BTO Research Report 414

Climate Change and Migratory Species

Authors

Robert A. Robinson[1], Jennifer A. Learmonth[2], Anthony M. Hutson[3],
Colin D. Macleod[2], Tim H. Sparks[4], David I. Leech[1],
Graham J. Pierce[2], Mark M. Rehfisch[1] & Humphrey Q.P. Crick[1]

A Report for Defra Research Contract CR0302

August 2005

[1] British Trust for Ornithology, The Nunnery, Thetford, IP24 2PU
[2] Department of Zoology, University of Aberdeen, Tillydrone Avenue, Aberdeen, AB24 2TZ
[3] IUCN - SSC Chiroptera Specialist Group
[4] Centre for Ecology & Hydrology, Monks Wood, Abbots Ripton, Huntingdon, Cambridgeshire, PE28 2LS

British Trust for Ornithology, The Nunnery, Thetford, Norfolk, IP24 2PU
Registered Charity No. 216652

CONTENTS

LIST OF TABLES, FIGURES AND APPENDICES

TABLES

FIGURES

APPENDICES

EXECUTIVE SUMMARY

Background

Our climate is changing and there is already compelling evidence that animals and plants have been affected. We conducted a literature review and consulted experts through a specially organised international workshop to identify the range of climate change impacts and to consider how migrant populations could be affected by these changes. The primary instrument for migratory species conservation is the Convention on the Conservation of Migratory Species of Wild Animals (CMS) and its daughter Agreements and Memoranda of Understanding. Several other international policy instruments cover some migratory species, but only the Ramsar Convention (an agreement concerning wetland site protection) explicitly mentions climate change.

Knowledge of the likely impacts of future climate change varies greatly between taxonomic groups, being best for birds. Of the bird species listed on the CMS, 84% face some threat from climate change, almost half because of changes in water regime; this is equivalent to the (summed) threats due to all other anthropogenic causes. Further understanding of how populations will respond, through knowledge of climate impacts on breeding performance and survival, will be necessary for successful predictions of impacts. However, understanding of this is poor for all groups of wildlife, particularly because breeding performance and survival often vary with population density to an unknown extent. Although it is thought that no species has yet become extinct solely because of climate change (Golden Toad is a possible exception), many extinctions (of both migratory and non-migratory species) are predicted in the future.

Climate Change Impacts on Migratory Species

Changes in range are widely documented in all taxa, with distributions of most shifting polewards. The incidence of ‘southern’ species, such as the Little Egret (a bird), Loggerhead Turtle and Red Mullet (a fish) is increasing in the UK. The wintering areas of bird populations are changing as a result of climate-driven changes in migratory behaviour. In response to warmer temperatures, many waders, such as the Ringed Plover, are now wintering on the east of Britain (closer to their breeding grounds) rather than the west coast. Increasing numbers of European Blackcaps are now migrating west to Britain rather than south, and Chiffchaffs are remaining in the UK over winter (rather than migrating south). Climate change will alter the probability of invasive and alien species establishing, which may have important effects on local biodiversity.

Barriers to migration may become more severe in response to climate change. Many migratory birds use the Sahel region of Africa to refuel before crossing the Sahara Desert. Decreased precipitation and over-grazing is causing increased desertification and reduced vegetation quality; breeding numbers of species such as Whitethroat are substantially lower in drier years, so further declines in trans-Saharan migrants might be expected with climate change. Interactions between climate change and human exploitation are widespread, though poorly quantified. For example, changes in migratory journeys of Wildebeest in Africa are hampered by the presence of park fences; changes in rainfall patterns in Southern America are leading to the construction of dams that are proving a major barrier to the migration of the Tucuxi (a river dolphin). Many waterbirds are reliant on a network of a few, widely separated wetland sites for migration, which are at risk from rising sea-levels. Many sites also face development and increasing water abstraction (due to climate change), exacerbating direct climate-driven threats.

A major conservation concern is for arctic and montane species (most of which are migratory), the distributions of which cannot shift further north in warmer climates. Many migratory waders, such as the Red Knot, face large population declines and some, such as the endangered Spoon-billed Sandpiper, face extinction. Among mammals, Polar Bear and northern seals are of key concern through the loss of Arctic sea ice. Sea-level rise is leading to loss of beaches used by nesting turtles (32% of beaches used by nesting turtles in the Caribbean could be lost with 0.5m sea-level rise) and seals (e.g. the endangered Mediterranean Monk Seal) and loss of shallow coastal areas used by whales, dolphins, dugongs and manatees (e.g. White-beaked Dolphins require cold water less than 200 m deep).

A major effect of climate on migratory (and other) species will be changes in prey distribution, some of which are already well documented. Such changes are a major threat in marine ecosystems. Large shifts in distribution (as much as 10° latitude) and abundance (with declines to a hundredth or a thousandth of former values) of plankton communities in response to changes in sea surface temperature have already been demonstrated (particularly for Krill, a key component of marine foodwebs). These changes have resulted in changes in the distribution and abundance of many marine species, such as Cod, Salmon, Long-finned Pilot Whale, Kittiwake and a number of penguin species. Breeding seals are particularly vulnerable to such climate change effects as they are dependent on access to relatively undisturbed haul-out sites that are within access of abundant prey.

Changes in the timing of many life history events are well documented. For example, migratory British birds are arriving in breeding areas two to three weeks earlier than thirty years ago. Laying dates have also advanced for both birds and turtles. However, changes in laying date of migratory birds (typically 2d/1^{o}C) appear to be less than changes in vegetation and invertebrate phenology (typically 6d/1^{o}C) which may lead to a mismatch between the birds and their prey. There is good evidence for this in some populations of birds, particularly Pied Flycatcher, but these effects can be regionally specific. In consequence, there is evidence that long-distance migrant birds, such as the Swallow, may be less able to adapt their phenology than short-distance migrants, such as the Chiffchaff. Warmer winters are encouraging the earlier emergence of bats from hibernacula but the population impacts of this are unknown.

Fecundity in bird species is positively related to temperature, and long-term increases have been reported in many species, such as the Pied Flycatcher, while cetaceans have lower fecundity in warmer waters (reduced fecundity of Sperm Whales during warm water El Niño events, gives some indication of future trends). To what extent populations will be able to adapt to these changes by shifting distribution is unknown. Sex ratios of hatchling turtles are dependent on temperature and increased warmth could potentially lead to all-female populations. Survival of individuals is also strongly related to climatic conditions. Amongst birds, warmer winter temperatures are likely to increase survival in those that winter in northern latitudes, as has been seen for some wader species, while those that winter in southern latitudes are likely to suffer from reduced precipitation. There is also the potential for changes in patterns of disease transmission as a result of climate change effects on the distribution of vectors and the growth of pathogens – but this is an area of great uncertainty due to lack of knowledge; potential examples include large-scale mortality of cetaceans and seals in the Mediterranean and North Sea over the last decade and increases in Fibropapilloma tumours in Green Turtles.

Changes in population size are a combination of changes in survival and breeding performance and the impact of climate change will depend on the relative balance of these two factors. For example, in one colony, increased sea surface temperatures meant that Emperor Penguins had to forage further from the breeding colony (reducing survival), but the penguins benefited from increased hatching success; the effects on survival were greater and colony size declined. In general, changes in survival and fecundity will interact with population density, and thus quantitative scenarios of changes in population size will require further development.

Future Priorities

In terrestrial systems, changes to water regime (e.g. increased water abstraction and drought frequency) and loss of vulnerable habitat (particularly Arctic tundra) are likely to affect the greatest number of migratory species. While adaptation (through habitat management) to climate change may bring benefits in terrestrial ecosystems and to some extent in marine systems, but mitigation of emissions will be required to achieve significant benefits in the marine environment. In many cases, a reduction in anthropogenic impacts (such as over-exploitation or habitat loss) will help taxa to adapt. More generally, maintenance of large population sizes to provide sufficient variation will allow populations the greatest chance of adapting. In terrestrial taxa, some migratory species require a coherent network of discrete sites and hence appropriately flexible site management in response to changing conditions. Others will require continuous habitat corridors and broad-scale land-use planning. Changing patterns of human exploitation in response to climate change are a major threat and conservation measures need to take these into account, both as threats and as opportunities for providing benefits through multi-functional ecosystem management.

A commitment to long-term support of monitoring schemes is critical to ensure best value, by utilising existing data collection networks (with standardised protocols), both in detecting long-term climate change impacts and monitoring the success of adaptation measures. There is also a need to collate information on migratory stopover sites to identify coherent migratory networks and target site conservation action. Targeted implementation and enforcement of existing measures should provide much of the protection needed, as would the broader use of existing guidance codes. Frameworks for integrated land-use planning exist in a number of different parts of the world, and they could valuably be developed and implemented more widely.

EXTENDED SUMMARY

1. Introduction

1.1. Climate change is one of the major factors likely to affect the earth's ecosystems in the coming decades[43,35]. The increase in global temperature in the 20th century was the largest in any century during the past 1,000 years and this has been associated with changes in weather patterns, precipitation, snow cover, sea-temperatures and sea-level.

1.2. There is already compelling evidence that animals and plants have been affected by recent climate change[79,53,35]. Migratory species, by travelling large distances, being subject to a wide range of environmental influences and relying on a wide range of natural resources, are particularly likely to be affected by climate change at some point in their life cycles. These may be effects that apply to all species in that area, or effects that are specific to migrants

1.3. This review aims to (i) assess the strength of current scientific evidence of links between climate change and migratory species' behaviour, abundance and distribution, (ii) identify what effects climate change has had, and may have in the future, on migratory species (iii) identify which species are threatened by climate change and comment on the measures proposed to tackle such threats and (iv) comment on the reliability or uncertainty of predicted effects.

1.3. The UK Government is party to a number of international treaties and agreements that seek to promote and maintain the conservation status of migrant species of wildlife and Defra takes a lead role for the Government in these areas, with the Convention on the Conservation of Migratory Species of Wild Animals (CMS) being the primary instrument of interest. In this review, we focus on migratory species which occur in the U.K. or its Overseas Territories (UKOTs).

1.4. For the purposes of this review, we follow the CMS in defining a migratory species as one in which 'a significant proportion of whose members cyclically and predictably cross one or more national jurisdictional boundaries'.

1.5. Although climate change may have effects on individual patterns of behaviour and physiology, from a conservation perspective impacts on population size and dynamics are of most interest. Thus changing climatic factors are most relevant if they impact on an organism's capacity to survive or to reproduce. We use the term 'impact' where a consequence for population size is likely, an effect where species biology is altered, but not population size directly.

2. Legislative Framework

2.1. The primary instrument for migratory species conservation is the Convention on the Conservation of Migratory Species of Wild Animals, signed in Bonn, Germany in December 1979, and since ratified by 91 parties (as at 1 July 2005; www.cms.int). Indeed, it is the only global intergovernmental convention that is established exclusively for the conservation and management of migratory species. It is a framework document supported by a Secretariat under the auspices of the United Nations Environment Programme and progressed through a triennial Conference of Parties.

2.2. The CMS recognises that states have a duty to protect migratory species that live within or pass through their jurisdictional boundaries and that their effective management requires concerted action from all states in which a species spends any part of its life-cycle (the 'Range States'). It provides for the protection of endangered species (listed on Appendix I) and for those that would benefit from internationally co-ordinated efforts (Appendix II).

2.3. The strength of the CMS is in its framework nature, under which daughter agreements can be concluded to provide specific coverage for particular groups. To date, six legally binding Agreements and seven formal (but non-binding) Memoranda of Understanding (MoU) between appropriate Range States have been concluded.

2.4. The Agreements cover European species of bats and cetaceans, seals in the Wadden Sea and two groups of birds, the oceanic albatrosses and petrels and migratory waterbirds that use the African-Eurasian flyway.

2.5. The MoU cover marine turtles (in African waters and the Indian Ocean), four species of birds (Siberian Crane *Grus leucogeranus*, Slender-billed Curlew *Numenius tenuirostris*, Great Bustard *Otis tarda* and Aquatic Warbler *Acrocephalus paludicola*) and one terrestrial mammal (Bukhara Deer *Cervus elaphus bactrianus*).

2.6. The Convention on Biological Diversity (CBD, www.biodiv.org) drawn up at the Earth Summit in Rio de Janeiro in 1992 has been ratified by 188 states and endorsed the aim of achieving 'by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on earth'. The UK has been successful in agreeing Action Plans (www.ukbap.org.uk) for 391 species, some covered by CMS and some habitats used by migratory species. Progress in the UK Overseas Territories (UKOTs) has been slower (and the British Antarctic and Indian Ocean Territories are excluded), but should be enhanced through the launch, in 2003, of the Overseas Territories Environment Programme to support the implementation of the Environment Charters within each Territory as well as Multilateral Environment Agreements.

2.7. Other instruments that affect migratory species include the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, www.cites.org), the United Nations Convention on the Law of the Sea (fish and cetaceans), the Migratory Bird Treaty Act (North America only, http://migratorybirds.fws.gov) and the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar, www.ramsar.org). This latter is particularly important for migratory birds, as most waterfowl are migratory. Also relevant, particularly for conserving habitat used by migratory species are the European Wild Birds (79/409/EEC) and Habitats (92/43/EEC) Directives, the Bern Convention on the Conservation of European Wildlife and Natural Habitats and Antarctic treaties, such as the Commission for the Conservation of Antarctic Marine Living Resources.

2.8. The Ramsar Convention is the only international instrument protecting migratory species that makes explicit reference to climate change calling upon parties, *inter alia*, to 'manage wetlands to increase their resilience to climate change and extreme climatic events, and to reduce the risk of flooding and drought in vulnerable countries, through promoting wetland and watershed and protections' and to 'make every effort when implementing the Kyoto protocol, including re-vegetation and afforestation, that this implementation does not lead to serious damage to the ecological character of their wetlands'[4]. Wetlands provide critical stopover areas for many bird species listed on the CMS.

3. Projected Climate Change

3.1. Our climate is changing[1]. The global average surface temperature has increased over the 20th Century by around 0.6˚C and precipitation has increased over the same period, particularly over mid- and high-latitudes. These have had secondary impacts, for instance the extent of ice cover has decreased and global sea-level is rising. Such changes are demonstrable.

3.2. The climate system comprises of a number of components: the atmosphere, oceans, land surface, cryosphere (ice areas) and biosphere (including human influences). Each of these systems is the result of a large array of drivers, and climate is a result of complex interactions between each of the components. Global Climate Models (GCM), which simulate the physical processes involved, are used to predict future changes under given scenarios of possible changes in greenhouse gas and other aerosol emissions. Regional Circulation Models, which build detail onto a GCM framework, have been used in certain areas, such as the UK, to provide more detailed inference of future climate changes.

3.3. The Intergovernmental Panel on Climate Change (IPCC) was formed by the World Meteorological Organisation and the United Nations Environment Programme, to provide a co-ordinated and broadly agreed consensus view on global climate processes. As part of its Third Assessment Report, it developed a series of marker scenarios (or alternative futures), which capture the broad range of variability of all scenarios that have been presented in the literature, for use as a basis in predicting the amount of greenhouse emissions and subsequent climate change[52]. These scenarios describe broad dichotomies between development of economic and environmental objectives and between global and regional development. Each narrative assumes a distinctly different direction for future developments, but together they encompass the range of underlying uncertainty in the development of the main driving forces behind climate change. No likelihood of occurrence can be assigned to each of these narratives, so each is considered equally plausible.

3.4. In climate change models, to avoid the effects of annual fluctuation, model results are usually averaged over a period of years. Thus, simulations usually run from the 'present' (1961-1990) until the period 2070-2099, referred to as the 2080s. Globally, temperatures are expected to increase over the next century, with the projected increase expected to be somewhere in the region of 1.4 to 5.8 °C[43]. This projected rate of warming is much larger than the observed changes during the 20th century. Warming is likely to be greatest over land areas, particularly at northern high latitudes in winter and lowest in southeast Asia (summer) and southern South America (winter). Global average precipitation is also likely to increase during the 21st century, however, there is likely to be much regional and seasonal variation and there is also more uncertainty in the magnitude of change[43].

3.5. Predictions for small island territories (such as the UKOTs) from large-scale GCMs are uncertain. The projected degree of warming is similar across UKOTs (in the order of 1 to 3 °C, but possibly higher[50,65]), with the two territories in the Mediterranean region (Gibraltar and the Cyprus SAFB) likely to experience a greater degree of warming; the South Atlantic Islands show least projected warming. Precipitation levels are likely to decrease generally in the two Mediterranean territories. Amongst the Caribbean territories, projections are mixed[50,65], but there is a tendency towards an increase in precipitation in the autumn and winter months (September through February) and a decrease in the summer months.

3.6. The Caribbean territories will be influenced by changes in the El Niño Southern Oscillation (ENSO), influences that will occur more broadly[7]. Warm episodes of ENSO have been more frequent, persistent and intense since the mid-1970s, leading to greater extremes of drying and heavy rainfall and increasing the risk of droughts and floods. It is uncertain whether there will be an increase in the frequency of tropical cyclones, but it is likely these will become more intense, with greater peak wind speeds, more intense rainfall and greater storm surges.

3.7. Climate change scenarios also suggest the North Atlantic Oscillation (NAO) will become more positive in the future, resulting in more wet, windy, mild winters along the north eastern Atlantic seaboard[43]. Associated with these shifts in large-scale climate patterns there is likely to be a greater frequency in the formation of storms; wind speeds and wave size have increased over the North Sea.

3.8. There is consensus on the broad pattern of climatic changes in the UK[42] and Europe[25,54],summarised in Table 1. Temperatures are likely to increase (but see 3.11), precipitation will decrease in summer and increase in winter and the frequency and severity of extreme events (e.g. floods, storms) will increase. The UK climate is already beginning to alter in these directions, though these changes may still be within the 'normal' range of variability.

3.9. As the UK is home to many migratory birds from Scandinavia and the Arctic (that spend their winter in the UK) and some UK breeders spend the winter in southern Europe or Africa, the climate in these areas also needs to be considered[11]. Temperatures are likely to increase markedly in northern latitudes and in Africa[43,50]. Precipitation in Africa, upon which vegetation is particularly dependent, is likely to decrease, particularly in western and southern Africa, where most of the UK bird populations spend the boreal winter[43,50].

3.10. Global ocean heat content has increased significantly since the late 1950s, with more than half of this increase in the upper 300 m of the ocean[43]. The North Sea is also warming, with an increase in annually averaged temperature of about 0.6°C over the past 70 to 100 years, most occurring in the last 20 years[42]. The temperature of UK coastal waters will continue to rise, although not as rapidly as over land.

3.11. There has been a retreat of sea-ice extent in the Arctic spring and summer by about 10 to 15% and a 40% decline in sea-ice thickness[43]. In the Arctic more freshwater from melting snow and ice will be released into the North Atlantic, through the Fram Strait between north-eastern Greenland and Svalbard, which may exert a strong influence on salinity in the North Atlantic and alter large-scale currents and circulation. Most models show a weakening of the thermohaline circulation in the North Atlantic leading to a reduction of heat transport into high latitudes of the Northern Hemisphere; scenarios predict a weakening of the Gulf Stream, perhaps by as much as 25% by the 2080s[43]; it is unlikely to stop completely[42].

3.12. Changes in seawater salinity are expected, but these will be regionally variable, and dependent on circulation patterns. For example, the salinity of Scottish oceanic waters has generally increased[75], indicating the arrival of warmer, saltier waters from further south in the Atlantic, however in the southern North Sea fishing areas there is an apparent trend of decreasing salinity linked to increasing freshwater inputs from coastal rivers.

3.13. Tide gauge data show that global average sea level rose between 0.1 and 0.2 m during the 20th century[43]; in the UK sea level has risen by 0.1 m[42]. Global mean sea level is projected to rise by 0.09 to 0.88 m by the 2080s, through, for example, the geographical variation in thermal expansion and changes in salinity, winds and ocean circulation; regionally, there is much variation. Sea-level rise will be an important consideration for low-lying coastal states (such as many of the UKOTs)[65,34].

