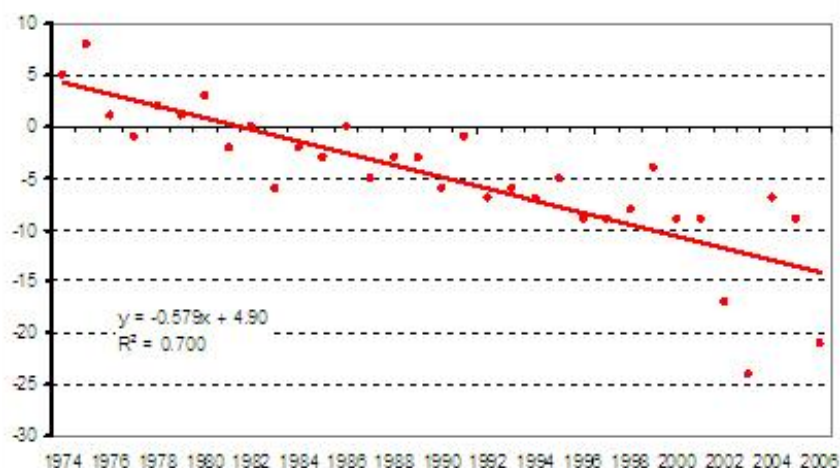
Figure 7.3. Annual median spring passage times of little gulls at the Dutch mainland coast relative to 30. April (=0). n = 484,385 individuals and 24,734 hours of observation (NZG/Club van Zeetrekwaarnemers unpublished data).

7.1.8   Other phenological changes: laying dates, nest dates, fledging dates

In general, seabirds commence breeding as early as conditions allow, which for most species in the northern hemisphere is in April–June. This is driven by a variety of ultimate and proximate factors. It is well known that for their size, seabirds exhibit protracted incubation and chick development periods (Lack, 1968). Thus, an early start to breeding is essential so that chicks are fledged before conditions deteriorate. This adaptation is particularly important in the highly seasonal environments within the northern portions of the ICES region, as summer season is relatively short and winter conditions harsh. Spring is also the time of year when phytoplankton react to high levels of nutrients and increasing amounts of sunlight, and reproduce, creating a rapid increase in primary productivity which eventually results in increased availability of organisms that form the basis of seabird diets (i.e. crustacea, small fish and squid; Ashmole, 1971). It is generally accepted that birds adjust their timing of breeding such that the chick rearing period, a time of maximal food and energy requirements for parents, coincides with the seasonal peak in food availability (Lack, 1968).

An ever increasing number of avian studies show that as average temperature increases as a result of climate change, so migration and timing of breeding advance (e.g. Crick 2004). Among seabirds, there are relatively few studies and the results are equivocal in that timing of breeding is advanced in some cases and retarded in others as a result of changes in climate (Durant *et al.,* 2004a,b; Barbraud and Weimerskirch 2006). Trends towards later breeding have been documented for several species in the North Sea (Frederiksen *et al.,* 2004a, Reed *et al.,* 2006, Wanless *et al.,* 2009), and in northern gannets throughout their E Atlantic range (Wanless *et al.,* 2008). Late breeding in the face of warmer conditions (the opposite of the general trend in birds) can result from movement or overall decline in forage species, which have relatively narrow tolerances to temperature due to poikilothermy. This is a frequent occurrence in the Pacific Ocean where thermal perturbations are often forced by ENSOs.

Frederiksen *et al.* (2004a) showed that the state of the North Atlantic Oscillation (NAO) index was correlated with timing of breeding for common guillemots and black-legged kittiwakes both of which disperse in winter over large spatial scales and thus are in a position to sample large-scale ocean climate variation as indicated by the

NAO. Although the NAO is a natural mode of variation in the North Atlantic, it has been suggested by general circulation models of climate that forcing due to human-induced greenhouse gas increases (specifically CO_2) may cause the NAO index to increase over the next 100 years (Gillet *et al.*, 2003).

In an interesting paper on Atlantic puffins nesting in Røst in the Norwegian Sea, Durant *et al.* (2004b) showed that timing of breeding was negatively related to the NAO index in two periods and not related (or slightly positively related) in an intervening period. They suggested that this was an indication of a regime shift possibly driven by food availability in the year preceding breeding. In a long-term study of Atlantic puffins in the Barents Sea, Barrett (2001) showed that timing of breeding was later in cooler years, with the suggestion that access to nest sites might have been hampered due to ice and snow in years with lower spring temperatures.

In summary, seabirds appear to react to climate change and variability of a variety of ways. In some circumstances, a warming trend advances timing of breeding and in others breeding is retarded. Seabirds show some flexibility in dealing with climate change in this regard but are ultimately constrained because of the finite (and often lengthy) time required to complete the breeding cycle. Because they are long-lived, seabirds are often able to "buffer" short-term (< 10 years) environmental variability, especially at the population level. Seabirds are vulnerable to both spatial and temporal mismatches in prey availability, especially when breeding at a fixed colony sites with the foraging constraints that these entail (e.g. Weimerskirch *et al.*, 1993).

7.1.9 Seabird demography and population dynamics in relation to ocean climate: new analyses

To investigate the utility of the datasets provided by the Working Group on Oceanic Hydrography (WGOH), and to illustrate the generic points about how seabirds are expected to be affected by environmental change, two sets of new analyses were carried out by WGSE in 2008. Each of these used highly detailed seabird datasets that have been used previously in many published studies:

- a) data on black-legged kittiwake breeding success and abundance from the Isle of May in southeast Scotland, provided by the UK Centre for Ecology and Hydrology and the Joint Nature Conservation Committee; and

- b) data on Atlantic puffin breeding success and abundance provided by the Norwegian Institute for Nature Research. Similar analyses could be carried out for several other long-term seabird datasets, including both detailed studies at breeding colonies and at-sea surveys of abundance and distribution.

7.1.9.1 Black-legged kittiwakes in the North Sea

Frederiksen *et al.* (2004b) demonstrated negative effects of high sea surface temperature (SST) on breeding success, adult survival and projected population growth for black-legged kittiwakes at the Isle of May colony in the North Sea (see previous sections, Figures 7.1 and 7.2). For breeding success, there was a 1 year lag, consistent with kittiwake dependence on 1-group sandeel, their main prey during the breeding season. New analyses showed that this pattern prevailed both for local SST and for the southeastern North Sea SST data provided by WGOH, whereas no relationship was found for the NAO (Figure 7.4). For year-to-year population growth, defined here as the log-transformed ratio of successive annual counts of breeders, there was an almost significant negative correlation with a 1 year lag, consistent with a negative

effect of SST on survival of adult breeders. Again, this pattern was apparent for both SST datasets, whereas no effect of NAO was apparent (Figure 7.4). These results demonstrate that lagged (i.e. indirect) effects of ocean climate on seabirds cannot be ignored, and that hydrographic variables must be selected carefully based on a good understanding of the local ecosystem in order to provide meaningful results.
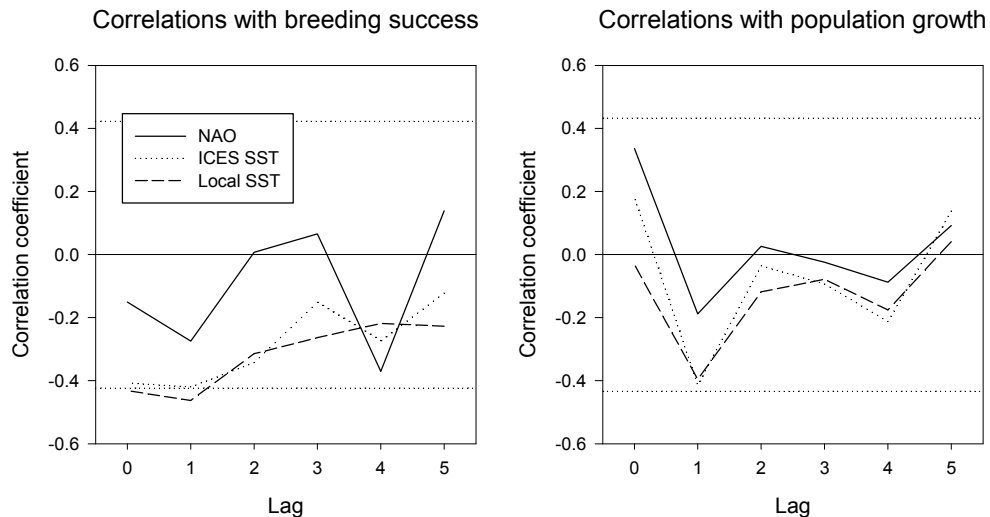

Figure 7.4. Magnitude of correlation coefficients between three hydrographic variables and two aspects of black-legged kittiwake population dynamics at the Isle of May in the North Sea. Horizontal dotted lines indicate conventional levels of significance (α = 0.05). Data provided by ICES WGOH, British Atmospheric Data Centre, Centre for Ecology and Hydrology and Joint Nature Conservation Committee.

7.1.9.2 Atlantic puffins in north Norway

Durant *et al.* (2003) have demonstrated that the breeding success of the Atlantic puffin in Røst, north Norway, is largely explained by the combined effect of local sea temperatures (i.e. within the Norwegian coastal current) in March–July and the size of first-year (0-group) herring they provide for their chicks in the same year. The repeated breeding failures have caused a severe decline in population size over several decades (Anker-Nilssen 1992). In a more recent paper Durant *et al.* (2006) showed that the nestling period of these chicks, and hence the quality of the reproductive output of the population, can be equally well predicted by using only local data for sea temperatures and salinity in March, which is the period of first growth for larval herring drifting northwards along this coastline. Simple correlations between different time-series for sea temperatures and an updated version of the dataset on breeding success for the Røst puffins (Anker-Nilssen and Aarvak, 2006 and unpublished data) suggest that temperatures sampled further away from the breeding site, at different depths, in different water masses and/or at different times of year are less able to reveal such relationships (Figure 7.5a). This highlights the importance of selecting the most relevant descriptors of environmental change, i.e. those that are expected to be most closely linked to the underlying ecological processes (in this case the growth and survival of young herring).

When repeating the analysis with the same set of environmental dataseries, but substituting fledging success with the rate of population change from year to year in the same colony (Anker-Nilssen and Aarvak 2006), no significant relationships emerge (Figure 7.5b). This emphasizes the unsuitability of breeding numbers as an indicator of the effect of climate change on this population. Not only are puffin numbers moni-

tored early in the egg-laying period when herring is expected to be a less important prey, but as the age at first breeding in this population is 5–7 years (Anker-Nilssen and Aarvak, 2006), these analyses are also biased by probably great variation in immature survival of different cohorts.
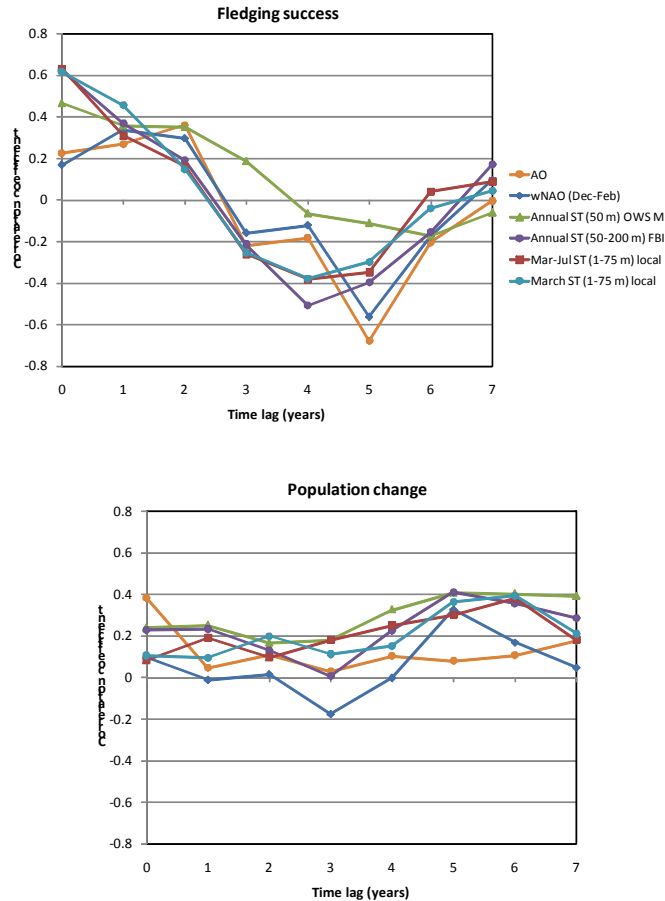
Figures 7.5a (top) and 7.5b (bottom): Degree of correlation between selected climatic variables and (a) fledging success, and (b) the ln-transformed change in annual breeding numbers of Atlantic puffins at Røst, northern Norway in 1979–2007. To test for indirect effects of trophic relationships and demographic processes, the data for puffin performance were also lagged by 1–7 years. Data provided by ICES WGOH, Svein Østerhus (for Ocean Weather Station Mike, OWS M), Harald Loeng (for Fugløya-Bear Island FBI), and Anker-Nilssen and Aarvak (2006, and unpublished data).