4. Impacts of Climate Change – General Patterns

4.1. The knowledge of the likely impacts of climate change varies greatly between taxonomic groups (Table 2). There is much knowledge, and some degree of confidence about the impacts on bird populations, less so for all other groups. The general patterns noted here are expanded in the next section.

4.2. Many of the impacts of a changing climate will apply to species irrespective of their migratory status, thus consideration of migratory species cannot be done in isolation from non-migratory taxa. However, migratory species face additional constraints relating to the length of the migratory journey and conditions *en route*, particularly the location and quality of stopover areas, where sufficient food must be available for the next leg of the journey.

4.3. A useful distinction is between 'broad-front' migrants, which migrate in short hops, stopping frequently on route, and often have geographically diffuse migration routes (most bats, insects, passerine birds and marine animals) and 'leap' migrants, which migrate in long-haul journeys stopping at only a few, usually discrete, sites, such as wetlands, often in large numbers; the primary example of these would be migrating shorebirds and waterfowl.

4.4. Species have three possible responses to climate change: (i) change geographical distribution to track environmental changes; (ii) remain in the same place but change to match the new environment, through either a behavioural response, such as shifts in phenology (for example timing of growth, breeding etc.) or a genetic response, such as an increase in the proportion of heat tolerant individuals; or (iii) extinction. Examples of geographical shifts[53,63] and behavioural changes[53,22] as a response to changing climates have been documented, but no species has unambiguously become extinct because of a changing climate yet, although the Golden Toad *Bufo periglenes* may be one such case[58] and many are predicted[74].

4.5. Many of the impacts of a changing climate are likely to be species-specific and related to particular ecological aspects of individual taxa, necessitating a species-based approach. However, some impacts will be important across all, or some, species groups (Table 3).

4.6. Changes in range are perhaps the most widely documented effect of climate change and have been demonstrated in a number of groups[53,62]. Such changes are relatively easy to measure and because climate is a fundamental determinant of whether an area is suitable for occupancy.

4.7. Further changes in distribution are predicted, often using an 'envelope' approach, i.e. defining current bioclimatic habitats occupied and modelling how these shift[11,37], however, habitat occupancy (and other) relationships may change in future, particularly if future conditions are outside the currently observed range. Understanding the actual mechanisms and population processes behind the observed patterns will be the only way to understand how these relationships will operate in future.

4.8. Changes in prey distribution are equally common (though sometimes less well documented because of poorer data) and will have widespread effects on the distribution and survival of species at higher trophic levels (i.e. predators). These changes might be spatial (through changes in range), or temporal (through differential changes in development rates), and lead to a mismatch between prey abundance and the need for resources.

4.9. Habitat loss and, importantly, changes in habitat quality will affect all species, but are likely to be particularly important for migratory species that need a coherent network of sites to facilitate their migratory journeys[57]. Habitat quality is particularly important on staging (stopover) sites, as individuals may need to consume a large amount of resource rapidly to continue their onward journey, particularly if this involves crossing an ecological barrier. In some cases migratory species will be better able to cope than others if their increased mobility enables them to exploit new situations.

4.10. Migration itself is a response to ecological conditions, and in many species is a flexible and adaptable trait[75]. Changes in the length, timing and location of migratory routes in response to changing climatic conditions have been documented[12]. These are leading to changes in patterns of occurrence in a wide range of taxa, including birds, turtles, cetaceans and insects[53].

4.11. The timing of migration occurs in the context of other life-history activities, such as breeding, moult or hibernation (depending on group). Changes in the timing of breeding are widely documented[22,29], and migratory species face additional constraints in adapting to this. Equally, changes in the nature of the migratory journey (particularly if it lengthens or becomes more difficult because of fewer resources) will have consequences for successful breeding, moult etc. These effects are poorly understood at present[20].

4.12. By altering distributions, climate change will bring some species into conflict with human activities, particularly amongst migratory species, which use a network of sites, and may constrain their ability to adapt to changes. Conversely, anthropogenic responses to climate change are likely to exacerbate the impacts on wildlife caused by changing climatic conditions, e.g. through increased water abstraction, changes in agri- or silviculture, or changes in fishing patterns.

4.13. Changing climatic distributions will extend the range of many species, but it will also increase the probability of introduced ('alien') establishing. These may have significant impacts on local communities and biodiversity.

4.14. Although the scenarios of climate change are generally within the known range of historical conditions, the rate at which they are changing is unprecedented, so organisms may be unable to adapt sufficiently rapidly[35].

4.15. Few measures specifically targeted at adapting to climate change impacts have been undertaken at present, though many undertaken for other reasons, such as the creation of habitat corridors (6.5) have been shown to be beneficial. 'Managed Realignment' of coastal defences in the face of rising sea-levels has been undertaken in the U.K.[5]. In the short-term these have not been very successful at re-creating bird inter-tidal communities, but properly designed programmes hold much potential for the longer term[5,83].

5. Impacts of Climate Change on Migratory Species

a. Marine Invertebrates, Fish and Turtles

5.1. Changes in distribution, abundance and community composition of fish and marine invertebrates, such as squid, are strongly related to sea temperature, as these species are ectothermic (i.e. unable to regulate their body temperature internally) and changes in temperature have caused changes in distribution of both exploited and non-exploited species[55] and in the recruitment of Atlantic Cod *Gadus morhua* in the North Sea[68].

5.2. Recruitment of Herring *Clupea harengus* and Squid are linked to climatic conditions[10,56] (through temperature impacts on the plankton ecosystem), with higher recruitment in warmer years, when migratory movements of Herring are also shorter. Increasing temperatures can therefore be expected to increase recruitment of at least some marine species.

5.3. The distributions of many marine species are associated with fronts between waters masses, and shifts in the location of these can have impacts on patterns of recruitment, which may impact on population size. However, increased temperatures will affect ocean circulation and the strength of marine upwellings, which is predicted to decrease global fish production[79].

5.4. The only fish listed on the CMS Appendices are the anadromous (migrating between freshwater and marine systems) sturgeons (Acipenseridae), the impacts of climate change on which are unstudied; their main relevance to CMS listed species is as prey to marine mammals.

5.5. Nesting biology of sea turtles is strongly affected by temperature, both in timing and in the sex-ratio of hatchlings[39], but the impacts of this on overall population size are unknown at present, though population structure is likely to be impacted with an increase in the relative number of females.

5.6. The range of many migratory turtles is shifting (or at least expanding) northwards, with an increasing number of records from UK waters[2]. These include five species listed on CMS Appendix I (Loggerhead *Caretta carreta*, Green *Chelonia mydas*, Leatherback *Dermochelys* *coriacea*, Hawksbill *Eretmochelys imbricata* and Kemps' Ridley *Lepidochelys kempii* turtles). While the population impacts of this increased movement are unclear, the number of Range States with a conservation interest in these species will increase.

5.7. Sea turtles are likely to be directly impacted by an increase in sea levels and the loss of egg laying beaches. Under a predicted sea-level rise of 0.5 metres this will amount to up to 32% of nesting beaches in the Caribbean[34].

b. Marine Mammals

5.8. Most cetaceans (whales and dolphins) are highly migratory, the larger baleen whales e.g. Blue Whale *Balaenoptera musculus*, undertake long seasonal migrations between tropical calving grounds in winter and high latitude feeding grounds in summer, as a response to the need to feed in colder waters and reproduce in warmer waters[49]. Movements of toothed whales (such as the Sperm Whale *Physeter macrocephalus*, Killer Whale *Orcinus orca* and dolphins) have different scales depending on geographic areas and species, with both north-south and inshore-offshore seasonal movements observed, probably in response to prey availability[49]. Dispersal and migration is also common in several pinniped (seal) species[49]. However, migratory journeys are poorly known (see Sperm Whale Case Study).

5.9. Changes in plankton, fish and squid (which are prey for cetaceans and pinnipeds) distribution, abundance and community composition are strongly related to climatic factors, particularly sea temperature (see 5.1 to 5.3 above). Shifts in plankton and fish community composition in the North Sea have been observed in plankton and fish communities[55,10], and reflected in changes in the cetacean community, with a greater representation of southern-water species further north[49]. Similar shifts have been shown elsewhere[13,17] and such shifts in prey distribution are likely to be the greatest threat from changing climates to marine mammal populations. Conservation of these, particularly in preferred areas would be important for conserving marine mammals[38].

5.10. Changing water temperature also has an effect on the reproduction of cetaceans (see Sperm Whale case study) and pinnipeds, indirectly through prey abundance, either through extending the time between individual breeding attempts, or by reducing breeding condition of the mother[81]. The growth and survival of Antarctic Seal *Artocephalus gazelle* pups is influenced by krill *Euphausia* abundance[16].

5.11. An indication of potential effects can be gained through currently extreme climatic events, which may reflect more typical conditions in the future (though species will have the chance of adaptation in the interim). For example, the warm water phase of the ENSO (which is becoming increasingly frequent) is associated with large-scale changes in movements, mortality and reproductive success of marine mammals, at least in part, through changes in prey abundance, there may thus be serious negative population impacts in future[81].

5.12. If prey abundance is low, there will be increased use of blubber reserves and the associated mobilisation of any accumulated anthropogenic contaminants, such as organochlorines, organobromines and polyaromatic hydrocarbons, can have marked effects on an individual's health[63]. The population consequences of this are unknown, but maybe locally severe

5.13. A major impact of sea level rise is likely to be as a reduction in the number of seal haul-out sites used for breeding, nurseries and resting. Endangered species, such as the Mediterranean Monk Seal *Monachus monachus* (listed on CMS Appendix I), which use a limited number of sites, may be especially vulnerable; disturbance and killing of individuals may be greater threats though[60]. This vulnerability is increased as the location of feeding areas is changing simultaneously, meaning new, undisturbed haul-out sites will be required.

5.14. Melting ice-sheets in the Arctic will reduce ocean salinities[43], which in turn will cause shifts in the distribution and biomass of major constituents of Arctic food webs (differing between species according to their ecology), with a tendency for poleward shifts in species assemblages and the potential loss of some polar species (such as Narwhal *Monodon monoceros*). Migratory whales, such as the Grey Whale *Eschrichtius robustus*, that use the Arctic for summer feeding grounds are likely to experience disruptions in the timing and distribution of their food sources[45].

c. Birds

5.15. The number of bird species that migrates varies with latitude. In the northern hemisphere, less than 10% of species living in tropical areas undertake migratory journeys, this proportion increases with distance away from the equator and more than 80% of species living within the Arctic Circle migrate south. Climate induced changes in habitat are predicted to be greatest in the Arctic[43], where the importance of migratory species is highest, these species have limited options for range shift due to limited availability of land at high latitudes and altitudes[84].

5.16. Most species listed by the CMS have the potential to be affected by climate change in some way. Of the bird species listed in the Appendices (excluding non-European Muscicapidae), 84% rely on vulnerable habitats (coastal, wetland, montane or tundra) at some point in their life cycle; many species use more than one habitat. In virtually all cases, the extent of the threat has not been quantified.

5.17. The most widespread threat (53% of species, Table 4) faced is changes in water regime (Table 4), reflecting the importance of wetland sites to migratory birds. Lowered mean water tables and an increased frequency of droughts will reduce habitat availability for aquatic species, such as Baikal Teal *Anas formosa* and reduce food availability for terrestrial species that forage in such areas, particularly on migration, such as Aquatic Warbler *Acrocephalus paludicola*. Habitat loss may compromise migrants' ability to complete their migratory journeys by reducing the coherence of the stopover site network.

5.18. Changes in wind patterns (and increases in storm frequency) have the potential to affect migratory journeys adversely. There is some evidence that a higher spring storm frequency in the Caribbean can cause problems for migrating passerine birds, and lead to reduced numbers reaching the breeding grounds[47]. The journeys of some of the longest distance-migrants, such as Red Knot *Calidris canutus* (see Case Study) and Bar-tailed Godwit *Limosa lapponica*, push individuals to the physiological limit, so any perturbations are likely to have adverse consequences; maintaining high quality stopover habitat will be important in this regard.

5.19. The timing of migration is changing[29,20]. The results of several studies investigating the spring arrival times of migrant species in temperate latitudes suggest that birds are reaching their breeding grounds progressively earlier in the season as the climate becomes warmer (e.g. Pied Flycatcher *Ficedula hypoleuca*, see Case Study), though this pattern is not universal[77]. Where no (significant) change has been observed in local temperatures, no advancement in arrival date has been observed and where local temperatures have become cooler, there has been a tendency for later arrival[47]. Evidence for later departure of migratory birds from their breeding grounds, and earlier arrival on their wintering grounds is sparser; some changes appear to be occurring, but these are inconsistent. Although these effects (and the role of climate change in them) are well demonstrated, the impacts on population size are unclear, mostly because of the presence of density-dependence[36].

5.20. Timing of arrival on the breeding grounds is important, as the breeding season should be synchronised with the availability of prey, the peak timing in abundance of which is, in many cases, shifting earlier in response to warmer temperatures[20,76], though the effects are regionally variable[77]. The timing of available food supply may be particularly critical in stopover areas, which are used for a fixed period of time, though no evidence demonstrating this exists as yet. Although populations will be able to adapt somewhat to these changes, it is unclear to what extent.

5.21. There is currently debate as to whether long-distance migrants may be more vulnerable to phenological changes, since the cues they use to time onset of spring migration may no longer be good measures of conditions on the breeding grounds, thus creating a mismatch between arrival date and optimal breeding date, as has been demonstrated for the Pied Flycatcher (see Case Study)[14].

5.22. Breeding output is known to vary with temperature and time in the season, being greater earlier in the season and at (not too) warmer temperatures[29,20,23]. There is evidence that such increases in productivity are occurring amongst temperate breeding species[22,15], though change will often be a complex function of weather variables[82]. Such changes may be beneficial, unless the breeding season becomes disjunct from the timing of peak prey abundance[21,14]. Studies of polar (particularly Antarctic) species show that increased temperatures are reducing breeding success (probably because of changes in prey distribution)[1].

5.23. Heavy precipitation can adversely affect breeding success, particularly during the period when fledglings are in the nest (and vulnerable to chilling). Overall, increased precipitation levels are predicted so impacts on productivity are predicted, though the timing of such rainfall will be critical, and it is possible that birds may be able to compensate by increased productivity in years of better weather, or by relaying if seasons become extended (though migratory species may be more constrained in this regard)[46].

5.24. For many temperate bird species, survival during the winter months is very important in determining population trend, and is strongly related to winter severity (usually some proxy of temperature)[61]. Increased winter temperatures appear to be leading to higher survival and to an increasing tendency for migratory species to winter in the UK, rather than at more southerly latitudes[80]. Such changes are likely to be beneficial to populations, though the presence of density-dependence in population processes may reduce these impacts[36].

5.25. Overall, breeding bird species (including migratory taxa) in the UK have extended their breeding ranges northwards by an average of around 9 km per decade[73] and southern species are colonising Britain[18], though attributing this solely to climate change is difficult in many cases. Similar range shifts have been demonstrated elsewhere[79,53], as have altitudinal shifts in montane species[58] and further changes are predicted[37].

5.26. The distribution of migratory species is also changing because of changes in migratory behaviour; migratory journeys are generally becoming shorter as has been demonstrated for Chiffchaffs *Phylloscopus collybita* and Blackcap *Sylvia atricapilla*, resulting in changes in wintering distributions[80,6,69]. While, these changes generally yield increases in fitness for the individuals concerned, the population impacts are unclear, though they are likely to be positive (however, such populations may be more vulnerable to, increasingly, occasional severe weather events).

5.27. The available habitat for coastal species is being influenced by sea-level rise, increased erosion from a higher frequency of storm events and greater wave action[21]; nearly 20% of bird species listed by the CMS have the potential to be impacted in such a fashion. Waders, such as Spoon-billed Sandpiper *Eurynorhynchus pygmeus*, and waterfowl, such as Lesser

White-fronted Goose *Anser erythropus*, may be particularly vulnerable in this regard as many important stopover areas are in such coastal habitat, often at a relatively limited number of discrete sites. The UK hosts internationally important numbers of several wader and waterfowl species, such as the Redshank *Tringa totanus* (see Case Study) both in winter and on passage and sea-level rise is affecting both breeding and wintering distributions, although habitat creation by 'managed retreat' from the sea has the potential to mitigate these impacts to some extent[5]. In the UKOTs, the available habitat for breeding seabirds may be reduced, both from rising sea-levels and increased erosion[65].

5.28 A major impact of climate change will be indirect through altering abundance, distribution and quality of prey (in addition to temporal effects described above). This has been shown to be important for a number of species of seabird, both in UK waters[30] and elsewhere, particularly the Antarctic[1], but probably also applies to other groups of birds[21]. Extrapolation from published relationships suggests around 25% of species listed on the CMS Appendices may be impacted by changes in prey distribution, though this should probably be considered a conservative guess; the true number is likely to be higher, though particular species may show considerable population buffering[9].

5.29 Prey abundance and quality is particularly important on stopover sites, especially those that are used for fuel preparatory to crossing an ecological barrier, such as the Sahara desert. Increased desertification in this area would adversely affect the ability of many Afro-European migrants to fatten sufficiently prior to crossing the desert[8]. Droughts in this region have significantly reduced population size previously, from which populations may take a long time to recover their former size[7].

5.30. Climatic impacts on migration are likely to be most important for the spring (northward) migration (because timing of arrival on the breeding grounds is critical, e.g. for mate and territory choice, and also because a reduction in numbers has a direct effect on breeding population size). Increased desertification of the Sahel region of Africa is of particular concern, since it is a key fuelling area for many migratory species.

5.31. Increased temperatures are thought to favour the spread of various diseases and parasites, which are an important source of mortality and can limit population growth in some cases[26]. However, it is not known to what extent climate change will increase the impact on bird populations (relatively little is known about bird-parasite/disease interactions).

5.32. A further poorly understood area is the degree to which effects carry over between seasons. For example, alterations in the timing of breeding will have consequences for the timing of moult, and hence migration and individuals that experience poor conditions in winter may start the breeding period at a disadvantage, and have a lowered reproductive potential[23]. These effects are beginning to be shown to be important and are likely to provide some of the mechanisms by which changing climatic conditions will impact on population size.

d. Bats

5.33. While it is probable that many species of bats are migratory, the scale and extent of such movements are largely unknown, though females are usually more migratory than males[64]. The distance and routes of migration in some tropical or subtropical species depend on variations in fruiting or flowering success of food plants.

5.34. In temperate areas, where all bats are insectivorous, migration is usually between warm sites suitable for pregnancy and lactation and with adequate food supplies in summer, and cool sites for hibernation in winter (this migration need not be North/South). Within the tropical or subtropical latitudes, migrations depend on variations in fruiting or flowering success of food plants and to allow the formation of large communal maternity colonies. In some cases, movements may be associated with retreat from seasonally arid areas to concentrate in moister areas where food supply may be more persistent.

5.35. There have been almost no studies of bats directly in relation to climate change in Europe, but the most significant impacts (in terms of population size) are likely to be indirect, influencing the availability of their food supply or roost sites.

5.36. Changes in the composition of bat communities are likely as species alter their distribution northwards, possibly through range expansion rather than a simple shift in range, but the impacts of this are largely unknown. Species dependent on caves (as roost sites for maternity colonies) which shift their range northwards may be constrained by a lack of suitable caves (or other appropriate underground habitats) in their potential new locations. This is unlikely to be a serious issue in the UK, but could be significant in parts of mainland Europe and may lead to longer migratory journeys.

5.37. The predicted decrease, or even the disappearance of extreme cold winters in the UK may result in a reduced period of hibernation, increased winter activity (when there may be limited food supply) and reduced reliance on the relatively stable temperatures of underground hibernation sites[59]. (This may also have implications for the use of roost counts to monitoring populations.)