7.1.10 Conclusions

There is a substantial body of evidence linking changes in seabird demography and population dynamics to changes in ocean climate. Most of these studies assume that climatic effects are indirect, i.e. mediated through the prey base. This assumption is strongly based on theoretical consideration, although it is rarely possible to elucidate all steps of the causal chain. For example, changes in abundance and distribution of *Calanus* copepods in the North Sea have been clearly linked to climate (e.g. Beaugrand *et al.*, 2003). Sandeels are known to eat mainly copepods, but there are no published studies showing exactly how the marked change in copepod community composition in the North Sea has affected sandeels. The documented low recruitment of sandeels in the North Sea in recent years is almost certainly the main direct reason for low reproductive success in several seabird species, but in the absence of spatially

explicit estimates of sandeel recruitment this hypothesis cannot be tested directly. Thus, although a coherent mechanistic hypothesis for how climate change affects North Sea seabirds can be constructed, it is not possible to test all elements of the hypothesis with existing data. Research is therefore often limited to analyses of the relationships between climatic variables and seabird demography, sometimes skipping several trophic levels.

The variation in adult survival rates of Atlantic puffins illustrates the point that in-depth understanding of trophic relationships, including spatial variation in main prey species, is needed to interpret relationships between seabird demography and climate. Even though mean survival has not been found to differ much between colonies located far apart, it reacts clearly differently to sea temperature changes in different sea areas (Harris *et al.,* 2005). The positive effect on puffin survival with a temperature increase in the Norwegian Sea most likely reflects the parallel positive effect of temperature on the survival of young herring of the Norwegian spring-spawning stock (Toresen and Østvedt 2000), which is the staple food for puffins in that area (e.g. Anker-Nilssen 1992). On the other hand, the negative effects of a temperature increase on puffin survival in the shallower North and Barents Seas are likely to reflect the parallel negative effects of temperature on the reproduction of the Barents Sea capelin and North Sea sandeel populations, respectively (Arnott and Ruxton, 2002; Hjermann *et al.,* 2004).

In conclusion, whereas a unified approach across taxonomic groups for investigating climatic effects on abundance and distribution of organisms would in principle be desirable, the nature of the available data combined with fundamental differences in basic ecology and life-history strategies renders this aim unrealistic. Limiting analytical approaches and explanatory variables according to a predefined list would unnecessarily restrict the strength of inference possible with the existing data. In contrast, using analytical approaches and explanatory variables, which have been optimized with respect to the available data (and thus differ among taxonomic groups), will allow stronger inference and more general conclusions to be reached. Also, for groups such as seabirds where detailed demographic data exist, and where long generation times obscure any direct links between climate and abundance, it is straightforward to integrate demographic effects in a population model, which then can be used to predict changes in abundance in response to environmental change.

7.2 Sensitivity of marine ecosystems to climate variability and regime shifts

Although climate-induced changes in seabird numbers as such are unlikely to cause drastic effects on other components of the systems, seabirds are valued parts of these systems and are very sensitive to changes, as well as being good indicators of changes that make a difference for the overall functioning of marine foodwebs. As an example, planktivorous seabirds serve well to illustrate that high Arctic marine systems are likely to be particularly sensitive to climate change.

Globally, seabirds feeding principally on pelagic crustaceans occur mainly in polar ecosystems. This is particularly the case in the Southern Ocean, where krill-feeding seabirds (e.g. some penguins and many petrels) occur in huge concentrations and constitute a very large proportion of the seabird community at high latitudes. In the northern hemisphere, planktivorous seabirds (mainly small alcids) are particularly important in the Bering and Chukchi Seas, both in terms of diversity and biomass. In the North Atlantic seabird community, the only numerous planktivore is the little auk, which occurs in enormous concentrations in northwest Greenland (Egevang *et*

al., 2003), and in somewhat smaller (but still large) numbers in East Greenland, Svalbard, Franz Josef Land and other archipelagoe in Arctic Russia.

Only relatively large crustaceans occurring at high density are sufficiently profitable as prey to sustain populations of little auks and other planktivorous seabirds. During the breeding season, little auks feed principally on two closely related large high Arctic copepod species, *Calanus hyperboreus* and *C. glacialis* (Weslawski *et al.,* 1994, Pedersen and Falk 2001). These copepods occur only in very cold waters, and are likely to be replaced by their boreal relative *C. finmarchicus* as climatic warming proceeds (Stempniewicz *et al.,* 2007). Indeed, recent observations off West Greenland suggest that this is already happening (Frederiksen *et al.,* 2008b). The consequences of this shift for marine ecosystems are likely to be profound. An increasing fraction of primary production will be channelled through *C. finmarchicus* and similar species to planktonic fish, which in turn will provide food for potentially increasing numbers of piscivorous seabirds, marine mammals and predatory fish (Stempniewicz *et al.,* 2007). Food chain length will thus increase, leading to potentially lower energy transfer efficiency to higher trophic levels. A similar pattern has been observed in the Bering Sea, where planktivorous seabirds have benefited at the expense of piscivorous species during years of high ice concentrations, and *vice versa* (Hunt *et al.,* 2002). Further south, *C. finmarchicus* is in turn being replaced by an even smaller congener, *C. helgolandicus,* with potentially severe effects on fish recruitment (e.g. Beaugrand *et al.* 2003).

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8 Eiders and blue mussels

ICES has been requested to advise on methodologies aimed at evaluating the interaction between the blue mussel fishery and the mussel eating bird populations in Natura 2000 sites in the Danish waters thus:

> estimation of the energetic requirements of Eiders and other mussel eating bird species in the Danish part of the Wadden Sea, including assessment of the amount of blue mussel necessary for the eiders;

> estimation of the energetic requirements of Eiders and other blue mussel eating bird species, in the NATURA 2000 sites outside the Wadden Sea; and

> estimation of the blue mussel stock and annual blue mussel production in the Danish part of Wadden Sea and in other relevant Danish NATURA 2000 sites.

WGSE was requested to address the first two parts of this adopted term of reference. The recommendations provided by WGSE follow the requests closely, and are therefore limited to a description of suggested methodologies for estimating energy requirements of mussel-feeding waterbirds. The ICES Benthic Ecology Working Group has been requested to address the third part of the term of reference – appropriate methodology for the assessment of quantities of mussels consumed. Whereas WGSE has not attempted to estimate these quantities for the Danish Wadden Sea and Natura 2000 sites, such estimations have already been attempted for common eiders in the Dutch Wadden Sea (Brinkman 2003).

8.1 Species and areas considered

Given the expertise of the Working Group, the advice given here is limited to the following bird species: common eider, common scoter, velvet scoter, goldeneye and herring gull. It does not extend to wader species such as Eurasian oystercatcher; the foraging behaviour of waders differs fundamentally from that of seaduck, so the detailed individual-based model outlined here could not be applied to waders. However, there does exist a well-developed individual-based model to quantify consumption rates of shellfish by oystercatchers in estuarine areas in UK (e.g. West *et al.* 2003), which is similar to the methods discussed here for seaduck, and which could be adapted to the Danish waters in question.

The suggested methodology is not restricted to a particular location and potentially can be applied to any site. Some of the model input parameters are location-specific (see Table 8.1), so the model can be used to derive site-specific estimates of prey consumption. It could therefore be applied equally to the Danish part of the Wadden Sea and Natura 2000 sites outside the Wadden Sea and so these are considered jointly.

8.2 Model complexity in estimating energy requirements of bird populations

For several decades, marine biologists have attempted to estimate the prey consumption of seabird communities and to understand the role of food in determining population size and community structure (e.g. Furness 1978). Quantifying the prey harvest of bird populations requires a bioenergetics modelling approach, incorporating a consideration of the energy or food consumption of an individual bird and scaling up to the consumption of the whole population within the area under consideration. In order to generate realistic estimates of food consumption under a range of scenarios, models need to adequately represent the key relationships and simple models are unlikely to perform well under a range of diverse situations.

The earliest attempts to estimate food consumption or energy expenditure of bird populations necessarily relied on a relatively simple approach to give a crude indication of the magnitude of prey harvest by seabirds. Belopolskii (1961), quantified prey consumption of a number of species of breeding seabirds simply on the basis of mean weight of fish carried in each foraging trip multiplied by the total number of trips each day and the population size of each species. Evans (1973), estimated energy consumption in the North Sea using summer and winter biomass totals of shorebirds, marine wildfowl and seabirds, combined with metabolic rates derived from the allometric non-passerine equation of Lasiewski and Dawson (1967), with allowances for foraging activity and reproduction. Subsequent attempts to model energy flow through marine avifauna have become increasingly complex, using simulation models. Wiens and Innis (1974) developed a model which considered not simply population size (which was allowed to vary over the course of the year) but also clutch size, mortality rates, breeding phenology, chick growth rates and adult mass as well as ambient temperature. Existence energy requirements were estimated from allometric equations (Kendeigh 1970), with allowance for additional costs of digestion, activity, moult, egg production and chick growth. Crucially, they also considered the sensitivity of their model predictions to variation in input parameters, though not to variation in the constants of the basic energetic equations. Furness (1978) developed a bioenergetics model to estimate energy budgets for seabird populations based on changes in numbers of seabirds at the colony, and their offspring, over the course of the breeding season. He also incorporated variation in daily activity budgets related to breeding stages to estimate energy requirements for each day of the breeding season. He estimated the energy costs associated with different activities as multiples of mass-specific standard metabolic rate. He also ran Monte Carlo simulations to estimate the confidence limits of model output estimates and applied a sensitivity analysis. Tasker and Furness (1996) used year-around monthly estimates of numbers of birds in the North Sea along with improved knowledge of diets and energetics of seabirds to model total community consumption. Barrett *et al* (2006) estimated seasonal prey consumption by seabird communities in both the northwest and Northeast Atlantic (NAFO and ICES areas respectively) on the basis of species' population sizes and average productivity, the number of individuals of non-breeding species and the daily energy requirements and energy density of each species' prey. Whereas the confidence limits of the estimates of some input parameters (such as population sizes of some species) may be wide, such an approach does provide a useful first approximation to the estimation of prey consumption over large areas.

Over the last 15 years increasingly complex and realistic models have been developed to describe the foraging behaviour and energy budgets of birds feeding on shellfish (Goss-Custard *et al.*, 1995, 2004, Stillman *et al.*, 2000a, 2000b, 2001, 2002, 2003, West 2003). The construction of such models begins with a consideration of the foraging

behaviour and energy requirements of a single individual, and hence are termed "individual-based" or "behaviour-based" foraging models. However, in order to understand and predict the foraging requirements of local populations of birds, such models can also incorporate the effect of competition among individuals and the effect of resource depletion on intake rates of individuals in relation to their competitive dominance. For models of wader foraging, incorporation of such effects is essential to realistic model predictions (Stillman *et al.*, 2003). Foraging models can be geographically referenced, incorporating site-specific factors such as abundance of prey of difference size classes, bivalve shell thickness (which influences handling time and/or costs), tidal current strength, and average water depth, as well weather effects such a temperature. The outputs of such models may be framed in terms of the total prey harvest over the course of a specified time interval (typically a winter period, or annually). Complex models that realistically predict the foraging behaviour and survival consequences of Eurasian oystercatcher feeding on blue mussels *Mytilus edulis* have been developed for a number of estuarine areas in the UK and a similar approach has been adopted for common eiders feeding in the Dutch Wadden Sea (Brinkman *et al.*, 2003). Whereas the development of realistic individual-based foraging models is both time-consuming and computationally challenging, once developed, a model may be used to examine the effect of variation in the values of any of the model input parameters (the effect of low temperatures, lower prey abundance, change in the size distribution of prey, or higher predator numbers for example).