5.38. An earlier advent of spring (by 1-3 weeks) would predicate a shorter hibernation period and hence an earlier appearance of most bats on the wing and this will require sufficient food to be available and may influence the timing of breeding[4]. Cold weather events later in the winter (after the ‘premature’ emergence of individuals) may inflict increased mortality on populations, but the incidence of these is expected to decrease.

5.39. The reproductive cycle of temperate zone bats is closely linked to their pattern of hibernation. Bats mate in autumn and winter, and spermatozoa are stored in the female reproductive tract until spring. If bats experience warm conditions and a supply of food in the second half of winter, they will arouse from hibernation prematurely, ovulate and become pregnant. Conversely, if bats experience periods of inclement weather associated with food shortages during pregnancy, they will become torpid and the gestation period is extended. Experimentally, timing of births can be altered by up to three months by manipulating environmental conditions[4]. Given this extreme dependence on external temperatures and food supply, the timing of reproductive cycles of temperate bats is likely to be significantly affected by climate change, although possibly not to their detriment.

5.40. For a large number of bat species, wetlands, waterways and water bodies and woodland provide key resources of insect biomass and diversity used by bats. Thus a decline in wet or moist areas is likely to affect bat populations and cause declines or behavioural changes; these changes will be particularly pronounced for Mediterranean populations.

5.41. The available evidence suggests that most bats do not undertake long continuous movements; rather the journey is interrupted at frequent intervals (perhaps daily) at ‘stopover’ points, with the bats resting and feeding to replenish energy requirements[28]. Thus, the maintenance of suitable migration corridors, and sufficient prey at stopover points, may be an important conservation requirement for migrating bats. These requirements may be threatened by other factors, such as land-use patterns, and climate change has the potential to exacerbate these problems.

5.42. A total of 22 bat species occur in the Caribbean UKOTs, but information on the status and populations of these species on most small islands is incomplete. Many of the Caribbean island populations have been recognised as separate (sedentary) subspecies, though their validity requires verification. Migratory individuals of other subspecies may also occur contemporaneously for part of the year.

5.43. The predicted increase in incidence and, particularly, intensity of storms in the Caribbean is likely to result in damage to roost sites (e.g. trees, buildings, etc) and foraging habitats (especially fruit and flower feeders through stripping of flowers and seeds/fruit)[65]. Studies of bat populations after historical events have shown mixed patterns[32,44]. Populations of some species do recover in the short to medium term, but given the generally slow reproductive rate of many species, an increased frequency of storms is likely to be of concern.

5.44. Sea-level rise may affect the suitability of some foraging habitats and coastal roost caves.

e. Terrestrial Mammals

5.45. Migratory journeys are less common in terrestrial mammals than other groups, the most familiar and well studied migrations are those undertaken by large herbivorous mammals that feed on seasonal grasses, such as Wildebeest *Connochaetes taurinus* and Caribou (Reindeer) *Rangifer taurandus*[31]. The CMS covers a number of 'technical' migrants, these are species such as the Mountain Gorilla *Gorilla gorilla beringei*, which cross range state boundaries in the course of their movements, but which do not have regular seasonal migrations in the more traditional sense.

5.46. The reasons for migration are not always clear but may include movements between areas of seasonal food abundance, changes in availability of drinking water, avoidance of predators or access to food with essential minerals[31,27]. A particular journey may be undertaken for a combination of these factors, and different factors may stimulate different phases of the annual migratory cycle. Consequently, many of the potential impacts of climate need to be assessed on a species by species basis.

5.47. As many migrations, particularly of herbivores, track seasonal changes in vegetation, climate change has the potential to alter migratory routes (and timings), which may increase conflicts with humans, particularly in areas where rainfall is low[72]. Land-use patterns in Africa can prevent animals adapting their migratory routes, for example, park boundary fences have been demonstrated to disrupt migratory journeys, leading to a population decline in Wildebeest[82].

5.48. Changed migratory routes may also have effects throughout the ecosystem[31]. Predator populations may experience a reduction in the number of available prey. Grassland ecosystems may require periods when grazing pressure is relatively low to recover from the effects of grazing and increase above-ground biomass to counter higher grazing pressure at other times of the year. As migration temporarily reduces local grazing pressure, local ecosystems may not be able to cope with high levels of grazing throughout the year if formerly migratory populations become resident[67].

5.49. Timing of reproduction in mammals is influenced by temperature, at least for northern populations; advancement in breeding season has been demonstrated in a few cases, though not in migratory species. It is unknown how this might be affected by changes in migratory patterns, consequent on changes in food supplies in relation to climate change. Growth rates, particularly of juveniles, have been demonstrated to be dependent on climatic factors in ungulate species and relate to the availability and, importantly, quality of the food supply[24]. The impacts of climate change on food supplies and migratory behaviour may have important consequences for the growth of migratory ungulates, but these are largely unexplored at the moment.

5.50. If mammal communities change in response to climatic shifts, inter-specific relationships (e.g. competition) are likely to alter. Such effects may be important in some instances and have been demonstrated in two cases: small rodent communities in Australian tropical forest[40], and in range changes in European shrew *Sorex* species[78]. However, generalisations are unlikely to be possible as these will be dependent on species-specific ecological factors.

f. Insects

5.51. Very little is known about the migratory behaviour of insects; virtually all the work that has been done concerns pest species, such as the desert locust *Schistocerca gregaria*[19], or the Lepidoptera (butterflies and moths), such as the Monarch *Danaus plexippus* (the only insect listed by the CMS (see Case Study), although most groups, particularly of the larger insects, have representatives that can be considered migratory.

5.52. The definition of a migratory species, as used by the CMS, is less applicable in insect taxa, as in relatively few species do particular individuals make a complete return journey. For invertebrates, the annual cycle of migration may consist of several successive generations rather than the same individuals; only in some situations can this be considered to be migration with a predictable trajectory and return phase. Few insects cross range state boundaries in their journeys; in many cases, this is a consequence of the scale of their journeys relative to territorial areas.

5.53. In broad terms, invertebrate migration occurs because the destination provides better potential opportunities for breeding and feeding resources than the current location. The location of suitable resources may vary from year-to-year, even from month-to-month, so migration destinations can be quite dynamic and unpredictable, as can range limits.

5.54. Almost by definition, pest species tend to be highly adaptable and occur in large populations[19]. Climate change is unlikely to adversely affect them, although it may shift their distributional range, which may have an impact on human activities.

5.55. There is growing evidence of distributional shifts in invertebrates, for example amongst butterflies and dragonflies (Odonata) in the UK[41,70]. A northwards shift in distribution has been witnessed as climate warming makes more northerly areas more suitable for colonisation, for example two species of butterfly Clouded Yellow *Colias croceus* and Red Admiral *Vanessa atalanta* are now over-wintering in the UK.

5.56. Changes in the timing of appearance of adult butterflies (which is dependent primarily on temperature) are well documented[64,71]. This may lead to mismatches between the appearance of populations and the abundance of food plants at an appropriate growth stage. Migratory species, being more mobile, will have a greater capacity to adapt to these changes than sedentary species (which often rely on highly specialised habitats), so are less at risk than other species.

6. Migratory Species – Conservation Priorities

6.1. In terrestrial ecosystems, two issues potentially affect a large range of migratory species: (i) **changes in water resources** - particularly wetland quality, site maintenance and increased desertification; (ii) **loss of vulnerable habitats** – particularly tundra, cloud forest, sea ice and low-lying coastal areas, especially in small island states. Many of these areas also face severe anthropogenic threats.

6.2. Different conservation approaches are required for ‘broad-front’ and ‘leap’ migrants (see 4.3). Broad-front migrants will benefit from modifications to extensive land-use along the migratory route, whereas, leap migrants require a coherent site network, with the quality of individual sites being of critical importance. **In most cases, the impacts of climate change need to be integrated with other economic, social and conservation objectives.**

6.3. **For leap migrants, maintenance of a coherent network of stopover sites will be required.** Currently there is a lack of even some of the most basic syntheses of information that are required for conservation action. **There is an urgent need to collate information on migratory stopover sites to identify coherent migratory networks.** This would provide a strategic, international overview and enable clear identification of site protection priorities for leap migrants. Much of this information is available for birds, so this could be achieved relatively straightforwardly for the key flyways. The same consideration may also apply to other taxonomic groups.

6.4. **For broad-front terrestrial migrants, the creation of suitable migratory habitat, such as wildlife-friendly field margins, hedgerows, small copses and ponds have potential to allow migrants to adapt to climate change**. Where these are absent, populations may not be able to adapt sufficiently and hence will suffer negative impacts. The UK's Entry Level Scheme for farmers provides an excellent model for encouraging such features.

6.5. **In areas with remaining pristine habitat, the creation of protected trans-boundary habitat corridors is likely to be a great benefit.** This will help broad-front migrants as well as migrants at the end of their migrations. Currently it is an approach applied particularly in the Americas, e.g. the Meso-American Corridor, through Central America.

6.6. **The priority for adapting to change in the marine environment will be to manage human impacts on the resources required by migratory species through ecosystem-based management.** One way to achieve this would be to designate marine protected areas (a.k.a. 'no-take zones') for the prey of marine mammals at key sites. However, the locations of such areas are likely to change over time, and protection will require very different legislation than anything that has been developed to date. There will need to be a degree of flexibility in the establishment of protected areas for marine mammals, such as Special Areas of Conservation (SAC) to take account of the potential for shifts in the range of species with climate change.

6.7. **Maintain large population sizes**. Successful adaptation to changed climatic factors (and consequently habitat) will require sufficient genetic variation present in the population, which will be related to population size.

7. Migratory Species – Monitoring and Research Priorities

7.1. Many long-term monitoring programs exist, which have been successful in identifying conservation priorities and providing base-line data against which to measure the impacts of climate change. **A commitment to long-term support of these schemes is critical to ensure their existence, and to ensure best value by utilising existing data collection networks.** Better use also needs to be made of existing data, for example in using populations on temperate non-breeding grounds to provide indices of arctic breeding populations (where large-scale data collection is impractical).

7.2. **Develop standardised protocols for monitoring populations.** Climate change is a global phenomenon and migratory species may cross many range boundaries. Standardised data collection is required if monitoring is to be effective. A unified system of alerts, to identify future problems, and thresholds to identify when environmental management is successful should be developed.

7.3. Although the importance of such monitoring is explicitly recognised by ASCOBANS, current knowledge of **cetacean population status, movements and habitat requirements is patchy and good baseline data are urgently needed for many species.** Although many European countries have cetacean strandings networks, which provide valuable data, the majority are run by the voluntary sector and both co-ordination of their work and the provision of core funding are needed to secure this source of information.

7.4. Information on occurrence, abundance and ecology of migratory species in the UKOT and on intra-tropical migrants (where anthropogenic threats are greatest) is limited, **structured programmes of survey and monitoring are needed to inform the setting of conservation priorities.**

7.5. **Identify indicator species**, including those that might indicate site condition and the condition of migration routes.

7.6. Populations using migratory staging do not do so synchronously, i.e. there can be a considerable turnover of individuals so the peak count may not relate to the total numbers using a site. This may affect the identification of designated sites, the importance of which is often determined by the peak number of individuals counted in the site. **There is a need to develop software for practitioners to accurately assess the total number of individuals using the site,** to ensure site importance is properly evaluated.

7.7. Quantitative predictions on the impacts of climate change on populations are extremely difficult as population processes are often density-dependent, resulting in a buffering of population size. **Research into assessing the strength and effect of density-dependent processes on population size is needed, though fraught with difficulties.**

7.8. In adapting to climate change, interactions with socio-economic factors, such as prevailing land-use are likely to be paramount, both as a constraint on the extent to which adaptation can occur and as an exacerbating factor. In general, anthropogenic factors, e.g. habitat loss and overexploitation of resources, are the most critical issues in the conservation of endangered species. **The interaction of socio-economic factors with climate change is poorly understood and predictions of climatic impacts currently take relatively little account of them.**

8. Migratory Species – Legislative Requirements

8.1. The CMS has already had many conservation successes, particularly through the development of regionally and taxonomically based agreements that aim to promote the conservation of certain groups of migratory wildlife throughout their range states. **Given the species specific nature of the climate change threats faced by migratory species, the explicit incorporation of climate change considerations within specific Agreements and Memoranda of Understanding will provide flexibility to address particular threats to migratory wildlife**. In many cases minimising other threats to populations to allow populations to adapt to a changing climate may be the most useful way forward.

8.2. **In terrestrial systems adaptation measures may be successful in maintaining or restoring a secure conservation status for many species. In marine systems, however, mitigation of climate change may be the only solution** (i.e. reduction in anthropogenic greenhouse gas emissions), as habitat management at a sufficient scale will be virtually impossible.

8.3. In addressing the conservation challenges of climate change, a multi-functional approach is likely to be most successful. This approach entails considering the benefits of ecosystem preservation from a holistic viewpoint, considering both the anthropogenic and wildlife benefits. It is much more likely that conservation goals will be achieved if they are part of ecosystem management with wider aims such as floodplain management, coastal protection or preventing deforestation to reduce soil erosion. **Frameworks for integrated land-use**

planning exist in a number of different parts of the world, and they could valuably be developed and implemented more widely elsewhere.

8.4. Climate change may be the ‘last straw’ for many marine species, which are already under severe anthropogenic pressure. **Strengthening protection for marine species and ecosystems should improve their ability to adapt to changing climatic conditions.**

8.5. **Exploiting synergies between treaties and conventions, e.g. joint work programmes, would provide increased value, better co-ordination and improved focus, as well as facilitating the development of key priorities.**

Table 1. Summary of changing climate from the present until the 2080s from two climate scenario models covering the UK (UKCIP) or Europe (ACACIA).

Variable	**UKCIP**	**ACACIA**
Temperature		
Mean Temperature	+2˚C to +5˚C	+0.8˚C to +3.2˚C
Spring Timing	1-3 wks earlier	-
Extreme Summer Temperatures	Increase	9-10x Increase
Extreme cold Winters	-	Disappear
Precipitation		
Mean Precipitation	0% to –15%	Variable
Summer Precipitation	Decreased	0% to +8% (N) 0% to –15% (S)
Soil Summer Moisture	-40%	Decrease
Winter Precipitation	Increased	Increased
Extreme Winter Precipitation	Increase	-
Snowfall	-30% to –90%	-
Other		
Sea-level Rise	-2 to +58 cm (NW) +26 to +86 cm (SE)	+5 to +90cm (NW) +35 to +140cm (SE)
Extreme Sea Levels	Increase	-
Gales	-	Increase

Table 2. Summary the extent of knowledge about climate change impacts on migratory species across taxonomic groups. Based on a consensus opinion of experts attending a workshop in Cambridge, March 2005.

Climate Change Factors	Birds	Bats	Terrestrial and marine Mammals	Fish	Turtles	Insects
Migration Patterns	***	*	**	*	*	*
Abundance & Distributions	***	**	**	**	**	*
Habitat use of each species to allow future modelling	***	**	*	*	*	*

*** = good information for some species; ** = some knowledge; * = little or no knowledge

Table 3. Summary of likely climate change impacts on the population dynamics migratory species across taxonomic groups. Dashes indicate the factor is not generally relevant for that group, particularly important effects that are well (relatively) well documented are highlighted. Almost nothing is known about climate change impacts on insects. Based on a consensus opinion of experts attending a workshop in Cambridge, March 2005, and the review in the main report.

Factors	Birds	Bats	Mammals	Fish	Turtles
Loss of Stopover Sites	Important	Yes	--	--	--
Temperature	Indirect	--	Yes (esp. Arctic, marine spp.)	Important	Yes
Loss of Breeding Habitat	Yes (Important for some)	Yes	Yes	Yes	Important
Longer Migratory Pathways	Yes	Yes ?	Yes (esp. terrestrial)	?	--
Mismatch in Timing	Yes	?	?	Yes	--
Changes in prey availability	Yes	Yes	Important (marine only?)	Yes	Yes
Inter-species Competition	Debated	Roosting sites ?	?	?	No
Non-breeding habitat/ wintering sites	Yes	Yes	?	?	Important

Table 4 Summary of threats faced by migratory species listed on the CMS. In each case the number of species affected is given; in many cases a species faces multiple threats. Based on Information in Appendix 1, Table 11.

Climate Change Impacts		**Anthropogenic Impacts**	
Lowered Water Tables	127	Hunting or Persecution	137
Increased Drought Frequency	84	Habitat Loss	132
(Water Tables and Drought)	(160)	Human Disturbance	76
Mismatch with Prey Abundance	73	Overgrazing	63
Sea Level Rises	55	Agricultural Intensification	22
Habitat Shifts	52	(Overgrazing and Intensification)	(70)
Changes in Prey Range	50	Direct Mortality	49
Increased Storm Frequency	20	Over-fishing / Long-lining	42
		Introduced Species	30
No Threats	35	No Threats	59
Total Number of Species	300		300

1. Ainley, D., Wilson, P. & Fraser, W.R. (2000) Effects of climate change on Antarctic sea-ice and penguins. *WCMC Biodiversity Series* **11,** 26-27.

2. Anon. (1999) Action plan for marine turtles in: *UK Biodiversity Group Tranche 2 Action Plans - Volume V: Maritime species and habitats*, p37. HMSO, London.

3. *Climate change and wetlands: impacts adaptation and mitigation.* Resolution VIII.3, adopted at CoP8 of the Convention on Wetlands, Valencia, Spain, November 2002.

4. Arlettaz, R., Criste, P., Lugon, A., Perrin, N. & Vogel, P. (2001) Food availability dictates the timing of parturition in insectivorous mouse-eared bats. *Oikos* **95,** 105-111.

5. Atkinson, P.W., Crooks, S., Drewitt, A., Grant, A., Rehfisch, M.M., Sharpe, J. & Tyas, C. (2004) Managed realignment in the UK - the first five years of colonization by birds. *Ibis* **146,** 101-110.

6. Austin, G. & Rehfisch, M.M. (2005) Shifting non-breeding distributions of migratory fauna in relation to climate change. *Global Change Biology* **11,** 31-38.

7. Baillie, S.R., *et al.* (2005) *Breeding Birds in the Wider Countryside: their conservation status 2004*. BTO Research Report No. 385. BTO, Thetford.

8. Bairlein, F. (1991) Seasonal occurrence, body mass and fattening of migratory birds in N. Algeria during autumn migration. *Vogelwarte* **34,**237-248.

9. Bairlein, F. & Hüppop, O. (2004) Migratory fuelling and global climate change. *Advances in Ecological Research* **35,**33-47.

10. Beaugrand, G., Brander, K.M., Lindley, J.A, Souissi, S. & Reid, P. C. (2003) Plankton effect on cod recruitment in the North Sea. *Nature* **426,** 661-664.

11. Berry, P.M., Dawson, T.P., Harrison, P.A. & Pearson, R.G. (2002) Modelling potential impacts of climate change on the bioclimatic envelope of species in Britain and Ireland . Global Ecology and Biogeography **11,** 453-462.

12. Berthold, P. (2001) Bird migration: a general survey. Oxford Univ. Press, Oxford.

13. Bjørge, A. (2002) How persistent are marine mammal habitats in an ocean of variability? In: *Marine mammals: biology and conservation.* P. G. H. Evans and J. A. Raga. New York, Kluwer Academic/Plenum Publishers: 63-91.

14. Both, C. & Visser, M.E. (2001) Adjustment to climate change is constrained by arrival date in a long-distance migrant bird. *Nature* **411,** 296-298.

15. Both, C., *et al.* (2004) Large-scale geographical variation confirms that climate change causes birds to lay earlier. *Proceedings of the Royal Society of London B* **271,** 1657-1662.

16. Boyd, I.L. (1996) Individual variation in the duration of pregnancy and birth date in Antarctic fur seals: the role of environment, age, and sex of fetus. *Journal of Mammalogy* **77,** 124-133.

17. Boyd, I.L. (2002) Antarctic marine mammals. In *Encyclopedia of Marine Mammals.* (eds W. F. Perrin, W.F.,Würsig, B. &. Thewissen, J.G.M. San Diego, Academic Press: 30-36.