8.3 Model choice: simplicity vs. precision

Any bioenergetics model represents a trade-off between simplicity (and reliance on correspondingly few input parameters) and ability to reliably estimate the output parameters under a range of contrasting conditions. The most appropriate method to adopt depends on the following considerations:

> size of the area under consideration;
>
> number of species for which prey consumption is to be estimated;
>
> extent of dietary specialisation of the species concerned;
>
> level of precision of output estimates required;
>
> time-scale and resources available for model development; and
>
> existence of models for similar systems, which may be readily modified.

8.4 Approaches to estimation of blue mussel consumption by seabirds

8.4.1 Simple models based on daily bird abundance and energy expenditure

A first approximation to estimate the quantity of mussels consumed over the course of a particular time period by seaduck and herring gulls would be derived simply from the following formula:

> Mussel consumption (g, fresh weight) = (N x D x E x P) / (C x A)

where:

> N = average number of birds present each day within the area;
>
> D = number of days over which consumption is estimated;

E = total daily energy expenditure per bird (kJ);

P = proportion of daily energy requirement furnished by mussels;

C = calorie density of consumed mussels (kJ/g fresh weight); and

A = assimilation efficiency.

This is the method used by Hilgerloh 1997 to estimate consumption of blue mussels on tidal flats in Lower Saxony by common eider, herring gulls and Eurasian oystercatchers. It would be a useful exercise to undertake in the context of the Danish Wadden Sea and Natura 2000 sites in order to provide a crude, preliminary estimate of extent of blue mussel consumption by each species, especially the herring gull, for which an individual-based model would require development (though could be based on the models developed for Eurasian oystercatchers). However, caution should be exercised in the interpretation of estimates of mussel consumption obtained in this way: whereas this approach may give a crude indication of the prey consumption by seabirds in relation to the total mussel stock, or fisheries catch, the estimates may be misleading if used to assess the level of competition between seabirds and the fishery, for a number of reasons. Firstly, only a proportion of the standing crop of mussels is likely to be available to foraging birds due to upper thresholds on the size of mussels that may be ingested, and lower thresholds on the size that are energetically profitable. Further, mussels may be unavailable to seaduck for considerable periods of the tidal cycle, when they are either submerged too deeply to be accessible to species with limited dive depth capability such as common goldeneye. Herring gulls will only have foraging access during low tide. Constraints on food availability may therefore be imposed not by the total abundance of mussel stocks, but rather by time constraints on foraging or the availability of mussels of a suitable size.

8.4.2 Individual-based models

In order to more reliably establish the likely interaction between seabirds and fishery harvest, WGSE recommends the development of individual-based models with the following characteristics.

- they be geographically referenced (i.e. to incorporate relevant site-specific input parameters, such as mussel size distribution, current strength, ambient temperature) that will influence output parameters (energy expenditure and food consumption);
- they adequately reflect aspects of the species' prey selection, handling and digestion that influence foraging costs and gains, in particular any aspects that impose constraints on foraging intake;
- they incorporate any effects of intra- or interspecific competition on prey resources;
- they incorporate effects of temporal and/or spatial variation in the availability of alternative prey types (e.g. cockles), which will influence levels of mussel consumption;
- they produce quantitatively reliable predictions regarding the effect size of changes in the input parameters (such as prey density, size frequency, ambient temperature) on measurable aspects of foraging behaviour (such as number of hours required foraging), for simple model validation;

- they allow reliable prediction of the distribution of foragers within the study area and movement of individuals within or away from the area on the basis of variation in prey resources;
- that for seaduck, they simulate selection and handling of both individual and multiple mussels per dive and foraging on both tidal mussel beds and culture lots;
- they include Monte Carlo simulations to estimate the confidence limits around estimates of energy and food requirements as a measure of the precision of output estimates; and
- they include a sensitivity analysis to identify those input parameters which have large influence on model estimates and whose importance may have been overestimated, or to highlight particular input parameters for which improved estimates are required (Stillman *et al.*, 2000b). Such a sensitivity analysis can also identify parameters that have very little influence on model estimates, and which, if problematic or costly to obtain, may be considered for removal from the model.

8.4.3 Example of a suitable bioenergetics model for estimating mussel consumption by seaduck

The model described by Brinkman *et al.* (2003) provides a very suitable initial approximation to the model necessary to estimate energy requirements and mussel consumption by common eider and other seaduck. The model is written in Pascal and available on request from the senior author. The model estimates total energy and heat budgets (costs and gains) of an individual bird on the basis of prey size preferences (in turn related to handling profitability) and the energy costs associated with the following activities:

Basal metabolism

Thermoregulation

Swimming

Diving

Flying

Prey handling below water and at the surface

Heating of ingested prey to body temperature

Gastric crushing of prey

Digestion

Values of most energy costs have been obtained from the literature, with the exception of diving costs which are calculated from the physical properties of common eiders (buoyancy, drag etc). The energy consequences of selecting mussels of different size classes are estimated from the size-related costs associated with gastric crushing of mussel shells and the energy gains from mussels of different size. A simplified list of model inputs is given in Table 8.1. The daily energy budget over the course of the annual cycle was then calculated for non-breeding birds assuming that prey choice is based on size-related profitability, linked to the size-distribution of shell lengths available, with an upper limit on the size of shell that could be swallowed, and that mussels are selected and handled individually.

Table 8.1. Parameters for inclusion in a model suitable for estimating energy requirements and mussel consumption by seaduck, including common eider.

	INPUT PARAMETERS
Bird characteristics	Body temperature
	Body area
	Fat and feather thickness
	Body volume
	Buoyancy
	Body frontal area
	Body mass (seasonally variable, and upper and lower mass limits)
	Basal metabolic rate
	Energy cost of flight
	Energy cost of swimming
	Time in flight per day
	Time swimming per day
	Dive speed
	Swimming speed
	Flight speed
	Search time
	Handling time
	Assimilation efficiency
	Mussel shell-length preferences
	Costs of salt excretion
	Costs of mussel shell crushing (shell size-specific)
Site characteristics	Area
	Average water depth during submersion period
	Emersion time (fraction of tidal period)
	Density and average size class distribution of prey
	Prey fresh mass, shell mass and ash-free dry mass
	Monthly variation in prey relative abundance
	Salinity
	Monthly air and sea temperature, windspeed

8.4.4 Extension and refinements to the existing model

The following extensions and refinements to the Brinkman model are necessary to address the question of assessing energy requirements of seaduck foraging on mussels and the total mass of mussels necessary for the seaduck:

1) Extend the range of species parameterized to other mussel-feeding seaduck in the study areas: common scoter, velvet scoter, and common goldeneye, including terms to account for the proportion of mussels in the diet of each;

2) Extend the model to incorporate the energy costs and benefits of foraging on alternative shellfish, such as cockles *Cerastoderma edule*. The availability and profitability of alternative prey sources will greatly influence seaduck and herring gull predation on mussels and the effect of both temporal and

spatial variation in availability of other prey types should be incorporated. This is likely to be one of the most challenging aspects of the development of the existing model;

3) Obtain counts of number of ducks of each species in each area during the course of the year, as model input parameters;

4) Critically evaluate the current model assumption that intra- and interspecific interference/competion between foraging seaduck is trivial and can be omitted from the model. If substantial levels of competition exist, these should be incorporated into future model development. Incorporation of individual variation in competitive ability of oystercatchers in foraging models was found to be a crucial element in generating reliable model predictions of survival rates;

5) Verification of current model assumptions regarding the proportion of time spent flying. Because flying is energetically costly for a seaduck, the proportion of time spent in flight can greatly influence the energy budget. Further model development should include empirical determination of activity budgets of each species to improve the model input values for time spent in flight daily; and

6) Consider extension of the model to incorporate enforced movements of seaduck within and into/from the study sites. Numbers of seaduck preying on shellfish within particular sections of the sea areas under consideration may be determined by factors other than simple foraging profitability. For example, human disturbance may restrict or prevent access to some foraging areas, leading to higher levels of local predation and greater competition within areas that are accessible. Such external constraints may be minor and very local, and therefore insignificant at the scale of the areas considered, or they may exert a substantial impact on the overall levels of prey consumption realized.

8.4.4.1 Model validation

Empirical validation of complex foraging models that have been developed on the basis of time budgets and the energy costs of behavioural and physiological components is a challenging task. In theory, it would be possible to assess field metabolic rates using the doubly-labelled water method, and demonstrate that model predictions of energy consumption under the observed field conditions were in agreement with field measurements. However, the requirements of the technique (repeat capture of the same individual after a period of several days' normal activity) are impractical in the current context. A more pragmatic approach to model testing and refinement is to assess how closely the model predicts seaduck foraging behaviour under a range of observed field conditions (variation in temperature, differential availability of different prey types, the effect of disturbance increasing flight costs and reducing time available for foraging, etc). A poor model fit under particular circumstances may lead to a refinement of model structure or a revision of the form of the relationships between certain parameters.

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Annex 2: English and scientific names of birds mentioned in this report

King penguin	*Aptenodytes patagonicus*
Black-browe d albatross	*Thalassarche melanophrys*
Wandering albatross	*Diomedea exulans*
Laysan albatross	*Phoebastria immutabilis*
Southern giant petrel	*Macronectes giganteus*
Northern fulmar	*Fulmarus glacialis*
Cory's shearwater	*Calonectris diomedeas*
Cape Verde shearwtaer	*Calonectris e. edwardii*
Greater shearwater	*Puffinus gravis*
Sooty shearwater	*Puffinus griseus*
Manx shearwtaer	*Puffinus puffinus*
Balearic shearwater	*Puffinus mauretanicus*
Leach's storm-petrel	*Oceanodroma leucorhoa*
Peruvian booby	*Sula variegate*
Northern gannet	*Morus bassanus*
American white pelican	*Pelecanus erythrorhynchos*
Peruvian pelican	*Pelecanus thagus*
Brown pelican	*Pelecanus occidentalis*
Great cormorant	*Phalacrocorax carbo*
Guanay cormorant	*Phalacrocorax bougainvillii*
European shag	*Phalacrocorax aristotelis*
Common eider	*Somateria mollissima*
Common scoter	*Melanitta nigra*
Velvet scoter	*Melanitta f. fusca*
Common goldeneye	*Bucephala clangula*
Bald eagle	*Haliaeetus leucocephalus*
Ruffed grouse	*Bonasa umbellus*
Eurasian Oystercatcher	*Haematopus ostralegus*
Black-legged kittiwake	*Rissa tridactyla*
Ivory gull	*Pagophila eburnea*
Sabine's gull	*Xema sabini*
Audouin's gull	*Larus audouinii*
Herring gull	*Larus argentatus*
Lesser black-backed gull	*Larus fuscus*
Glaucous gull	*Larus hyperboreus*
Great black-backed gull	*Larus marinus*
Black noddy	*Anous minutus*
Sooty tern	*Onychoprion fuscatus*
Little tern	*Sternula albifrons*
Caspian tern	*Hydroprogne caspia*
Roseate tern	*Sterna dougallii*
Common tern	*Sterna hirundo*
Arctic tern	*Sterna paradisaea*

Sandwich tern	*Sterna sandvicensis*
Great skua	*Stercorarius skua*
Arctic skua	*Stercorarius parasiticus*
Long-tailed skua	*Stercorarius longicaudus*
Little auk	*Alle alle*
Common guillemot	*Uria aalge*
Brunnich's guillemot	*Uria lomvia*
Razorbill	*Alca torda*
Whiskered auklet	*Aethia pygmaea*
Crested auklet	*Aethia cristatella*
Atlantic puffin	*Fratercula arctica*
Tufted puffin	*Fratercula cirrhata*