18. Burton, J. (1995) *Birds and Climate Change.* Christopher Helm, London.

19. Cannon, R.J.C. (1998) The implications of predicted climate change for insect pests in the UK, with emphasis on non-indigenous species. *Global Change Biology* **4,** 785-796.

20. Coppack, T. & Both, C. (2003) Predicting life-cycle adaptation of migratory birds to global climate change. *Ardea* **90,** 369-378.

21. Crick, H.Q.P. (2004) The impact of climate change on birds. *Ibis* **146,** 48-56.

22. Crick, H.Q.P. & Sparks, T.H. (1999) Climate change related to egg-laying trends. *Nature* **399,** 423-424.

23. Dunn, P. (2004) Breeding dates and reproductive performance. *Advances in Ecological Research* **35,**69-87.

24. Ericsson, G., Ball, J.P. & Danell, K. (2002) Body mass of moose calves along an altitudinal gradient. *Journal of Wildlife Management* **66,** 91-97.

25. European Environment Agency (2004) *Impacts of Europe's changing climate*. European Environment Agency, Copenhagen.

26. Faustino, C., *et al*. **(**2004**)** *Mycoplasmal gallisepticum* infection dynamics in a House Finch population: empirical analysis of seasonal variation in survival, encounter and transmission rate. *Journal of Animal Ecology* **73,** 651-669.

27. Ferguson, S.H. & Elkie, P.C. (2004) Seasonal movement patterns of woodland caribou (*Rangifer tarandus caribou*). *Journal of Zoology, London* **262,** 125-134.

28. Fleming, T.H. & Eby, P. (2003) Ecology of Bat Migration. in *Bat Ecology*. (Eds Kunz, T.H. & Fenton, M.B.) Pp 156-208. The University of Chicago Press, Chicago.

29. Forchhammer, M.C., Post, E. & Stenseth, N.C. (1998) Breeding phenology and climate…. Nature **391,** 29-30

30. Frederiksen, M., Wanless, S., Harris, M.P., Rothery, P. & Wilson, L.J. (2004) The role of industrial fisheries and oceanographic change in the decline of North Sea black-legged kittiwakes. *Journal of Applied Ecology* **41,**1129-1139.

31. Fryxell, J.M. & Sinclair, A.R.E. (1988) Causes and consequences of migration by large herbivores. *Trends in Ecology and Evolution* **3,** 237-241.

32. Gannon, M.R. & Willig, M.R. (1994) The effects of Hurricane Hugo on bats of the Luquillo Experimental Forest of Puerto Rico. *Biotropica* **26,** 320-331.

33. Gauthreaux, S.A. (in prep.) Atmospheric trajectories and spring bird migration across the Gulf of Mexico. *Journal of Ornithology*.

34. Gill, J., Watkinson, A. & Côté, I. (2004) Linking sea level rise, coastal biodiversity and economic activity in Caribbean island states: towards the development of a coastal island simulator. *Tyndall Centre for Climate Change Research. Technical Report 9*.

35. Gitay, H., Suárez, A., Watson, R.T. & Dokken, D.J. (2002) *Climate change and biodiversity*. IPCC Technical Paper V.

36. Green, R.E. (1999) Applications of large-scale studies of demographic rates to bird conservation. *Bird Study* **46,** S279-S288.

37. Harrison, P.A., Berry, P.M. & Dawson, T.P. (2001) *Modelling natural resource responses to climate change (MONARCH).* Environmental Change Institute, Oxford.

38. Harwood, J. (2001) Marine mammals and their environment in the twenty-first century. *Journal of Mammalogy* **82,** 630-640.

39. Hays, G.C., Broderick, A.C., Glen, F. & Godley, B.J. (2003) Climate change and sea turtles; a 150-year reconstruction of incubation temperature at a major turtle rookery. *Global Change Biology* **9,** 642-646.

40. Heihsohn, G. & Heinsohn, R. (1999) Long-term dynamics of a rodent community in an Australian tropical rainforest. Wildlife Research **26,** 187-198.

41. Hickling, R., Roy, D.B., Hill, J.K & Thomas, C.D. (2005) A northward shift of range margins in British Odonata. *Global Change Biology* **11,** 502-506

42. Hulme, M., *et al.* (2002) *Climate change scenarios for the United Kingdom: the UKCIP02 scientific report*. Tyndall Centre for Climate Change Research, Norwich.

43. IPCC (2001b) *Climate Change 2001: the scientific basis*. Cambridge University Press, Cambridge.

44. Jones, K.E., Barlow, K.E., Vaughan, N., Rodrigues-Duran, A. & Gannon, M. (2001) Short-term impacts of extreme environmental disturbance on the bats of Puerto Rico. *Animal Conservation* **4,** 59-66.

45. Jones, M.L. & Swartz, S.L. (2002) Gray whale. In: *Encyclopedia of Marine Mammals*. (Eds Perrin, W.F., Würsig, B. & Thewissen, J.G.M.) pp 524-536. Academic Press, San Diego

46. Leech, D.I., & Crick, H.Q.P. (in prep*)* Influence of weather variables on the productivity of single-brooded bird species in Britain.

47. Lehikoinen, E., Sparks, R.H. & Zalakevicius, M. (2004) Arrival and departure dates. *Advances in Ecological Research* **35,** 1-32.

48. Levey, D.J., Bolker, B.M., Tewksbury, J.J., Sargeant, S., Haddad, N.M. (2005) Effects of landscape corridors on seed dispersal by birds. *Science* **309**, 146-148.

49. MacLeod, C.D., *et al.* (2005) Climate change and the cetacean community of north-west Scotland. *Biological Conservation* **124,** 477-483

50. Mitchell, T.D., Carter, T.R., Jones, P.D., Hulme, M. & New, M. (2004) *A comprehensive set of high resolution grids of monthly climate for Europe and the Globe***.** Tyndall Centre for Climate Change Research, Norwich.

51. Moss, R., Oswald, J. & Baines, D. (2001) Climate change and breeding success: decline of the capercaillie in Scotland. *J. Anim. Ecol.,* **70,** 47-61.

52. Nakicenovic, N. *et al.* (2000) *Special Report on Emissions Scenarios.*Cambridge University Press, Cambridge.

53. Parmesan, C. & Yohe, G. (2003) A globally coherent fingerprint of climate change impacts across natural systems. *Nature* **421,** 37-42.

54. Parry, M.L. (ed) (2001) *Assessment of Potential Effects and Adaptations for Climate Change in Europe: The Europe ACACIA Project* Jackson Environment Institute, Norwich.

55. Perry, A.L., Low, P.J., Ellis, J.R. & Reynolds, J.D. (2005) Climate change and distribution shifts in marine species. *Science* **308,**1912-1913.

56. Pierce, G.J. & Boyle, P.R. (2003) Empirical modelling if interannual trends in abundance of squid (Loligo forbesi) in Scottish waters. *Fisheries Research* **59,** 305-326.

57. Piersma, T. & Lindström, Å. (2004) Migrating shorebirds as integrative sentinels of global environmental change. *Ibis* **146,** (S1): 61-69.

58. Pounds, J.A., Fogden, M.P.L. & Campbell, J.H. (1999) Biological response to climate change on a tropical mountain. *Nature* **398,** 611-615.

59. Racey, P.A. & Entwistle, A.C. (2000) Life-history and reproductive strategies of bats. In: *Reproductive Biology of Bats*. (Eds Crighton, E.G. & Krutzsch, P.H.) Pp363-414 Academic Press, London.

60. Reijnders *et al.* (1993) Seals, Fur Seals, Sea Lions, and Walrus. Status Survey and Conservation Action Plan. IUCN Seal Specialist Group. Gland, Switzerland.

61. Robinson, R.A., Baillie, S.R. & Crick, H.Q.P. (in prep) Weather-dependent survival: implications of climate change for passerine population processes.

62. Root, T.L. *et al.* (2003) Fingerprints of global warming on plants and animals. *Nature* **421,** 57-60.

63. Ross, P.S., Vos, J.G. Birnbaum, L.S. & Osterhaus, A.D.M.E. (2000) PCBs are a health risk for humans and wildlife. *Science* **289,** 1878-1879.

64. Roy, D.B. & Sparks, T.H. (2000) Phenology of British butterflies and climate change. *Global Change Biology* **6,** 407-416.

65. Sear, C., Hulme, M., Adger, N. & Brown, K. (2001) The impacts of climate change on the UK Overseas Territories. Natural Resources Institute, Chatham Maritime, Kent/Tyndall Centre for Climate Change Research, Norwich.

66. Shimazaki, H. *et al.* (2004) Network analysis of potential migration routes for Oriental White Storks (*Ciconia boyciana*). *Ecological Research* **19**, 683-698.

67. Sinclair, A.R.E. & Fryxell, J.M. (1985) The Sahel of Africa: ecology of a disaster. *Canadian Journal of Zoology* **63,** 987-994.

68. Sissener, E.H. & Bjørndal, T. (2005) Climate change and the migratory pattern for Norwegian spring-spawning herring - implications for management. *Marine Policy* **29,** 299-309.

69. Soutullo, A.. (2004) Climate change and shifts in winter distribution of European breeding birds. M.Sc. Thesis, University of East Anglia, Norwich.

70. Sparks, T.H., Roy, D.B. & Dennis R.L.H. (2005) The influence of temperature on migration of Lepidoptera into Britain. *Global Change Biology* **11,** 507-514.

71. Stefanescu, C., Peñuelas, J. & Filella, I. (2003) Effects of climatic change on the phenology of butterflies in the northwest Mediterranean Basin**.** *Global Change Biology* **9,** 1494-1506.

72. Thirgood, S., *et al.* (2004) Can parks protect migratory ungulates? The case of the Serengeti wildebeest. *Animal Conservation* **7,**113-120.

73. Thomas, C.D. & Lennon, J.J. (1999) Birds extend their ranges northwards. *Nature* **399,** 213.

74. Thomas, C.D. *et al.* (2004) Extinction risk from climate change. *Nature* **427,** 145-148.

75. Turrell, W.R. (1999). *Scottish Ocean Climate Status Report 1998*. Fisheries Research Service, Aberdeen.

76. Visser, M.E., Both, C. & Lambrechts, M.M. (2004) Global climate change leads to mistimed avian reproduction. *Advances in Ecological Research* **35,** 89-110.

77. Visser, M.E. *et al.* (2003) Variable responses to large-scale climate change in European Parus populations. *Proc. R. Soc. Lond. B* **270,** 367-372.

78. Vogel, P., Jutzeler, S, Rulence, B & Reutter, B.A. (2002) Range expansion of the greater white-toothed shrew *Crocidura russula* in Switzerland results in local extinction of the bicoloured white-toothed shrew *C. leucodon*. *Acta Theriologica* **47,** 15-24.

79. Walther, G.R., *et al.* (2002) Ecological responses to recent climate change. *Nature* **416,** 389-395.

80. Wernham, C.V. *et al.* (2002) *The migration atlas: movements of birds in Britain and Ireland*. Poyser, London.

81. Whitehead, H. (1997) Sea surface temperature and the abundance of sperm whale calves off the Galapagos Islands: implications for the effects of global warming. *Report of the International Whaling Commission*. **47,** 941-944.

82. Whyte I.J. & Joubert S.C.J. (1988) Blue wildebeest population trends in the Kruger National Park and the effect of fencing. South African Journal of Wildlife Research **18,**78-87.

83. Zedler, J. (2004) Compensating for wetland losses in the United States. *Ibis* **146,** 92-100.

84. Zöckler, C. & Lysenko, I. (2000) Water birds on the edge: first circumpolar assessment of climate change impact on Arctic breeding wader birds. *WCMC Biodiversity Series* **11,** 20-25.

1. INTRODUCTION

Climate change is one of the major factors likely to affect the earth's ecosystems in the coming years and centuries. The increase in global temperature in the 20th century was the largest in any century during the past 1,000 years and this has been associated with changes in weather patterns, precipitation, snow cover, sea-temperatures and sea-level. The IPCC Special Report on Emission Scenarios projects that globally averaged surface temperature will increase by 1.4-5.8°C between 1990 and 2100. The projected rate of warming is much larger than the observed changes during the 20th century and is without precedent during at least the last 10,000 years. There is already compelling evidence that animals and plants have been affected by recent climate change (e.g. Walther *et al.* 2002, Parmesan & Yohe 2003, Rehfisch & Crick 2003, Root *et al.* 2003, Crick 2004). These effects include earlier breeding (e.g. Crick *et al.* 1997; Crick & Sparks 1999); changes in timing of migration (e.g. Sparks & Braslavska 2001); changes in breeding performance (e.g. Thompson & Ollason 2001); changes in population sizes (e.g. Crick 1999); changes in population distributions (e.g. Berry *et al.* 2001; Austin & Rehfisch 2005); and changes in selection differentials between components of a population (Visser *et al.* 1998; Visser & Lambrechts 2004). Migrant wildlife, by travelling large distances, being subject to a wide range of environmental influences, and relying on a wide range of natural resources, are particularly likely to be affected by climate change at some point of their life cycles.

The UK Government is party to a number of international treaties and agreements that seek to promote and maintain the conservation status of migrant species of wildlife and Defra takes a lead role for the Government in these areas. Fundamental to these is the Bonn Convention on the Conservation of Migratory Species of Wild Animals (1979) (CMS), which is particularly concerned with the conservation of species listed (a) as endangered in Appendix I of the Convention and (b) as having unfavourable conservation status in Appendix II of the Convention. AEWA, EUROBATS, ASCOBANS, ACCOBAMS and the recently agreed ACAP are examples of Bonn Convention agreements. In addition, the Convention on Biodiversity (1992) has led to the development of the UK Biodiversity Action Plan including several Species Action Plans for migratory species. Other key international legal and policy instruments for nature conservation that cover migrant species are the Ramsar Convention (1971) and the EC Birds and Habitats Directives. The maintenance of the conservation status of, and suitable habitats for, migrant species is a key part of meeting the UK's obligations. However, climate change is already beginning to exert impacts on the natural environment and land-use, which may have far-reaching effects on the resources and habitats that migrants require (e.g. Root *et al.*2003; Parmesan & Yohe 2003). Migrants not only require suitable habitats at each end of their migration route but also need suitable conditions and habitat *en route*. Thus wind speed and direction or ocean currents may be important for the successful completion of a migratory journey, and stop-over sites for resting or foraging may also be of key importance.

The impacts of climate change on migratory wildlife may usefully be classified into two general categories. Firstly, climate change may affect the species' biology directly, for example, increased temperatures may allow longer reproductive periods (e.g. Crick *et al.* 1997), increased wind may lead to greater heat loss through wind chill (Wiersma & Piersma 1994) or may lessen migratory costs if it is in the direction of an animal's migration (Piersma & Jukema 1990; Butler *et al.* 1997). Alternatively, the impacts may be indirect, for example, increased temperatures are likely to give rise to changes in sea-level, which may in turn affect habitat availability, particularly for coastal species (Hughes 2004; Watkinson *et al.* 2004). The impact of many of these indirect effects is difficult to predict. There is a further dimension to the indirect effects, which derives from how society will respond to climate change. The impacts on socio-economics may include major shifts in the patterns of agricultural practice that will in turn have major impacts on the wildlife using an area.

Although migratory wildlife species are potentially vulnerable to the effects of climate change at some point on their journeys, or through some aspect of their life cycle that is directly related to their migratoriness, there has not to date been a specific review of climate change in relation to migrants. This review aims to fill this gap, drawing together information on a wide range of types of animal.

The overall aim is to provide an information source to Defra, and other parties to the CMS, that will help them to address the issues associated with the impacts of climate change on migratory wildlife.

1.1. Aims and methods

The aims of the project were as follows:

a. To assess the strength of current scientific evidence of links between climate change and changes in migratory species' behaviour, abundance and distribution.

b. To identify what effects climate change has had, and may have in the future, on migratory species.

c. To identify which species are threatened by climate change and comment on the measures proposed to tackle such threats.

d. To comment on the reliability or uncertainty of predictions about effects of climate change.

To achieve these aims we have conducted a major review of the available published literature for the main taxonomic groups that contain a substantial number of migratory species, i.e. birds, marine and terrestrial mammals, bats, turtles, marine fish, marine invertebrates (primarily cephalapods) and insects. Where appropriate we supplemented this information with recent studies in the pre-publication stage. We also consulted with experts on the biology, ecology and conservation of these taxa.

While this work considered information from throughout the world, special consideration has been given to those species that occur in and/or pass through the UK and its Overseas Territories (UKOTs). Firstly, we give a general overview of the relevant legislation (Chapter 2) and a summary of the ways in which the global climate has changed and is predicted to change in the next century (Chapter 3). We then present an overview of the effects of climate change on migratory species and a qualitative assessment of the predicted impacts on population size, in so far as this is possible, for each taxonomic group (chapters 4-9). This review draws on published studies of non-migratory species where relevant to assessing the impacts likely on migratory species. In general, we have discussed effects where there is good evidence, in at least some species, that the impact has either occurred, or is likely to occur, based on knowledge of species' ecology. We have consciously eschewed some of the more speculative literature, but have referred to it where appropriate and indicated its nature; of necessity this was more frequent for some taxonomic groups than others.

We then examine in some depth the climate change impacts on a number of species included on the CMS Appendices in a series of Case Studies (Chapter 10). These species were chosen as relatively well-studied or important examples, which highlight the types of impacts climate change may have on migratory species. For each Case Study, we discuss how the impacts relate to those in other migratory species.

Finally, we present, in a series of tables, information on the occurrence of species in UK and UK Overseas Territories and their associated waters and the likely climate impacts that each species might face, often in relation to threats posed by other environmental factors, where known, to illuminate the relative importance of climate change impacts. These assessments are of necessity based largely on expert judgement, although the information presented in the main chapters was used to ground these assessments.

The review was assessed and augmented by a panel of international experts brought together for a two-day workshop in Cambridge. One of the aims of the workshop was to review the robustness of the evidence and to grade the different types of evidence according to the uncertainties involved. The workshop attendants were also able to provide information from other sources, such as research reports and papers in press. The workshop was structured to consider initially the climate change impacts on a taxonomic basis, then to address cross-cutting issues from a functional basis (such as effects on physiology and population dynamics). A second main aim was to consider the policy implications of the biological/ecological results, and a proportion of the invitees were specialists in this area. The combination of ecological and policy experts was also designed to promote synergies between the two fields of expertise. The results of this workshop are presented in Appendix 2.

Before moving onto the review proper, we discuss below some of the more general aspects of the topic, relevant to and providing context for the subsequent sections..

1.2. Certainty in Climate Change Impacts

Weather systems are extremely complex and it is therefore necessary to take into account a very large number of factors when trying to predict patterns of future climatic change. Effects on the marine environment are particularly difficult to predict because of the complex interactions between ocean processes and climate, and will vary greatly between areas; uncertainties about the nature and degree of future climate change make it impossible to know exactly how weather, ocean circulation, and biological productivity will be affected (Weaver and Zwiers 2000). Therefore, predictions of the effects on species and populations are necessarily to some extent speculative (Würsig *et al.* 2002). The impacts of climate change will depend on the time and geographic scale of the environment considered, as well as on the longevity, generation time, and geographic distribution of the species. However, the number of independent models producing similar scenarios continues to increase, validating the methodology and providing increased support for the conclusions drawn. In addition, the predictions made by many such models also agree with recent observations made in the field (Easterling *et al.* 2000), suggesting that our ability to forecast climatic changes continues to improve.

Large but ‘slow’ (in the order of decades or centuries) shifts in the climate have occurred throughout Earth’s history, and these have helped drive the evolution of adaptive characteristics, within-species variations, population discreteness, and extinctions. However, of most concern is the impact of rapid or localised changes in climate, especially on species that depend on limited patches of specific habitat types, such as polar species, nesting turtles, or species with a restricted range (Zöckler & Lysenko 2000; Harwood 2001; Würsig *et al.* 2002).

Modelling the future incidence and distribution of extreme weather conditions such as floods, droughts, tornadoes and hurricanes, is particularly problematic as, by their very definition, these events occur both erratically and infrequently, greatly reducing the opportunity for climatologists to collect sufficient data. As more information is collected, so the predictions generated by models of climate change will become progressively more accurate. Climate modellers currently suggest that it is likely that extreme events will increase in frequency, but that the scale of this change is uncertain (Hulme *et al.* 2002).

Understanding the processes underlying the functioning of ecosystems is an equally complex task, again necessitating the collection of large amounts of data concerning a wide range of potentially important factors. Where species range expansion or contraction occurs in response to climate change, changes in the level of competition and predation may occur (Davis *et al.* 1998a, b; Harrington *et al.* 1999). The potential for invasive and alien species to have detrimental impacts is another important factor that needs to be considered: some species that are currently benign or inhibited from colonising certain areas may change their attributes under future environmental conditions.

Predicting the outcome of interactions between weather conditions and migratory populations is therefore difficult due to the large number of potential mechanisms by which climatic changes may influence the population dynamics. Making such predictions is further complicated by the influence of density dependence. Stenseth *et al.* (2002) point out that climate variability can affect populations in a density-independent manner, but may also affect the strength of density dependence regulating a population. In the absence of such changes, population declines will tend to reduce levels of competition between individuals, potentially increasing survival rates and productivity and acting so as to regulate population size about a certain level. If the strength of density dependence changes, then populations will shift to a different level of abundance. The influence of climate changes on population processes is a largely unexplored area at present.

There are a number of methodological difficulties in studying the impacts of climate change (Fiedler *et al.* 2004; Møller & Merilä 2004). One criticism often levelled at studies of the interactions between weather and population processes is that relationships reported are predominantly correlational, as it is almost impossible to simulate large-scale climatic changes to study these interactions experimentally except by using small-scale and simple model ecosystems involving plants and invertebrates (e.g. Davis *et al.* 1998a, 1998b). It is therefore possible that observed relationships between climatic variables such as temperature and population processes are in fact caused by confounding factors, including habitat destruction, disease, shifts in predation, etc. This is particularly true when considering large-scale climate variability, such as the North Atlantic Oscillation (NAO), as the same (measured) climatic condition may have different effects in different areas. For example, large NAO index values are associated with low precipitation in spring in southern Europe, but heavy precipitation on the breeding grounds of migrants in northern Europe (Møller & Merilä 2004). However, a number of recent meta-analyses (Parmesan & Yohe, 2003; Root *et al.* 2003) have shown that many of the relationships observed hold true across a broad range of taxa, habitats and regions. In addition, in some studies, changes in the direction of the ecological trends are closely matched by changes in direction of the climatic trends (e.g. Crick & Sparks, 1999). As the patterns of variation become more complex, so the probability of both population processes and climatic variables displaying simultaneous fluctuations by chance is reduced, and thus the probability that climatic changes are responsible for the ecological trends observed increases.

1.3. Biological Adaptation to Climate Change

Birds, and other taxa, face a continually changing environment to which they clearly can adapt over time to respond to new pressures and exploit new opportunities. The best studied group in this respect are the birds; the issue of whether birds will be able to adapt to the changing climate is the subject of much recent research and results are still emerging (Pulido & Berthold 2004). It is clear that organisms can adapt (in a genetic sense) to changing climatic conditions, and empirical studies are beginning to emerge demonstrating this (Bradshaw & Holzapfel 2001; Réale *et al.* 2003). Amongst birds, although a number of studies have shown adaptation to climate change, most do not separate the phenotypic component of adaptation from the genetic (Pulido & Berthold 2004). Phenotypic change may be sufficient to allow some populations to adapt to changes in the short-term, but is unlikely to be able to do so in the long-term as changes increase. Perhaps the best documented adaptations involve Darwin's Finches *Geospiza* spp., whose beak morphology can change remarkably rapidly (in either direction) through genetic change depending on prevailing climatic conditions (Grant & Grant 2002; Kinnison & Hendry 2001). However, changes in response to a changed climate need not necessarily be genetic, as demonstrated Przybylo *et al.* (2003), who showed that changes in laying date of Collared Flycatchers *Ficedula albicollis* could be explained entirely by behavioural responses, with no underlying genetic change.

Gene flow is an important consideration in determining a population's ability to respond to environmental changes. Too much mixing of populations over a wide area may slow adaptation to local conditions, however, high levels of inbreeding can also slow adaptive responses, as has been shown for the endangered Red-cockaded Woodpecker of North America (Schiegg *et al.* 2002). It is possible that the spread of southern populations northward may help in adapting northern populations to warmer temperatures by providing an influx of pre-adapted gene complexes (Pulido & Berthold 2004).

Examination of the fossil record suggests that, in the past, adaptation to climatic change has been achieved mostly through range shift than direct adaptive evolution (e.g. Parmesan *et al.* 2000), though the relevance of this to current climate change is questionable (Travis & Futuyma 1993). However, the current rate of climate change is much higher than in the past, and may be too high for animals to adapt sufficiently quickly. Similarly, an increased frequency of extreme events, which can cause large directional selection, may also compromise the ability of populations to adapt to overall or average change, if opposite extremes are both represented. Thus, the extent to which bird populations will be able to adapt intrinsically is unclear, not least because a complex array of factors may be relevant (Sheldon *et al.* 2003).

1.4. Climate Change and other threats

Climate change is only one of many threats faced by migratory species. In general, it is a longer-term threat, whereas anthropogenic threats often present a more urgent threat. The balance of threats will vary with the ecosystem. In marine systems, migratory species face a wide range of threats, of which by-catch (accidental entanglement in fishing gear) is the perhaps the most problematic. Marine pollution is another serious threat that calls for a coordinated international approach. Acoustic disturbance, for example from heavy shipping traffic in the Baltic and North Seas, is a further cause of concern. Amongst terrestrial species, habitat loss, persecution and the impacts of agricultural intensification are particularly widespread. Because quantitative and predictive models of population change are not generally available, it is difficult to assess the relative degree of threat from anthropogenic and climate factors. However, in tropical systems (habitat loss, over-grazing) and marine systems (over-exploitation and by-catch) anthropogenic threats seem to predominate. In polar regions, climate-driven loss of habitat is probably the most serious threat to many species (although future exploitation of oil reserves may become more important in some areas).

Climate threats do not exist in isolation of other, including anthropogenic, threats. Rather the latter are likely to exacerbate the effects of climate change, or prevent adaptation of animals to it. For example, park boundary fences may prevent migratory mammalian herbivores from shifting migratory routes in response to changed rainfall patterns (Whyte & Joubert 1988), and new migratory routes may bring them into greater conflict with humans (Fryxell & Sinclair 1988). Similarly, in marine systems, changes in migratory journeys may place marine species in areas of high exploitation leading to a greater incidence of fishing mortality (as target species or by-catch), and (in the case of marine mammals) greater conflict with humans, with whom they may be perceived as competing for resources (Harwood 2001).

On land, the key interaction between climate change and land management issues will involve changed agricultural practices. Perhaps the biggest impacts will arise from conversion of wetland and marginal habitats. These are habitat types frequently used by migratory birds and bats (and possibly insects), either as staging areas or as migratory corridors. Widespread impacts are also likely from increased water abstraction, which is likely to be greatest in the driest areas, where wetland resources are important to migratory species, particularly as staging areas before or after major ecological barriers (i.e. deserts). Other habitats important for wildlife, which may be threatened with agricultural conversion as a result of a changing climate, include tundra, steppe and chalk grassland and tropical forest.

Consequently, the responses of migratory animals to climate change need to be understood and managed in the context of other threats. In many cases, alteration of other anthropogenic influences may allow (biological) adaptation to the longer-term climate threat. More generally, adaptation to the effects of climate change is likely to require a multi-benefit ecosystem approach. Thus, it is much more likely that conservation goals will be achieved if they are part of ecosystem management with wider aims such as floodplain management, coastal protection or reducing deforestation, all of direct benefit to the inhabitants of the areas concerned, as well as to wildlife. The ecosystem management approach of the Convention on Biological Diversity provides many of the mechanisms for these potential adaptation solutions, but this approach requires the full cooperation of all the stakeholders involved, particularly, the local inhabitants.

2. LEGISLATORY FRAMEWORK

Climate change is one of the major factors likely to affect the earth's ecosystems in the coming years and centuries. The increase in global temperature in the 20th century was the largest in any century during the past 1,000 years and this has been associated with changes in weather patterns, precipitation, snow cover, sea-temperatures and sea-level. The IPCC Special Report on Emission Scenarios projects that globally averaged surface temperature will increase by 1.4-5.8°C between 1990 and 2100 (Nakicenovic *et al.* 2001). The projected rate of warming is much larger than the observed changes during the 20th century and is without precedence during at least the last 10,000 years. There is already compelling evidence that animals and plants have been affected by recent climate change (e.g. Crick 2004, Rehfisch & Crick 2003, Walther *et al.* 2002, Parmesan & Yohe 2003, Root *et al.* 2003). These effects include earlier breeding (e.g. Crick *et al.* 1997; Crick & Sparks 1999); changes in timing of migration (e.g. Sparks & Braslavska 2001); changes in breeding performance (e.g. Thompson & Ollason 2001); changes in population sizes (e.g. Crick 1999); changes in population distributions (e.g. Berry *et al.* 2001; Austin & Rehfisch 2005; Rehfisch *et al.* 2004); and changes in selection differentials between components of a population. Migrant wildlife, by travelling large distances, being subject to a wide range of environmental influences and relying on a wide range of natural resources are particularly likely to be affected by climate change. This review aims to identify the likely range of effects of climate change and to consider how migrant conservation status could be affected by these changes.

The UK Government is party to a number of international treaties and agreements that seek to promote and maintain the conservation status of migrant species of wildlife and Defra takes a lead role for the Government in these areas. Fundamental to these is the convention on the Conservation of Migratory Species (CMS), which is particularly concerned with the conservation of species listed (a) as endangered in Appendix I of the Convention or (b) as having unfavourable conservation status in Appendix II of the Convention. AEWA, ACCOBAMS, ASCOBANS, EUROBATS and the recently agreed ACAP are examples of Bonn Convention agreements (see below). In addition, the Convention on Biodiversity 1992, has led to the development of the UK Biodiversity Action Plan with several Species Action Plans for migratory species. Other key international legal and policy instruments for nature conservation that cover migrant species are the Ramsar Convention and the European Council Birds and Habitats Directives. The maintenance of the conservation status of, and maintenance of suitable habitats for, migrant species is a key part of meeting the UK's international conservation obligations. However, climate change is already beginning to exert impacts on the natural environment and land-use, which may have far-reaching effects on the resources and habitats that migrants require (e.g. Root *et al.* 2003; Parmesan & Yohe 2003). Migrants not only require suitable habitats at each end of their migration, but need suitable conditions and habitat while *en route*. Thus wind speed and direction or ocean currents may be important for the successful completion of a migratory journey, and stop-over sites for resting or foraging may also be of key importance.

2.1. Definition of a Migratory Species

In common with many other behavioural traits, migration is evolutionarily labile and phenotypically plastic (Alerstam 1990; Berthold 2001). That is, individuals are likely to differ to some degree in the extent to which they migrate and the proportion of the population that does migrate may vary through time and these two measures are likely to respond to selective pressures. Consequently, amongst species there is an almost continuous spectrum from those that are entirely sedentary to those composed entirely of long-distance migrants (e.g. Siriwardena *et al.* 2002).

There are several definitions of migration, including the seasonal movement between two geographic locations that is related to the reproductive cycle, changes in temperature, and prey availability (Forcada 2002), the persistent movement between two destinations (Cockeron and Connor 1999) and, the mass directional movements of large number of a species from one location to another (Thain and Hickman 2000). The CMS define a migratory species as 'a significant proportion of whose members cyclically and predictably cross one or more national jurisdictional boundaries'. The basic driving forces for migration are ecological and biogeographic factors like seasonality, spatiotemporal distributions of resources, habitats, predation and competition (Alerstam *et al.* 2003).

The definition of a 'migratory species' is thus, in some senses, arbitrary. For convenience we follow the definition used by the CMS in that a migratory species is one in which 'a significant proportion of whose members cyclically and predictably cross one or more national jurisdictional boundaries'. This definition can be extended to include species whose populations regularly irrupt to some extent each year. This particularly applies to some insects, primarily the Lepidoptera, a significant proportion of whose populations migrate northwards each year, even though individuals may not make the return journey.

2.2. Legislative Background

Migratory species, as considered in this report, cross jurisdictional boundaries on a regular basis, therefore most of the relevant legislation for their conservation tends to be in the form of international treaties and conventions and national legislation tends to be derived from these, though many national site protection measures will also be relevant to migratory species. These may be either species based or site-based (where the sites support important numbers of migratory species) and they exist in a number of instruments (e.g. Boere & Taylor 2004).

Pre-eminent amongst species-based agreements is the Convention on the Conservation of Migratory Species of Wild Animals (CMS), signed in Bonn, Germany in December 1979, and since ratified by 89 parties (UNEP/CMS 2002). It is the only global intergovernmental organization that is established exclusively for the conservation and management of migratory species. CMS is a framework document under which Agreements and Memoranda of Understanding have been formulated for a number of particular taxonomic groups, species and populations (see below).

A number of other international conventions may provide specific coverage for particular groups of migratory species and/or regions, though often their primary focus is elsewhere. These include both biologically-centred texts, such as the Convention of Biological Diversity (CBD) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) as well as other, more general, texts, such as the UN Convention on the Law of the Sea (UNCLOS), which provides for migratory fish.

Site-based agreements may also provide valuable coverage for migratory species by protecting habitat, either on breeding or wintering grounds or, perhaps more importantly, sites used on migratory stopovers. Such instruments include the Ramsar Convention, the World Heritage Convention and the European Council's Birds and Habitats Directives.

In general, these agreements do not have explicit provisions for the effects of climate change on species or sites (UNEP 2001). The major exception to this is Ramsar Convention, which passed a resolution on the climate change impacts on wetlands at its 8th Conference of Parties in 2002. Below we summarise the main provisions of these agreements in relation to migratory species.

2.3. Convention on the Conservation of Migratory Species

The CMS recognises that states have a duty to protect migratory species that live within, or pass through, their jurisdictional boundaries, and that effective population management requires concerted action from all states in which a species spends any part of its life-cycle, so-called 'Range States.

The CMS itself has two main provisions for protection of migratory species, for protection of endangered species (listed on Appendix I of the Convention) and for those that would benefit from internationally co-ordinated efforts (listed on Appendix II of the Convention). Many of the benefits of the CMS stem from its framework nature under which individual instruments may also be concluded, these include a series of legally binding Agreements and also Memoranda of Understanding (MoU) between concerned Range States, for particular species or groups of species.

Appendix I of the CMS provides for protection of species considered to be endangered (i.e. 'in danger of extinction throughout all or a significant portion of its range'). For these species the signatory states will 'strive towards strictly protecting these animals, conserving or restoring the habitats in which they live, mitigating obstacles to migration and controlling other factors that might endanger them'. Parties to the convention shall endeavour to:

conserve (and where feasible restore) habitats of importance to the species.
remove, compensate for or minimise any obstacles to migration.
take action against factors that endanger the species, including the control of relevant non-native species.
prohibit the taking of individuals belonging to these species.

Of these, the first two are likely to be directly influenced by a changing climate (and the third may be indirectly) through causing range changes in non-native species, or limiting areas that may be used by altering their quality (in a very broad sense).

Appendix II of the CMS provides for species that have an 'unfavourable conservation status or would benefit significantly from international co-operation' and the CMS has acted as a framework document under which six Agreements and seven Memoranda of Understanding have been concluded, with birds and marine mammals and reptiles being best represented (see Table 2.1.). In addition to the direct conservation measures summarised in Table 2.1. all provide for greater research into, and raising the awareness of, the conservation issues of each species or species group. None of these thirteen instruments mentions climate change explicitly, even those that have been concluded in recent years when awareness of such issues has been high. However, as with the provisions under Appendix I, the ability to implement many of the measures summarised in Table 2.1., and the manner in which they will need to be implemented, is likely to be affected by the impacts of global changes in climate.

2.3.1. Bats

There are around 1100 species of bats and, being largely nocturnal, relatively little is known about most of them, particularly outside Europe and North America. However, increased agricultural and forest exploitation and general habitat degradation are major threats. They also face a range of more specific threats (Hutson et al. 2001, Mickleburgh et al. 1992).

The CMS provides protection for the 45 species of bats found in Europe (including those that are not migratory) through the Agreement on the Conservation of Populations of European Bats (EUROBATS), which was concluded in 1991 and entered into force in 1994 and covers 48 countries within Europe. To date, 31 countries are Party to the Agreement.

The aim of EUROBATS is to conserve these bats through legislation, education, conservation measures and international co-operation amongst signatories and with those countries that have not yet joined. It requires legal protection standards, while developing and promoting transboundary conservation and management strategies, research and public awareness across the Agreement area. It also assists in finding financial support for mainly cross-border oriented projects. EUROBATS has also developed a wide-ranging Conservation and Management Plan, which is the key instrument for the Agreement's implementation. It addresses issues such as legal requirements, population survey and monitoring, roosts, foraging habitats, the use of pesticides and the promotion of public and professional awareness. It should be seen as a model agreement for the conservation of bats in other areas where protection is less advanced.

The Agreement is developed through its three-yearly Meeting of Parties, with an annual meeting of its Advisory Committee and Intersessional Working Groups. Its spheres of interest cover a wide range of activities, including the compilation of a European atlas of migration, development of Europe-wide population monitoring strategies, educational activities (e.g. for buildings industry), forestry management practices, identification of key underground habitats and their conservation, use of pesticides, impact of wind turbines, impact of bat rabies in Europe and co-ordination of research, management of certain research activities, identification of required research. A large number of Parties (and non-party range states) provide annual or triennial reports on their activities and updates of the status of their bats faunas.

The Council of Europe has published two Species Action Plans (for *Rhinolophus ferrumequinum* and the medium-range migrant *Myotis dasycneme*). The implementation of these plans is to be carried out in co-operation with the European bats Agreement.

In 2004, draft proposals were presented to the CMS to suggest the inclusion of eight additional bat species on the appendices of the Convention (CMS/ScC12/Doc.12. 2004. *Draft proposals for the inclusion of bat species on CMS Appendices*.):

Pteropodidae:	*Pteropus vampyrus*. SEAsia. Fruit bat.
	Eidolon helvum. Africa. Fruit bat
Phyllostomidae:	*Choeronycteris mexicana* .C/N America. Fruit/flower
	Leptonycteris curasoae. S/C/N America. Fruit/flower
	Leptonycteris nivalis. C/N America. Fruit/flower
Vespertilionidae:	*Miniopterus schreibersii*. Old world. Insectivore (African populations)
Molossidae:	*Otomops martiensseni*. Africa. Insectivore
	Tadarida brasiliensis. Americas. Insectivore

Note that although *T. brasiliensis* was included on Appendix I when this Appendix was first developed (1985), there has never been any documented justification for this, nor has CMS identified any activities for the species.

Apart from the above, a more comprehensive list of bat species for which there is some indication of migration is being compiled for the CMS by one of the authors of this report (A.M. Hutson).