Annex 3: WGSE Draft Terms of Reference 2010

The **Working Group on Seabird Ecology** [WGSE] (Chair: Jim Reid, UK) will meet at ICES HQ in Copenhagen, Denmark from 15–19 March 2010 to:

a) review the status of relevant seabird populations in relation to the OSPAR ecological quality objective (EcoQO) for seabird populations, and within the QSR 2010 and EU Marine Strategy Framework Directive contexts where appropriate;

b) update and extend the review of studies of the distribution and habitat associations of seabirds in ICES waters based on remote tracking of individual birds;

c) review progress towards a Community Plan of Action to reduce seabird bycatch in EU waters, and report any new data on fishing effort and seabird bycatch in these waters;

d) explore the use of demographic, behavioural and physiological data as early warning systems of population change in seabirds;

e) review the predicted interactions between parasites and climate change on seabirds;

f) review and summarize the literature on foraging interactions among seabirds, cetaceans, and predatory schooling fish, especially tuna, mainly in North Atlantic waters but with relevant material from all oceans;

g) review methodological approaches applied in, and progress with, the identification of marine protected areas for birds in EU waters.

WGSE will report by 20 April 2010 to the attention of SCICOM.

Supporting Information

Priority:	This is the only forum for work being carried out by ICES in relation to marine birds. If ICES wishes to maintain its profile in this area of work, then the activities of WGSE must be regarded as of high priority.
Scientific justification and relation to action plan:	All proposed Terms of Reference pertain directly to one or more of the high priority research topics contained in the three thematic areas of the ICES Science Plan.
	Term of Reference a)
	Convened in association with WGSE 2008, ICES WKSEQUIN recommended that WGSE review annually the status of selected seabird populations in the context of the EcoQO on seabird populations it has formulated. Development of the EcoQO was in response to a request by OSPAR, and was recommended by WGSE in 2001. For effective consideration of this proposed ToR, however, further development of the EcoQO would be necessary. The possibility exists for the EcoQO to serve as a model for similar initiatives under the OSPAR QSR 2010 report and biodiversity descriptors reporting under the EU MSFD.
	Term of Reference b)
	Identification of important seabird habitats is critically important for spatial planning and can help to identify Marine Protected Areas and area of common usage by seabirds and fisheries; tracking of individual birds using satellite tags and other data loggers is one of the most important sources of information available for this purpose.
	Term of Reference c)
	The EC is committed to prducing a Community Plan of Action to reduce the incidental bycatch of seabirds in EU waters. Bycatch affects many species of

seabird, including some critically endangered populations, but actual bycatch rates are not known with certainty for any species or regions. A crucial part of the Plan is to assess the extent of bycatch in all fishing gears. WGSE has recommended that fisheries effort data be made available for this purpose so that the proper analyses and application of the data be made.

Term of Reference d)

ICES WKSEQUIN recommended that WGSE review annually the status of selected seabird populations with regard to the EcoQO on seabird populations. Typically, there is a lag between environmental change and population change, so WGSE consider it useful to review intrinsic early warning systems of population change to provide more rapid assessments of environmental impacts.

Term of Reference e)

WGSE considers this issue to be of relevance because of current general interest in seabird-parasite interactions and in climate change in their own rights. However,, the impact of parasites on the behaviour and demography of seabirds in the specific context of climate change is of growing interest to the research community since increasing temperatures are expected to have profound effects on host susceptibility, pathogen survival, and disease transmission.

Term of Reference f

WGSE considers that a review of the feeding interactions and associations among top predators would be an important contribution to further understanding the ecosystem at a high trophic level, and would have policy-relevant applications in seabird, marine mammal and tuna conservation.

Term of Reference g)

WGSE first considered progress with marine Special Protection Area classification in 2003 and revisited the topic in 2006 and 2007. Since then, there has been rapid progress in application of novel techniques for identifying protected areas and also with classification of SPAs under the EC Birds Directive. In view of this and the higher profile being accorded ICES in the science behind implementation of European Directives, most recently the Marine Strategy Framework Directive, WGSE considers it timely to update its review of work aimed at identifying protected areas for birds at sea as required by the Birds Directive.

Resource requirements:	Facilities for WGSE to work at ICES HQ are anticipated to be excellent.
Participants:	Meetings of WGSE are usually attended by ca. 15 nominated and Chair-invited members. Although the Working Group should be able to achieve most of the above objectives, some members may not be able to attend through lack of funding. Funding of these members from Member Countries would be very welcome.
Secretariat facilities:	Routine office and IT support at ICES HQ.
Financial:	No financial assistance will be required for participation of nominated members of WGSE and venue costs. Funding of Chair-invited participants in the meeting would be very welcome.
Linkages to advisory committees:	ACOM
Linkages to other committees or groups:	WGSE is keen to continue the process of integration of seabird ecology into ICES.
Linkages to other organizations:	EU, OSPAR, HELCOM

Annex 4: Recommendations

RECOMMENDATION	FOR FOLLOW UP BY:
1. ICES to recommend to OSPAR that if the EcoQO on seabird populations is to be applied then its further development and quantification should be taken forward in a second WKSEQUIN workshop, and also that provision should be made via that workshop for the supply of seabird population data from OSPAR states to WGSE annually	ACOM
2. ICES to recommend to the European Union that the formulation and implementation of a Community Plan of Action to mitigate the incidental catch of seabirds in fisheries operating in EU waters continue to be progressed, and that the comments and observations relating to the draft *pro forma* for recording of fisheries effort and bycatch contained in this report be forwarded to the EU as soon as possible	ACOM
3. That the WGSE Sharepoint sites (and those of other EGs?) be reorganized to allow easier access to older WGSE material, including older reports. Currently there are two WGSE Sharepoint sites – one for the 2008 meeting and one for the 2009 meeting. WGSE recommends that a single site be established within which older and archive material be hosted in separate folders for each year.	ICES Secretariat

Annex 5: Technical Minutes RGPROT 2009

Review of the Report of the Study Group of Bycatch of Protected Species (19-22 January 2009) and the report of Working Group on Seabird Ecology 2009 (March 2009)

Reviewers: Nicole LeBoeuf, Henrik Skov (Chair), and Paul Thompson

Audience to write for: These comments are to be provided to the Advice Drafting Group on Protected Species for consideration at its meeting on 12-13 May 2009

Review of Quality Assurance Arrangements for Select EcoQOs

OSPAR 5 asked ICES to review the quality assurance arrangements for the following EcoQOs and make suggestions for their further development and/or improvement on:

- i) oiled guillemots
- ii) harbour seal population trends; and
- iii) grey seal pup production

The Working Group on Marine Mammal Ecology was requested to review the geographical subunits for these EcoQOs, taking into account biologically appropriate management units for seals in the North Sea. The Working Group reviewed available information in order to propose biologically appropriate management units for seals in the North Sea.