2.3.2. Marine Mammals

Being part of the 'charismatic' megafauna, cetaceans (whales and dolphins) are particularly well-covered, both under CMS and other international treaties. Within European waters, cetaceans in the southern half of the continent are the focus of the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Areas (ACCOBAMS), whereas those in northern waters are referred to by the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS). ASCOBANS is the earlier Agreement, having been concluded in 1991 and entering force in 1994; ACCOBAMS was concluded in 1996 and entered force in 2001

ASCOBANS covers all species, subspecies or populations of small cetaceans in the Baltic Sea and North Sea, with the exception of the Sperm Whale *Physeter macrocephalus*, with a particular focus on the Harbour Porpoise *Phocoena phocoena*, which it treats as a 'flagship species'. Small cetaceans in the Baltic and North Seas migrate between their breeding, feeding and overwintering areas, or follow their prey over long distances. In doing so, they cross international borders and face a wide range of human-made threats of which by-catch –(the accidental entanglement in fishing gear) is the most problematic. Marine pollution is another serious threat that calls for a coordinated international approach. Acoustic disturbance, due among other things to heavy shipping traffic in the Baltic and North Seas, is a further cause of concern. The Mediterranean and Black Seas are highly vulnerable ecosystems, being embedded in one of the most industrialized and populated regions of the world. Around 600 million people live in the Mediterranean and Black Seas riverine states (these with tributary rivers to these seas), with a high percentage of coastal urbanization and activities. Additionally, some of the major European rivers discharge into the Black Sea, adding waste drained from half of the European continent. The main threats cetaceans face are direct exploitation and capture, by-catch in fisheries, habitat loss and degradation, contaminants and disturbance from increased vessel traffic. Pressure is most intense on coastal species, but pelagic species can also be severely affected.

ASCOBANS includes a Conservation and Management Plan that briefly describes the conservation, research and management measures that should be applied by the signatories. This plan foresees measures towards the mitigation of marine pollution and the reduction of by-catch, surveys and research about species ecology and population status and the establishment of an international database of cetacean information. Additionally the plan further calls for Parties to adopt national laws to prohibit the intentional taking and killing of small cetaceans where such regulations are not already in force. General guidelines on public awareness and participation are also included in the plan.

Unlike ASCOBANS, ACCOBAMS covers both small and large cetaceans and aims to reduce threats to all cetaceans in its area, promoting closer cooperation amongst signatories with a view to conserving all cetacean species present in the area. ACCOBAMS calls also on its members to enforce legislation to prevent the deliberate taking of cetaceans in fisheries by vessels under their flag or within their jurisdiction, and to minimise incidental catches. As part of ACCOBAMS the International Sanctuary for Mediterranean Mammals was designated (entering force in 2002) in the central Mediterranean region primarily to reduce various man-made threats to cetaceans such as by-catch, maritime traffic or urbanization and industrialisation of coastal areas.

Pinnipeds (seals), like cetaceans are also charismatic species and, following a dramatic decline in seal populations in the Wadden Sea in the late 1980s (from Phocine Distemper Virus), the Agreement on the Conservation of Seals in the Wadden Sea was concluded in 1990 between Germany, the Netherlands and Denmark, entering force in 1991. The aim of the Agreement is to promote close cooperation amongst the Parties in order to achieve and maintain a favourable conservation status for the Common Seal *Phoca vitulina* population, which is an irreplaceable component of the Wadden Sea and an important indicator of its environmental health. At the core of the agreement is the Seal Management Plan (effective until 2006), which builds on the obligations of the Seal Agreement and contains objectives and action points on habitat protection, research and monitoring, pollution and wardening, taking of individuals and public information.

The Seal Management Plan covers the Wadden Sea stock of the Common Seal *P.v.* and is also extended to cover the two breeding stocks of the Grey Seal *Halichoerus grypus* in the Wadden Sea, although the latter species is not covered by the actual Wadden Sea Seal Agreement. The overall aim is restore and maintain viable stocks and a natural reproduction capacity, including juvenile survival, of the Common and Grey Seals.

2.3.3. Birds

Birds are well covered under the CMS with two wide-ranging Agreements (on waterbirds and petrels) and several MoU for particular species or populations. The largest Agreement so far under the CMS, is the African-Eurasian Waterbird Agreement (AEWA), which was concluded in 1995 and entered force in 1999. It covers 235 species of migratory waterbird and 117 Range States throughout Europe and Africa (which includes parts of Canada and central Asia from which some Afro-Eurasian wintering populations derive). The most recently concluded Agreement under the CMS, the Agreement on the Conservation of Albatrosses and Petrels (ACAP) covers the oceanic wandering albatrosses (all 21 species) and petrels (7 species), which mostly occur in the southern hemisphere. It was concluded in 2001 and entered force in 2004. ACAP complements other existing instruments such as the Convention for the Conservation of Antarctic Marine Living Resources and the FAO International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries.

Migratory birds may cross many national boundaries on their annual journeys, so AEWA is predicated on a flyway approach to conserving waterbird populations. A flyway approach entails considering migratory population as biological units, thus all threats that a population of waterbird faces during its journey are identified and addressed; it also ensures populations are covered throughout their life-cycle as a flyway consists of a biologically coherent set of populations. Major threats include, for example, habitat destruction of various kinds, unsustainable hunting or lack of food due to over exploitation of resources. These threats can only be eliminated or mitigated through international cooperation across the flyway. At the core of AEWA is the Action Plan. This provides legal protection of individuals for the species covered (including from disturbance), the establishment and rehabilitation, of protected areas and mitigation of human impacts on waterbird populations, together with guidance on research, monitoring and education. In 2003, the Global Environmental Facility (GEF) agreed to finance a US$12 million project within the AEWA area to enhance and catalyse strategic measures to conserve a network of critical wetland areas that migratory waterbirds depend upon to complete their annual cycle by establishing a network of sites, enhancing technical capacity and improving communication and coordination.

ACAP includes all areas of land or water that any albatross or petrel inhabits, resides in temporarily, crosses, or over-flies at any time on its normal migration routes, which for at least some albatross species may cover the entire southern oceans (Croxall *et al.* 2005). It covers 25 Range States in the Southern Hemisphere including, for example, Argentina, South Africa and New Zealand. The Agreement aims to stop or reverse population declines by coordinating action between the Range States to mitigate known threats to albatross and petrel populations. To achieve this ACAP includes an Action Plan that describes a number of conservation measures to be implemented by signatories. These include research and monitoring, reducing of incidental mortality in fisheries, eradicating of non-native species at breeding sites and reducing of disturbances, habitat loss and pollution.

Memoranda of Understanding have been concluded for four species or populations of birds: the Siberian Crane *Grus leucogeranus* (concluded in 1993, revised 1999), Slender-billed Curlew *Numenius tenuirostris* (1994), Aquatic Warbler *Acrocephalus paludicola* (2003) and the middle European population of Great Bustard *Otis tarda* (2001). Each represents a formal agreement between Range States to implement measures aimed at conserving the species and to provide a common framework for research, monitoring and education.

2.3.4. Other Memoranda of Understanding

Three other Memoranda of Understanding (MoU) have been concluded under CMS, two cover populations of marine turtles and a third the Bukhara Deer *Cervus elaphus bactrianus*.

Marine turtles are the subject of two MoU, one covering populations along the Atlantic coast of Africa (effective July 1999) and in the Indian Ocean and waters of south-east Asia (effective 2001), which between them cover seven species. Major threats to marine turtles include unsustainable exploitation, destruction of nesting and feeding habitats and incidental mortality in fishing operations. Threatened or endangered in many parts of the world, marine turtles are considered as flagship species on which to base interventions aimed at protecting habitats of importance for a myriad of other marine species. At the heart of both MoU is a comprehensive Conservation Plans which focus on the establishment of a database on turtle ecology (distribution, migration patterns, etc), reducing threats (nature and extent of direct exploitation, by-catch rate, impact of coastal management, pollution, etc) and raising public awareness.

The Bukhara Deer is a subspecies of the Red Deer (found in the UK and throughout northern and central Europe), which occurs in central Asia. The MoU covers four Range States: Kazakhstan, Tajikistan, Turkmenistan and Uzbekistan and became effective in 2002. The species is at risk extinction from a number of human threats. Artificial regulation of the water regime, habitat destruction and illegal hunting are the main reasons for the Bukhara Deer's decline in numbers. The Action Plan Concerning Conservation and Restoration of the Bukhara Deer is the main tool for conservation activities under the MoU. The Plan provides for the restoration of the range and number of the Bukhara Deer in suitable habitats, the development of a trans-boundary network of protected areas, legal protection measures and enhanced international cooperation.

2.4. Species-based Instruments

The Convention on Biological Diversity drawn up at the Earth Summit in Rio de Janeiro in 1992, is more of a political statement of intent than a legal instrument. However, it has mobilised efforts in a number of ways, perhaps the most important of these for the UK has been in inspiring the creation of the UK Biodiversity Action Plan and, in particular, the production of 391 Species Action Plans. These include a number of species covered by the CMS, with group plans for baleen and toothed whales and marine turtles being significant (see Table 2.2.). For birds the major problem seems to be loss of habitat, though climate-related effects were cited as causing problems for Spotted Flycatcher (drought on migration sites) and Roseate Tern (flooding of breeding sites). For cetaceans and marine turtles, human activities predominate as having adverse effects, and it is noted that climate change may have an impact on cetaceans, though this will be difficult to predict.

Implementation of the CBD goals in the Overseas Territories has been slow, at least initially, with lack of finances and appropriate legislation being the main hurdles (Cross & Pienkowski 1998). The British Antarctic and Indian Ocean Territories are specifically excluded from the CBD ratification, due to other treaty obligations. However, in 2003 the UK Government launched the Overseas Territories Environment Programme to support the implementation of the Environment Charters within each Territory as well as Multilateral Environment Agreements (including CBD and CMS, as appropriate) to enable the UK and the UKOTs to meet their respective obligations (UKOTCF 2004). The Programme has already supported a range of projects, including a project on *Preparing for and adapting to climate change in the Caribbean* which covers Anguilla, British Virgin Islands, Cayman Islands, Montserrat and Turks & Caicos Islands (Pienkowski 2005).

In the United States of America (US), the primary legislation for the protection of migratory birds is the Migratory Bird Treaty Act of 1918 (http://laws.fws.gov/lawsdigest/migtrea.html), with more recent amendments. This also forms the basis of four bilateral conventions the US has with Canada, Mexico, Japan and Russia for migratory birds that breed in these countries. The primary driver for the act, as with so much early bird protection legislation, was to prevent the taking of birds for the feather trade. The main provisions prohibit, subject to certain exceptions, people to 'pursue, hunt, take, capture, kill, attempt to take, capture or kill, possess, offer for sale, sell, offer to purchase, purchase, deliver for shipment, ship, cause to be shipped, deliver for transportation, transport, cause to be transported, carry, or cause to be carried by any means whatever, receive for shipment, transportation or carriage, or export, at any time, or in any manner, any migratory bird, included in the terms of this Convention . . . for the protection of migratory birds . . . or any part, nest, or egg of any such bird.' Although this treaty does not apply to the UK Overseas Territories directly, many of the species covered by it will occur in the Caribbean OTs and there is some overlap in the species listed with the CMS Appendices (also CITES and the US Endangered Species Act).

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), agreed in 1973, is amongst the largest conservation agreements in existence, now with 167 Signatory Parties and provides for the control of trade of wild animals and plants. Species are listed on three Appendices, according to their degree of threat. Some species listed on the CMS Appendices are also covered by CITES, notably the turtles, sturgeon fish and many of the land mammals and cetaceans.

The exploitation of fisheries is at least partly covered under the United Nations Convention on the Law of the Sea. In particular, it stipulates that contracting parties shall 'ensure through proper conservation and management measures that the maintenance of the living resources in the exclusive economic zone is not endangered by over-exploitation', such measures being designed to restore or maintain populations at levels which produce maximum sustainable yields. For highly migratory fish species (species of tuna, marlin, sailfish, sharks and cetaceans) it directs states to co-operate internationally to ensure the conservation and optimum utilisation of species. It also provides for the conservation of anadromous species (e.g. salmon, sturgeons), which migrate between fresh and salt-water areas at different stages of the life-cycle. Of these migratory species, only sturgeons, Whale Shark *Rhincodon typus* and the cetaceans are covered by the CMS.

Many commercially fished species are migratory, in the sense of the CMS as they regularly cross marine political boundaries and the UN adopted an Agreement on the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks in 1995 aimed at ensuring that the management of these fish stocks is based on the precautionary approach and the best available scientific information, with states co-operating to ensure conservation and promote the objective of the optimum utilization of fisheries resources both within and beyond the exclusive economic zone. These species are, however, not covered by the CMS.

2.5. Site-based Instruments

In Europe, protection is afforded to many species, particularly migratory ones as part of the Convention on the Conservation of European Wildlife and Natural Habitats, signed in Bern 1979, which came into force in 1982. The principal aims of the Convention are to ensure conservation and protection of all wild plant and animal species and their natural habitats (listed in Appendices I and II of the Convention), to increase cooperation between contracting parties, and to afford special protection to the most vulnerable or threatened species (including migratory species).

The Bern Convention was implemented in the EU through two directives: the 1979 Directive on the Conservation of Wild Birds (Directive 79/409; the ‘Birds Directive’) and the 1992 Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora (Directive 92/43; the ‘Habitats Directive’). This latter Directive covers all fauna, including birds (both resident and migratory) and it includes additional provisions, and to some extent supersedes, the earlier Birds Directive. Among other things a primary goal of the Directives is to provide for the establishment of a European network of protected areas (Natura 2000), to tackle the continuing losses of European biodiversity on land, at the coast and in the sea.

Both Directives provide for the maintenance of species populations occurring in the European Union (while taking into account economic/development requirements) by maintaining a sufficient diversity of habitats through the establishment of a network of protected sites (Special Protection Areas (SPA) for birds, Special Areas for Conservation (SAC) for other taxa and habitats. Both Directives also give explicit regard to migration sites as being important in the conservation of species, and state that land planning and development policies should support this network of sites to enhance the potential for migration, dispersal and genetic connectivity. Protection for the sites includes avoidance of pollution, disturbance and habitat deterioration, though mitigation or compensatory measures are allowed to maintain the integrity of the network. Many of the principles in these Directives have also been transferred into UK domestic law through the Conservation (Natural Habitats, etc.) Regulations 1994 and the Offshore Petroleum Activities (Conservation of Habitats) Regulations 2001 (OSPAR).

The Birds Directive makes provision for the special protection of 170 species listed under Annex I and mentions migratory birds, particularly waterfowl as requiring similar levels of protection.

The Habitats Directive makes provision for around 300 animal species, listed under Annex II, that require special protection including the establishment of SACs and for a wider range of animal species or groups of species, in Annex IV, that require full protection (European protected species). The Habitats Directive also requires Member States to endeavour to encourage the management of features of the landscape which are of major importance for wild flora and fauna. These features are those that, because of their linear and continuous structure or their function as stepping stones, are essential for migration, dispersal and genetic exchange. Examples given in the Directive are rivers with their banks, traditional field boundary systems, ponds and small woods.

The Convention on Wetlands of International Importance Especially as Waterfowl Habitat signed in Ramsar, 1971, provides for the protection of migratory waterfowl globally by identifying wetland sites as Wetlands of International Importance. Although the focus is on migratory waterfowl, the convention considers all wetland habitats. Consequently, the definition of a wetland is very broad including e.g. fen and wet peatland, as well as marine areas to 6m depth. In addition to including many sites on which migratory species breed and spend the (boreal) winter, the Register includes many sites that are important as migratory stopovers. Its mission is to 'conserve and promote the wise use of wetlands by national action and international cooperation as a means to achieving sustainable development throughout the world'.

The Ramsar Convention is unusual in that it has explicitly recognised the threats caused by climate change by adopting, at its 8th Conference of Parties in Valencia 2002, a Resolution on Climate Change and Wetlands (van Dam *et al.* 2003; Boere & Taylor 2004). Of particular relevance to migratory species protection are calls upon parties to the Convention to 'manage wetlands to increase their resilience to climate change and extreme climatic events, and to reduce the risk of flooding and drought in vulnerable countries, through promoting wetland and watershed protection' and to 'make every effort when implementing the Kyoto protocol, including re-vegetation and afforestation, that this implementation does not lead to serious damage to the ecological character of their wetlands'. It also notes that work is required in understanding the relationship between wetlands and future climate changes.

2.6. National legislation

At the level of individual countries, for example in the UK, a range of domestic legislation is in place to ensure the conservation of species and habitats. It is usually the case that the requirements of international treaties are broadly met by pre-existing domestic legislation, but some additional legislation may be required to meet all the obligations. Such national legislation tends not to distinguish between migratory and non-migratory species (the US is a notable exception to this).Thus, the scope of domestic legislation can be both broader in application and more restrictive in detail than corresponding international obligations, as it is a general tenet of international treaties that they set minimum standards for contracting parties (Stroud 2003). For example, the 1981 Wildlife and Countryside Act (WCA) was introduced to bring Great Britain in line with the 1979 Berne Convention and EU Birds Directive, followed by the Wildlife (Northern Ireland) Order in 1985. These were later supplemented by the implementations of the EU Birds and Habitats Directives, such as the Conservation (Natural Habitats, etc.) Regulations 1994 (see above). The introduction of the Countryside and Rights of Way (CroW) Act in 2000 (in England and Wales) made enhancements to the WCA, particularly through the provision of custodial sentences for certain offences.

In the UK, and probably in most other countries, the domestic wildlife legislation generally does not include consideration of the impacts of climate change explicitly. One particular provision of the WCA that relates to weather processes concerns the hunting of wildfowl. Such hunting is allowed under Section 2(4) of the WCA for the winter season (Stroud 1992), but the relevant Secretary of State has the power to introduce a temporary close season in response to periods of severe weather. The incidence with which this has been necessary has decreased recently.

Table 2.1. Key provisions of agreements concluded under the CMS for each agreement/ memorandum of understanding with respect to climate change.

		Prohibit Taking	Control Non-natives	Obstacles to Migration	Conserve Food Source	Protect Habitats	Designate Site Network	Climate Change
Agreements								
Wadden sea Seals	1990	Y	-	N	N	Y	Y	N
EuroBats	1991	Y	-	N	N	Y	N	N
ASCOBANS (Cetaceans, Baltic/N. Sea)	1992	Y	-	N	Y	N	N	N
AEWA (migratory waterbirds)	1995	N	Y	Y	N	Y	Y	N
ACCOBAMS	1996	Y	-	N	N	N	Y	N
ACAP (albatrosses & petrels)	2004	Y	Y	N	Y	Y	Y	N
Memoranda of Understanding								
Slender-billed Curlew	1994	Y	-	Y	N	Y	Y	N
Siberian Crane	1999	Y	Y	N	N	Y	N	N
Marine Turtles (Atlantic Africa)	1999	(Y)	-	N	N	Y	N	N
Marine Turtles (Indian Ocean & SE Asia)	2001	N	-	N	N	Y	Y	N
Great Bustard (Middle Europe)	2001	Y	-	Y	Y	Y	Y	N
Bukhara Deer	2002	Y		Y	N	Y	Y	N
Aquatic Warbler	2003	Y		N	N	Y	Y	N

Table 2.2. Species listed on the Appendices of CMS for which UK Species Action Plans are available.

Species	Annex	Species Action Plan
Cetaceans		
Sei Whale	I/II	Baleen Whales
Blue Whale	I	Baleen Whales
Fin Whale	I/II	Baleen Whales
Common Dolphin	II	Small dolphins
Northern Right Whale	I	Baleen Whales
Long-finned Pilot Whale	II	Toothed Whales
Risso's Dolphin	II	Small dolphins
Northern Bottlenose Whale	II	Toothed Whales
White-sided Dolphin	II	Small dolphins
White-beaked Dolphin	II	Small dolphins
Humpback Whale	I	Baleen Whales
Killer Whale	II	Toothed Whales
Common Porpoise	II	Harbour Porpoise
Sperm Whale	I/II	Baleen Whales
Striped Dolphin	II	Small dolphins
Bottlenose Dolphin	II	Small dolphins
Bats		
Barbastelle	II	Barbastelle
Bechstein's Bat	II	Bechstein's Bat
Greater Mouse-eared Bat	II	Greater Mouse-eared Bat
Pipistrelle	II	Pipistrelle
Greater Horseshoe Bat	II	Greater Horseshoe Bat
Lesser Horseshoe Bat	II	Lesser Horseshoe Bat
Turtles		
Loggerhead Turtle	I/II	Marine Turtles
Green Turtle	I/II	Marine Turtles
Leatherback Turtle	I/II	Marine Turtles
Hawksbill Turtle	I/II	Marine Turtles
Kemp's Ridley Turtle	I/II	Marine Turtles
Birds		
Aquatic Warbler	I/II	Aquatic Warbler
Eurasian Bittern	II	Eurasian Bittern
Corncrake	II	Corncrake
Roseate Tern	II	Roseate Tern
Spotted Flycatcher (Muscicapidae)	II	Spotted Flycatcher

3. SCENARIOS OF CLIMATE CHANGE

3.1. Introduction

Our climate is changing (IPCC 2001b). The global average surface temperature has increased over the 20th Century by around 0.6°C and precipitation has increased over the same period, particularly at mid- and high-latitudes. These have had secondary impacts, for instance the extent of ice cover has decreased and global sea-level is rising. Such changes are demonstrable from the global network of climate instruments and, over a longer time-scale, from the use of historical proxies such as tree-rings and ice cores. The causes of such changes are open to more debate, but most of the observed warming over the last fifty years is likely to have been due to increased CO_2 emissions, which are likely to continue. Similar changes have been observed in the UK and Europe (e.g. Hulme *et al*. 2002; EEA 2004).

Because of the global scope of climate and its fundamental effect on the biosphere, changing climates are likely to present a major challenge to the world's wildlife, and overall levels of biodiversity. Changing climates have already been demonstrated to have had a number of impacts on wildlife, across a range of taxa, and these impacts are set to continue at an increasing rate, unless suitable mitigation measures are taken (e.g. Walther *et al*. 2002; Parmesan & Yohe 2003; Root *et al*. 2003; EEA 2004; Leech *et al*. 2004; Parmesan & Galbraith 2004). In a particularly comprehensive review of the impacts of climate change, Parmesan & Yohe (2003) found that, of the 1,598 species considered, 59% showed detectable changes and most (80-90% depending on the climate driver and impact) changed in the manner predicted by regional climate change.

Future changes in the global climate are more difficult to predict. The climate system is comprised a number of components: the atmosphere, oceans, land surface, cryosphere (ice areas) and biosphere (including human influences). Each of these systems is the result of a large array of drivers, and climate is a result of complex interactions between each of the components. The only way to make quantitative predictions about future changes in climate is through the use of global climate models (GCM). These mathematical simulations use physical laws to simulate processes in each component in a three-dimensional grid over the globe. At present, each component subsystem (ocean, atmosphere etc.) is modelled largely in isolation (Nakicenovic *et al*. 2001), although there are likely to be complex non-linear interactions between them – this is an area of extensive model development work using advances in computer power created by distributed computing (e.g. Stainforth *et al*. 2005).

Climate models require some knowledge of how the drivers of climate are likely to change over the period for which predictions are required. Thus scenarios need to be developed which quantify the extent of anthropogenic emissions and natural forcings (eg solar radiation) over the period to be modelled. Currently, there are more than 600 such scenarios existing in the literature (Morita 1999). These scenarios, which cover both global and regional areas, were developed for a variety of purposes and, in sum, consider a large range of possible emission levels. The scenarios include futures in which measures are taken to address emissions (intervention) and those in which no measures are undertaken (non-intervention). In most scenarios, global carbon dioxide emissions are projected to increase. Compared to current (1990) emissions of around 6 gigatonnes per annum (GtC), the models predict future emissions of between 2 and 37 GtC in 2100, with a median of 16 GtC. Non-intervention scenarios predict a greater increase in total emissions with a median of 21 GtC in 2100.

The most extensively used scenarios, currently, are those compiled by the Intergovernmental Panel on Climate Change (IPCC) in its Third Assessment Report (IPCC 2001a,b). In particular they developed a series of marker scenarios, which capture the broad range of variability of all scenarios that have been presented in the literature (Nakicenovic *et al.* 2001). These 'marker' scenarios are often referred to as the SRES (Special Report on Emissions Scenarios) scenarios, after the report in which they were presented. The SRES scenarios describe broad dichotomies between economic and environmental objectives and between global and regional development. Each narrative assumes a distinctly different direction for future developments, but together they encompass a significant portion of the underlying uncertainties in the development of the main driving forces behind climate change.

Although most climate models predict similar trends in carbon emissions, and other variables, it is impossible at this stage to assign probabilities of occurrence to any particular scenario. With the current state of knowledge (and ability to predict future technological developments) each must be considered equally likely. Consequently, in considering future climate change, it is necessary to consider a range of scenarios (Mearns *et al*. 2001). In this section we consider global climate change scenarios first, before going on to discus potential changes in the UK and UKOT climate more specifically.

3.2. Global Climate Change Modelling

Although possible impacts of a changing climate have been discussed since at least the 1960s (e.g. Johnson & Smith 1965), it is only in the last 15-20 years that people have started attempting quantitative predictions of how the climate system will evolve. This is at least partly due to advances in our understanding of how climate processes work, and advances in computational power. At an international level, there is much work in the area of global climates and ascertaining potential changes. In order to achieve consensus between different approaches and research groups, the IPCC was formed by the World Meteorological Organisation and the United Nations Environment Programme, to provide a co-ordinated and broadly agreed view on global climate processes (Houghton *et al*. 1990).

The IPCC has considered the production of predictive models in each of its three assessments on the nature of climate change. At the time of the first assessment in the late 1980s (Houghton *et al*. 1990), predictive climate modelling was in its infancy and the models produced then were further developed in 1992 (Leggett *et al*. 1992; Pepper *et al*. 1992). These models were formally evaluated in 1994 and although they were recognised as ground-breaking at the time, the state-of-the art had moved on and there was room for further development (Alcamo *et al*. 1995; Parikh 1992). Thus, in 1996 a further modelling round was initiated, with an open, inclusive approach to the modelling process and aimed at providing coordinated and consensus approach (Nakicenovic *et al*. 2001).

In assessing the extent of future climate change there are two major areas of uncertainty: in the extent of anthropogenic emissions and, secondly, in the nature of climate processes and their interactions. To capture the range of possible future emissions, the IPCC has developed four broad narratives outlining possible futures (Nakicenovic *et al*. 2001; Table 3.1). These describe broad dichotomies between economic and environmental objectives and between global and regional development. Each narrative assumes a distinctly different direction for future developments, but together they encompass a significant portion of the underlying uncertainties in the development of the main driving forces behind climate change. These narratives cover the spectrum from a technologically intensive future with rapid economic development (A1), to one with slower economic growth and an emphasis on sustainable development (B1). Within the A1 narrative, further scenarios representing alternative technological futures were developed, giving futures with intensive fossil fuel use (A1FI, a ‘worst-case’ with regard to CO_2 emissions), one in which primarily non-fossil energy sources were progressed (A1T), and one with a balance between these options (A1B) were developed. These scenarios are similar to those used in the UK’s Technology Foresight exercise (Berkhout *et al*. 1999). This described the scenarios as World Markets (equivalent to A1), Global Sustainability (B1), Provincial Enterprise (A2) and Local Stewardship (B2) and more detailed descriptions are provided by Parry (2000).

To address model uncertainty, these broad narratives have been developed into forty quantitative scenarios by six modelling teams, using models with varying assumptions about the underlying climate process under the aegis of the IPCC (Nakicenovic *et al*. 2001). Within each narrative, one scenario (the ‘marker’ scenario) has been chosen to be indicative of the likely changes under that narrative. Though this marker scenario is no more, or less, likely than the other scenarios within a narrative it is considered to be typical of the possible outcomes. Between them the six marker scenarios cover the range of outcomes from current models and scenarios in the literature. Most modelling exercises use these scenarios as a basis for their future predictions.

Climate change models obviously simulate climates for varying periods into the future. In order to avoid the effects of annual fluctuation, model results are usually averaged over a period of years, often thirty. Thus, the 'present' is usually taken to be the period 1961-1990. For present purposes we consider climate simulations until the period 2070-2099, referred to as the 2080s.

Mitchell *et al*. (2004) present high-resolution gridded datasets based on four of the IPCC SRES scenarios (A1FI, A2, B1, B2) and four climate models (from the Canadian Centre for Climate Modelling and Analysis, CSIRO (Australia), Hadley Centre (UK) and the National Centre for Atmospheric Research (USA)) giving 16 model-scenario combinations. Between them these 16 model-scenario combinations cover 93% of the uncertainty in global warming until 2100 described by Nakicenovic *et al*. (2001). Because these grids have been derived at high resolution, using a 0.5 degree grid, predictions can be made regionally across the globe (important for migratory species, whose journeys span the globe). As can be seen from Fig 2.1, which presents changes in temperature and precipitation until 2100 for the United Kingdom, the 16 model scenarios give broadly the same results, though there is some scatter.

3.3. UK Climate Change Modelling

Although it is possible to interpolate the global climate grids discussed above to make predictions for individual countries, a more reliable assessment of climate change for smaller areas comes from Regional Circulation Models (RCM). These allow for greater topographical detail, as they often have a resolution of around 50km (compared to 200-300km in GCMs). However, it should be noted that these models are not automatically more 'accurate' than GCMs just because of their greater spatial detail. This spatial detail, is in some ways a hindrance since the underlying physical processes to be modelled will be more complex, and such RCMs are dependent on boundary estimates for their parameters from an underlying GCM.

The leading climate models for the UK have been developed by a team working at the Hadley Centre (e.g. Johns *et al*. 2001). Their latest global climate model (HadCM3) was included in the IPCC's Third Assessment Report (Nakicenovic *et al*. 2001) and in the comparative exercise of Mitchell *et al*. (2004) described above. This model simulates climates on a relatively coarse grid (250-300km over the UK), however, and a finer resolution is needed to assess the spatial pattern of changes at the regional level of the UK. The HadCM3 model was used as the basis for the UK Climate Impacts Program (UKCIP) scenarios, which provide the most comprehensive assessment of climate change impacts in the UK (Hulme *et al*. 2002). UKCIP took a hierarchical approach using the outputs from HadCM3 to set boundary conditions for the finer-scale RCMs (this was, in fact, done in a two stage process, with intermediate 120km models also used). This allows presentation of results, and interpretation of climate change at a 50km scale.

The computational cost, however, of producing such detailed models is such that only a limited number of scenarios that can be simulated. Only scenarios corresponding to the IPCC A1FI (three) and B2 (one) scenarios were explicitly simulated. Results for the other SRES emissions scenarios were estimated using a technique known as 'pattern scaling'. This essentially takes the average results from the three simulated A1 scenarios and scales them according to the emissions level in different scenarios. This introduces an extra degree of uncertainty into the scenario outputs. However, comparison of an appropriate pattern-scaled output with that of the explicitly simulated B2 scenario shows the method is broadly valid, producing comparable results for temperature and rainfall over the UK in most seasons.

A further source of uncertainty with UKCIP outputs is that they are derived from simulations using one climate modelling exercise. Thus they represent only one view of climate processes. The UKCIP scenarios are the only available scenarios at such fine resolution, thus comparing with other scenarios at the same scale is impossible. An attempt, however, has been made to compare the outputs of the HadCM3 model with those of nine other GCMs, though is obviously over a coarser scale (Hulme *et al*. 2002). In general, the HadCM3 performed well compared to these models, with most predictions falling broadly in the middle of the range of those provided by the other GCMs, thus the UKCIP scenario results are likely to be representative of the results that would be achieved had other modelling approaches been taken. The exception to this stems from the extent of summer drought that might be expected in 2100. There was more scatter in outputs between the models for this variable, indicating greater uncertainty in future trends. The HadCM3 model results were at the dry end of the spectrum, indicating that it, perhaps, overestimates the decrease in summer precipitation compared to other models. Similarly, in the comparative exercise carried by Mitchell *et al*. (2004) of four GCMs (under four scenario assumptions), the HadCM3 model yielded projections broadly in line with the other models tested, though summer precipitation was at the low end of the range of simulated outcomes. It should be noted, however, that with the present state of knowledge we don't know whether the HadCM3 is overestimating changes, or the other models are underestimating, either case is plausible.

Despite these difficulties, the UKCIP scenarios are probably the most reliable guide to future climatic changes in the UK. Four scenarios have been developed (using pattern scaling from the simulated A2 scenarios) to encompass the range of uncertainty in emission levels. These are High, Medium High, Medium-Low and Low and broadly correspond to the IPCC marker scenarios A1FI, A2, B2, B1, but the names focus on making the emission assumptions used in each case explicit.

An alternative perspective on climate change in the UK comes from the European ACACIA (A Concerted Action towards a comprehensive Climate Impacts and adaptations Assessment for the European Union) project (Parry 2000). This project used results from eight different GCMs (including HadCM2, the precursor to HadCM3 used by UKCIP) to simulate four climate scenario outcomes. As with the UKCIP project these were based on the IPCC SRES scenarios.

3.4. Projected Climate Change – Terrestrial Systems

3.4.1. Global

Globally, temperatures are expected to increase over the next century, with the projected increase expected to be somewhere in the region of 1.4 to 5.8 °C over the period 1990 to 2100 (IPCC 2001). This projected rate of warming is much larger than observed changes during the 20th century. Warming is likely to be greatest over land areas, particularly at northern high latitudes in winter and lowest in south-east Asia (summer) and southern South America (winter).

It is very likely that precipitation has increased by 0.5 to 1% per decade in the 20th century over most mid- and high latitude areas of the Northern Hemisphere continents, and it is likely that rainfall has increased by 0.2 to 0.3% per decade over the tropical land areas (10°N to 10°S) (IPCC 2001b). In the mid- and high latitudes of the Northern Hemisphere over the latter half of the 20th century, it is likely that there has also been a 2 to 4% increase in the frequency of heavy precipitation events (IPCC 2001b). Global average precipitation is projected to increase during the 21st century, with regional increases and decreases (IPCC 2001b). More intense precipitation events are very likely over many areas (IPCC 2001b).

The UK is home to migratory wildlife from Scandinavia and the Arctic (who spend their winter in the UK). This includes large numbers of bird species, particularly waterbirds (e.g. Austin *et al*. 2004) and thrushes. Similarly, some UK breeding birds spend the winter in southern Europe or Africa, so we briefly consider predicted climate changes in these areas Table 3.4). Temperatures are likely to increase markedly in northern latitudes, but also in Africa. Precipitation in Africa, upon which vegetation is particularly dependent, is likely to decrease, particularly in western and southern Africa, where most of the British populations of birds occur.

The North Atlantic Oscillation (NAO) is a north-south alteration in atmospheric mass between the subtropical atmospheric high-pressure centre over the Azores and the atmospheric subpolar low-pressure centre over Iceland. It measures the strength of the westerly winds blowing across the North Atlantic Ocean between 40^{o}N and 60^{o}N. Variability in the direction and magnitude of the westerlies is responsible for fluctuations in wintering temperatures and the balance of precipitation and evaporation across the Atlantic and the adjoining landmasses. During positive phases of the NAO, the westerly winds are strengthened and moved northward, causing increased precipitation and temperatures over northern Europe and the south-eastern United States and dry anomalies in the Mediterranean region (Planque and Taylor 1998; Stenseth *et al.* 2002).

Warm episodes of the El Niño Southern Oscillation (ENSO), which affects regional variations of precipitation and temperature over much of the tropics, sub-tropics and some mid-latitude areas, have been more frequent, persistent and intense since the mid-1970s, compared with the previous 100 years (IPCC 2001b). Even with little or no change in El Niño amplitude, global warming is likely to lead to greater extremes of drying and heavy rainfall and increase the risk of droughts and floods that occur with El Niño events in many different regions (IPCC 2001b). Climate change scenarios also suggest the NAO will tend to become more positive in the future, resulting more wet, windy, mild winters (Hulme *et al.* 2002). There is a greater frequency in the formation of hurricanes and typhoons when water temperatures are 28^{o}C or above, for example even short-term changes in climate, such as ENSO events can affect the incidence and severity of such storms (IPCC 2001a).

3.4.2. Overseas Territories

Table 3.2 shows that temperatures are likely to increase in all UKOTs by 2100. The degree of warming is similar across all territories and is likely to be in the order of 1 to 3 ˚C on the basis of these projections. The two territories in the Mediterranean region (Gibraltar and the Cyprus SAFB) are likely to experience a greater degree of warming than elsewhere. The South Atlantic Islands show least projected warming. Considering the summary of models presented by Mitchell *et al.* (2004) for the Overseas Territories, precipitation levels are likely to decrease generally in the two Mediterranean territories, though there is some uncertainty over this in the combined model projections, particularly in the summer months. Amongst the Caribbean territories, projections are mixed, with projecting increased precipitation, others a decrease. There is a tendency towards projection of an increase in the autumn and winter months (September through February) and a decrease in the summer months, but this must be regarded as uncertain. Precipitation is likely to increase by small amounts throughout the year in the south Atlantic territories (South Georgia and the Falkland Islands). However, predictions for such small island territories from global circulation models (which have a resolution of 200-300km) are likely to be tentative at best.

Specific information on the extent of climate change in the UKOTs is scarce. Sear *et al.* (2001) reviewed the evidence for six representative territories: three in the Caribbean, Anguilla, Montserrat and Turks & Caicos Islands; two in the south Atlantic: St Helena & Tristan da Cunha, and the Pacific island of Pitcairn. They suggested that although the trends were clear the magnitude of the change was uncertain, though the impacts might be felt as early as 2015. They predict an estimated increase in temperature of 3.5°C by 2100, in the middle of the range projected by the IPCC (2001), but at the upper end of the range of model scenario combinations reviewed by Mitchell *et al.* (Table 3.2). Further, they advise planning for the worst-case scenario, which they quote as a 6°C rise in the Caribbean territories and a 5°C rise in the Atlantic territories. Perhaps the most important factor in determining climate of the Overseas Territories (which are generally island groups) is the El Nino Southern Oscillation (ENSO) system. The relationship between global warming and the ENSO are poorly understood, but the current trend towards more frequent, and more extreme, events is likely to continue, resulting in greater seasonal differentiation, more storms, and a greater incidence of floods (El Nino events) and droughts (La Nina events). It is uncertain whether the frequency of tropical cyclones will increase, but it is likely these will become more intense, with greater peak wind speeds, more intense rainfall and greater storm surges. The Caribbean Territories are likely to be especially vulnerable to such increased storminess.

3.4.3. United Kingdom

Possible future changes in UK climate are given in Table 3.5. Consistent with the scenario-based approach taken in regard to the global climate, the Table gives ranges of potential change from the different simulations performed by each project. Although the two listed approaches differ in quantitative detail over the range of changes that might occur, there is broad agreement over the direction of changes for most variables. The biggest discrepancy is over changes summer precipitation, but there is likely to be small-scale regional variation in this, which will be captured to differing extents by the two approaches as UKCIP uses a RCM, whereas ACACIA used several GCMs which average out much of the regional variation, thus this difference may be more of an artefact than real. Throughout the UK, winters over the last 200 years have become wetter relative to summers, with a larger proportion of winter precipitation in all regions falling on heavy rainfall days compared to 50 years ago (Hulme *et al.* 2002). Climate change scenarios for the UK predict that winter precipitation will increase, with increases ranging from 10 to 35% by the 2080s. The pattern for summer precipitation is reversed, with almost the whole of the UK becoming drier (Hulme *et al.* 2002).

Within the UK, all models reviewed by Mitchell *et al*. (2004) project precipitation to increase outside the summer months. During summer the HadCM3 model projects large decreases in precipitation and the CGCM2 model predicts small decreases, the other two models included project small to moderate increases. The projected changes in mean temperature and precipitation from these two exercises are broadly in line with those obtained from the more detailed analyses outlined above. Thus, there seems to be a general consensus over both the direction and magnitude of climate change in the UK, at least for the more easily measured variables of temperature and precipitation.