For harbour seals, the Working Group recommended the use of the following four management units within southern Scandinavia waters in the North Sea area:

- 1) Skagerrak,
- 2) Kattegat,
- 3) central Limfjord, and
- 4) the Wadden Sea.

This proposal splits the current EcoQO sub-unit Kattegat, Skagerrak and Oslofjord. The Working Group further recommended slight alterations to the UK EcoQO sub-unit names to more accurately describe the areas that are monitored most frequently. These recommendations are contained within Chapter 6 of the Report of the Working Group on Marine Mammal Ecology (2-6 February 2009).

The Working Group further recommended that genetic studies of harbour seals be carried out in areas where such information is lacking, in particular for populations were hunting is conducted, and that samples for genetic analyses should be obtained from breeding sites whenever possible.

For grey seals, the Working Group recommended maintaining the current OSPAR EcoQO grey seal sub-units, as outlined in 2007 OSPAR handbook. The Working Group also recommended slight alterations to the UK EcoQO sub-unit names to include two recently established colonies from Norfolk, as well as a re-naming of the German sub-unit. Lastly, the Working Group recommended the removal of the grey seal "French North Sea and Channel coast" sub-unit as they may not actually be geographically within the boundary of the North Sea.

The Working Group on Marine mammal Ecology recommended that a Northeast Atlantic wide genetic study of grey seal population structure be initiated by coordi-

nating the activities already ongoing in the distribution area of the species, using standardized genetic markers.

With regard to data needed to support EcoQO sub-units for both species, the Working Group noted that regular surveys are required to determine trends for all harbour and grey seal management sub-units and that removal of harbour and grey seals, catch and bycatch, should be recorded for all sub-units.

The proposed revision of harbour seal population units appears sensible and pragmatic based upon the available data. However, it should be noted that the finer-scale scale sub-division of Scandinavian populations is based on more recent and powerful analyses than those used for earlier studies of other ICES areas. Rather than calling of additional work in those areas where data are currently lacking, it may be beneficial to encourage a wide scale analyses of all populations of interest, and use a common analytical approach to identifying population sub-units.

Quality assurance guidelines have not previously been established for harbour and grey seal EcoQOs, although the Working Group noted that the EcoQO trigger levels were specified to detect declines in their populations. The Working Group recommended that power analysis should be used to assess the effectiveness of the existing survey schemes, relative to the specific EcoQO.

For grey seals, the Working Group recommended that the EcoQO be changed for the Wadden Sea using moult counts instead, noting, however, the importance to continue efforts in obtaining pup count data. UK.

For harbour seals, the Working Group noted that although the EcoQO was triggered in a number of sub-units in 2007, they were unaware of actions taken or advice provided by OSPAR in response to this. The Working Group recommended feedback from OSPAR, in an appropriate time frame, when EcoQOs are triggered and asked that OSPAR and ICES encourage and support the responsible entity (e.g. *governments)* to take appropriate action when such triggers are reached.

The report correctly highlights that existing survey schemes for harbour seals proved suitable for detecting declines of 11–40%. What is less clear is how sampling frequency affects the power of these schemes to detect *when* changes in population growth occurred. Given the importance of this information for understanding the drivers of such change, it would be useful if power analyses included simulations to compare the ability of different survey schemes to identify the year in which populations started to decline.

The report discusses the difficulties of reporting N. Sea wide trends when different survey schemes are used in different sub-populations. Whilst differences in the frequency of surveys make the integration of these different time-series more complex, it should be possible to develop a statistical framework that can be used to model overall trends. Perhaps the development of such a framework could form an additional recommendation.

The Working Group on Seabird Ecology addressed actions that may be taken to ensure the highest probability of reaching the EcoQO for oiled guillemots. Firstly, the Working Group noted that quality assurance guidelines have not yet been established for the oiled guillemot EcoQO, indicating that some such guidelines should be established in order to adequately assess trends in the oiled guillemot EcoQO. The Working Group noted that the EcoQO refers to both dead and dying birds. Because living birds could escape, and therefore not be available for determination of age or

oiling status, thereby biasing the ratio of oiled to unoiled birds, the Working Group recommended that living birds should not be included in the sample of oiled birds and that the wording of the EcoQO would have to be modified accordingly.

The reviewers agreed that biases could be introduced into the evaluation of the EcoQO via the escape of live birds that are not sampled. However, as the Working Group also noted, the common guillemot is the species most frequently found oiled on beaches surrounding the North Sea, and is therefore an appropriate choice for an EcoQO aimed at monitoring of chronic oil pollution. This being the case, the reviewers recommend that the Working Group consider some mechanism by which oiled, live birds may also be taken into account. Chronic oil pollution, rather than the acute impacts of an oiling event, may result in sublethal effects to birds that are also important to document. The Working Group may also wish to remind OSPAR contracting parties of the potential chronic, sublethal effects of oil pollution on seabirds, encouraging the sampling of live birds within each nation's own study protocols, although not for the purposes of this EcoQO. With this in mind, The Working Group should consider addressing this issue within their review of the quality assurance guidelines by drawing a distinction between what is to be gained from the analyses of dead oiled specimens versus live oiled specimens.

The Working Group noted data collection challenges, such as the aging of guillemots, and recommended that each country appropriately train those recovering the specimens and collecting samples in the relevant identification techniques, including, where necessary, organising training for volunteers to judge on acceptability (in terms of freshness) and age of the corpses, proper detection of oil on bird plumages, and other information that is to be recorded. The reviewers strongly support this recommendation, as well as the Working Group's recommendation that OSPAR contracting parties seek to standardize the time of year during which the data is collected. Where this is not possible, the reviewers agree that analysis of seasonal fluctuations by sub-regions is recommended.