3.5. Projected Climate Change – Marine Systems

3.5.1. Temperature

Globally the average surface temperature (the average of near surface air temperature over land, and sea surface temperature) has increased over the 20th century by 0.6 ± 0.2^{o}C, with an increase of 0.4 to 0.7^{o}C in marine air temperature and a 0.4 to 0.8^{o}C increase in sea surface temperature since the late-19th century (IPCC 2001b). The global ocean heat content has increased significantly since the late 1950s, with more than half of the increase in heat content having occurred in the upper 300 m of the ocean, equivalent to a rate of temperature increase in this layer of about 0.04^{o}C/decade (IPCC 2001b). The globally averaged surface (sea and land) temperature is projected to increase by 1.4 to 5.8^{o}C over the period 1990 to 2100 (IPCC 2001b). Projections indicate that the warming would vary by region (IPCC 2001a).

In most areas of the North Atlantic during 2003, temperature in the upper water layers remained higher than the long-term average, with new records set in several regions (ICES 2004). Over the northern North Sea, average air temperatures have risen by 0.8^{o}C since 1960. Since 1995, winter sea temperatures in Scottish coastal waters have been warming faster than summer ones, resulting in a smaller annual range each year. The overall trend is one of warming, with an increase in coastal sea temperatures of about 1^{o}C since 1970. Winter seabed temperatures at fishing grounds in the North Sea show a long-term warming trend since the 1970s. Over the last 30 years, Scottish offshore waters have also warmed by between 1^{o}C and 1.5^{o}C. In oceanic waters at the edge of the UK's continental shelf there has been a steady rise in temperature over the past 100 years (FRS 1998; FRS 2003). There has been an overall warming of UK coastal waters, with an increase in annually-averaged temperature of about 0.6^{o}C over the past 70 to 100 years, with a substantial increase over the last 20 years (Hulme *et al.* 2002). Climate change scenarios for the UK predict that the annual temperature across the UK may rise by between 2^{o}C and 3.5^{o}C by 2100 (see Table 3.5). The temperature of UK coastal waters will also increase, although not as rapidly as over land. However, offshore waters in the English Channel may warm in summer by between 2°C and 4°C over the same period (Hulme *et al.* 2002).

In the UK Overseas Territories the projected temperature increases by 2100 are 0.8-5.8°C for Montserrat, Turks and Caicos Islands and Anguilla; 0.7-5.2°C for St Helena and Tristan da Cunha; 0.6-6.4°C for Pitcairn Island (Sear *et al.* 2001). These increases in temperatures are also valid for sea surface temperature around the coasts of these islands. However, changes in ocean currents and up-welling may lead to variations that cannot be predicted and could directly impact the marine ecosystem in these areas (Sear *et al.* 2001).

3.5.2. Sea Levels

Tide gauge data show that global average sea level rose between 0.1 and 0.2 metres during the 20th century (IPCC 2001b). Global mean sea level is projected to rise by between 0.09 and 0.88 metres between 1990 and 2100. The geographical distribution of sea level change results from, for example, the variation in thermal expansion and changes in salinity, winds and ocean circulation. Therefore the range of regional variation is substantial compared with the global average sea level rise (IPCC 2001b).

Around the UK the average sea level is approximately 10 cm higher than it was in 1900, after adjusting for natural land movements (Hulme *et al.* 2002). Climate change scenarios predict an increase in sea level around the UK coast although this will vary with location. By the 2080s sea level may be between 2 cm below and 58 cm above the current level in western Scotland and between 26 and 86 cm above the current level in southeast England, depending on the climate change scenario. Extreme sea levels, occurring through combinations of high tides, sea level rise and changes in winds, are also predicted to become more frequent in many UK coastal locations (Hulme *et al.* 2002).

Under natural conditions, increases in sea levels would cause inter-tidal habitats, such as mudflats and salt marshes, to retreat inland. As habitat is lost by inundation on the seaward edge, so new habitat will develop at the landward edge, with the total area remaining relatively constant. However, such a retreat is prevented in many areas of the UK by the presence of sea defences or human habitation (Pethick & Crooks 2000; Crooks 2004). If retreat is not possible, submergence of the seaward edge of these habitats will reduce their total area, a process known as ‘coastal squeeze’ (Lee 2001).

3.5.3. Ocean Circulation

In the Arctic, more freshwater from melting snow and ice will be released into the North Atlantic through the Fram Strait between north-eastern Greenland and Svalbard. This could exert a strong influence on salinity in the North Atlantic, shift the Gulf Stream current, and even affect upwelling related to the Great Ocean Conveyor Belt current system.

Most models show a weakening of the ocean thermohaline circulation leading to a reduction of heat transport into high latitudes of the Northern Hemisphere. The current projections using climate models do not exhibit a complete shut-down of the thermohaline circulation by 2100. Beyond 2100, the thermohaline circulation could completely, and possibly irreversibly, shut-down in either hemisphere (IPCC 2001b). Climate change scenarios predict a weakening of the Gulf Stream during the 21st century, perhaps by as much as 25% by 2100; a complete shut-down of the Gulf Stream is not predicted in any climate models (Hulme *et al.* 2002).

3.5.4. Sea-ice Extent

There has been a retreat of sea-ice extent in the Arctic spring and summer by about 10 to 15% since the 1950s. It is likely that there has been about a 40% decline in Arctic sea-ice thickness during the late summer to early autumn in recent decades and a slower decline in winter sea-ice thickness (IPCC 2001b). In the Northern Hemisphere snow cover and sea-ice extent are projected to decrease further

(IPCC 2001b). Over the past 100 to 150 years, observations show that there is very likely to have been a reduction of about two weeks in the annual duration of lake and river ice in the mid- to high latitudes of the Northern Hemisphere (IPCC 2001b).

3.5.5. Changes in salinity

Changes in salinity may occur as a result of increased evaporation with increased temperature and changes in ocean circulation. There may also be more localised changes as a result of changes in precipitation and associated river input and land run-off or the melting of ice sheets.

In most areas of the North Atlantic during 2003, salinity in the upper layers remained higher than the long-term average, with new records set in several regions (ICES 2004). The salinity of Scottish oceanic waters has generally increased, with values approaching the highest recorded over the past 100 years. This may indicate the arrival of warmer, saltier waters from further south in the Atlantic (FRS 1998).

In southern North Sea fishing areas (e.g. German Bight), there is an apparent trend of decreasing salinity at the seabed in winter, which may be linked to freshwater inputs from rivers around the coast (FRS 2003). Inshore waters off the north-east of Scotland have experienced a decrease in salinity in the past 5 year (FRS 2003).

3.5.6. Storm frequency, Wind Speed and Wave Conditions

Over the northern North Sea average wind speeds have become 2 knots faster since 1960 (FRS 1998). Waves in the North Sea have increased in size, by about 20 cm every 10 years, as a result of increases in the average wind speed (FRS 1998). Around the UK coastline there was an increase in average wave height of 10-15% between the 1980s and 1990s. The roughening wave climate over the last 40 years is likely to result from a change in the strength of the NAO (Hulme *et al.* 2002). In the last decade the UK has experienced an increase in gale frequency, although this is not unprecedented in the historic record as gale frequencies are also related to the NAO (Hulme *et al.* 2002).

Table 3.1. IPCC Narratives of future change until 2100 (from IPCC 2001b)

Narrative	Description
A1	Very rapid economic growth, and a rapid introduction of new technologies; global population increases until mid-century and declines thereafter; there is convergence among regions, capacity building and a substantial reduction in differences in regional per capita income.
A2	Economic development occurs regionally, with economic growth and technological change more fragmented; populations increase continuously.
B1	Population increases and then decreases as in A1, but with rapid changes in economic structures towards a service and information economy; introduction of clean, resource-efficient technologies; global solutions to sustainability, but without additional climate initiatives.
B2	Emphasis is on local solutions to sustainability; continuously growing population, though at a lower rate than A2; intermediate economic growth with less rapid and more diverse technological change than A1 or B1

Table 3.2. Modelled changes in seasonal temperature in the UK and its overseas territories between the present (1961-90) and the 2080s (2070-2099) in ˚C. Data are derived from an ensemble of four climate models and four emissions scenarios (Mitchell *et al*. 2003). Seasons are labelled with respect to the northern hemisphere, so Spring refers to March – May; Summer: June - August; Autumn: September - November; and Winter: December - February. Overall change is provided where the 5% and 95% probabilities are either both positive or both negative.

Territory	Season	Median	5%	95%	Change
United Kingdom	Spring	1.9	1.4	2.7	Increase
	Summer	2.1	1.0	3.6	Increase
	Autumn	2.6	1.7	3.4	Increase
	Winter	2.4	1.4	3.2	Increase
Gibraltar	Spring	3.0	1.8	5.8	Increase
	Summer	3.6	2.5	7.4	Increase
	Autumn	3.1	1.8	5.4	Increase
	Winter	2.6	1.6	3.8	Increase
Cyprus SAFB	Spring	2.6	1.4	3.9	Increase
	Summer	3.4	1.9	4.8	Increase
	Autumn	3.1	1.9	4.2	Increase
	Winter	2.6	1.6	3.7	Increase
Bermuda	Spring	2.2	1.3	3.2	Increase
	Summer	2.2	1.3	3.5	Increase
	Autumn	2.4	1.2	3.8	Increase
	Winter	2.3	1.4	3.5	Increase
British Virgin Islands	Spring	2.1	1.2	3.3	Increase
	Summer	2.1	1.2	3.0	Increase
	Autumn	2.0	1.3	3.0	Increase
	Winter	2.1	1.0	3.2	Increase
Turks & Caicos	Spring	2.2	1.2	3.5	Increase
	Summer	2.1	1.2	3.3	Increase
	Autumn	2.4	1.2	3.4	Increase
	Winter	2.2	1.2	3.4	Increase
Anguilla	Spring	2.1	1.0	3.3	Increase
	Summer	2.0	1.0	3.1	Increase
	Autumn	2.0	1.2	3.0	Increase
	Winter	2.1	1.0	3.2	Increase
Montserrat	Spring	2.1	0.8	3.2	Increase
	Summer	2.0	1.0	3.0	Increase
	Autumn	2.0	1.2	3.0	Increase
	Winter	2.1	1.0	3.2	Increase
Cayman Islands	Spring	2.0	1.2	3.4	Increase
	Summer	2.0	1.0	3.4	Increase
	Autumn	2.2	1.3	3.3	Increase
	Winter	2.0	1.2	3.1	Increase
British Indian OT	Spring	1.9	1.2	3.1	Increase
	Summer	2.0	1.3	3.3	Increase
	Autumn	2.0	1.2	3.4	Increase
	Winter	1.9	1.2	3.1	Increase

Territory	Season	Median	5%	95%	Change
Ascension Is.	Spring	1.8	0.9	3.2	Increase
	Summer	1.9	1.2	3.3	Increase
	Autumn	1.8	1.0	3.3	Increase
	Winter	1.6	0.8	3.1	Increase
St Helena	Spring	1.9	0.8	3.2	Increase
	Summer	2.0	1.0	3.3	Increase
	Autumn	1.8	1.1	3.3	Increase
	Winter	1.8	1.0	3.2	Increase
Tristan da Cunha	Spring	1.9	1.0	3.0	Increase
	Summer	1.8	1.2	2.8	Increase
	Autumn	1.8	1.2	2.8	Increase
	Winter	1.8	0.8	3.0	Increase
Falkland Islands	Spring	1.7	1.0	2.6	Increase
	Summer	1.6	1.0	2.6	Increase
	Autumn	1.6	0.8	2.6	Increase
	Winter	1.6	1.0	2.6	Increase
South Georgia	Spring	1.4	0.6	3.0	Increase
	Summer	1.6	0.8	3.0	Increase
	Autumn	1.4	0.2	3.2	Increase
	Winter	1.2	-0.1	3.1	

Table 3.3. Modelled changes in seasonal precipitation in the UK and its overseas territories between the present (1961-90) and the 2080s (2070-2099) in mm. Data are derived from an ensemble of four climate models and four emissions scenarios (Mitchell *et al*. 2003). Seasons are labelled with respect to the northern hemisphere, so Spring refers to March – May; Summer: June – August; Autumn: September – November; and Winter: December - February. Overall change is provided where the 5% and 95% probabilities are either both positive or both negative.

Territory	Season	Median	5%	95%	Change
UNITED KINGDOM	Spring	19.8	14.5	32.6	Increase
	Summer	7.4	-55.7	18.4	
	Autumn	11.4	4.4	26.3	Increase
	Winter	33.7	8.7	58.6	Increase
Gibraltar	Spring	-29.0	-57.1	-8.8	Decrease
	Summer	-14.8	-25.5	-2.2	Decrease
	Autumn	-16.8	-41.1	6.3	
	Winter	-8.9	-48.0	9.8	
Cyprus SAFB	Spring	-17.9	-56.2	-2.7	Decrease
	Summer	4.5	-7.1	32.6	
	Autumn	-14.7	-33.6	13.1	
	Winter	-17.6	-52.6	9.8	
Bermuda	Spring	-1.0	-62.8	58.7	
	Summer	0.1	-16.8	58.8	
	Autumn	24.9	-44.0	189	
	Winter	64.5	-5.2	161	
British Virgin Islands	Spring	-21.9	-89.7	92.0	
	Summer	-32.8	-144	48.9	
	Autumn	-9.8	-126	55.4	
	Winter	-10.8	-39.4	40.4	
Turks & Caicos	Spring	-5.8	-53.7	49.0	
	Summer	-9.1	-120	42.9	
	Autumn	18.6	-64.9	83.0	
	Winter	40.6	-2.4	106	
Anguilla	Spring	-15.2	-92.6	108	
	Summer	-50.4	-147	6.4	
	Autumn	-20.7	-119	58.1	
	Winter	-6.8	-38.4	26.8	
Montserrat	Spring	-25.8	-81.5	105	
	Summer	-64.2	-172	8.5	
	Autumn	-1.5	-119	57.0	
	Winter	-15.0	-27.9	19.7	
Cayman Islands	Spring	0.9	-93.8	78.0	
	Summer	1.7	-185	78.0	
	Autumn	12.4	-135	57.0	
	Winter	30.7	-74.4	63.8	
British Indian OT	Spring	34.2	-3.7	187	
	Summer	14.2	-9.7	82.3	
	Autumn	39.4	-125	109	
	Winter	62.6	-64.0	142.7	

Territory	Season	Median	5%	95%	Change
Ascension Is.	Spring	14.0	-352	59.6	
	Summer	-30.5	-84.5	16.7	
	Autumn	2.2	0.8	27.4	Increase
	Winter	-28.8	-98.4	13.8	
St Helena	Spring	-28.0	-71.8	5.6	
	Summer	-4.0	-38.1	10.1	
	Autumn	-3.7	-12.0	3.5	
	Winter	-4.4	-11.2	17.0	
Tristan da Cunha	Spring	4.2	-14.4	49.7	
	Summer	19.7	1.8	36.2	Increase
	Autumn	18.2	-3.2	33.0	
	Winter	-2.2	-14.4	21.3	
Falkland Islands	Spring	2.1	-3.9	14.8	
	Summer	11.6	-17.1	26.6	
	Autumn	-1.6	-13.6	11.2	
	Winter	3.9	-9.7	14.5	
South Georgia	Spring	19.1	6.1	35.1	Increase
	Summer	5.0	-6.9	28.1	
	Autumn	18.9	3.3	26.2	Increase
	Winter	20.1	7.0	29.6	Increase

Table 3.4 Modelled changes in seasonal temperature in the UK and areas used by migratory species occurring in the UK, between the present (1961-90) and the 2080s (2070-2099) in ˚C. Data are derived from an ensemble of four climate models and four emissions scenarios (Mitchell *et al*. 2003). Seasons are labelled with respect to the northern hemisphere so Spring refers to March – May; Summer: June – August; Autumn: September - November and Winter: December - February

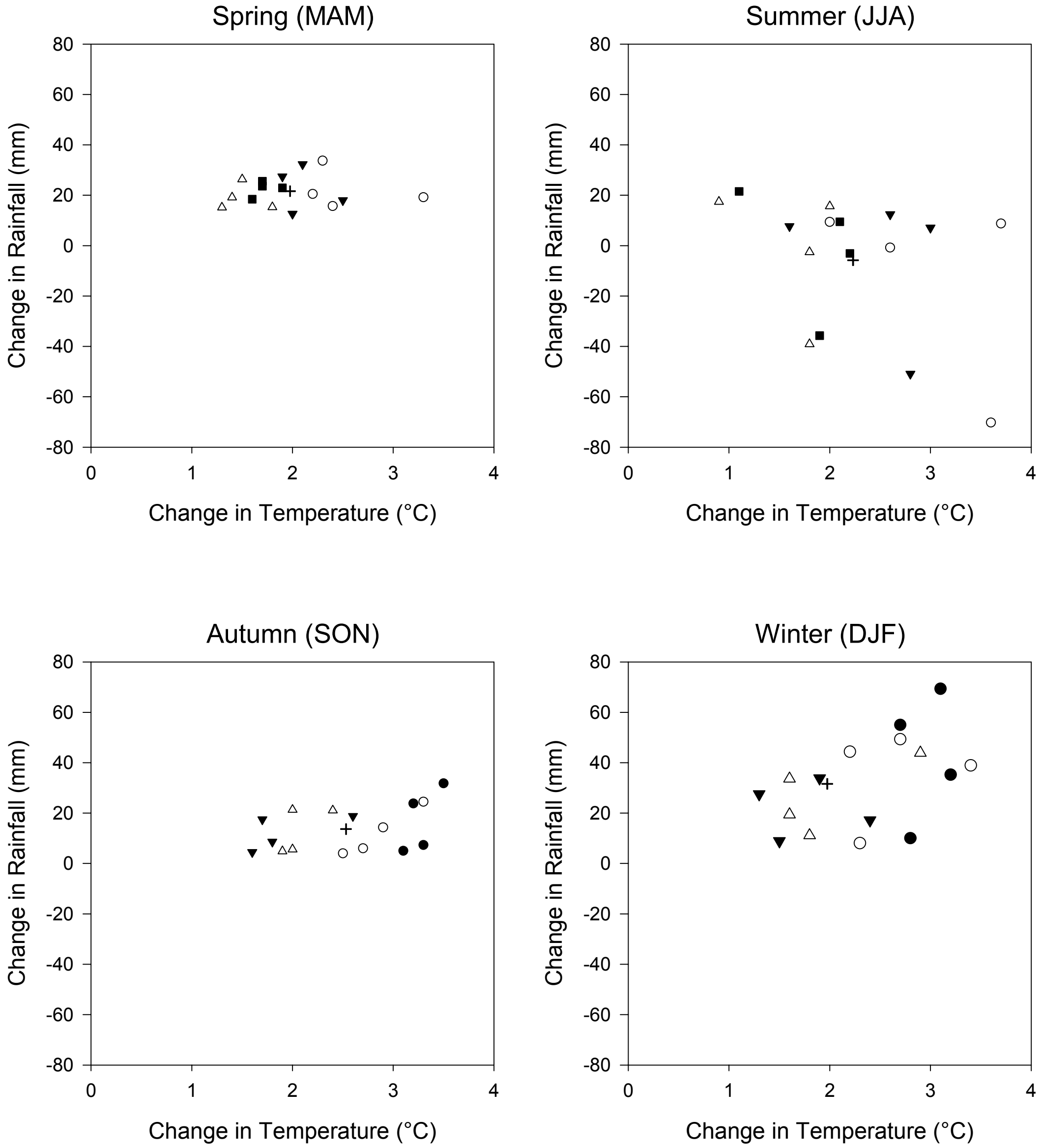
Territory	Season	Median	5%	95%	Change
United kingdom	Spring	1.9	1.4	2.7	Increase
	Summer	2.1	1.0	3.6	Increase
	Autumn	2.6	1.7	3.4	Increase
	Winter	2.4	1.4	3.2	Increase
Fennoscandia	Spring	4.2	2.5	7.3	Increase
	Summer	3.0	1.9	4.7	Increase
	Autumn	3.5	1.8	5.1	Increase
	Winter	4.9	3.1	7.2	Increase
Iberia	Spring	2.6	1.7	4.4	Increase
	Summer	3.9	2.0	7.6	Increase
	Autumn	3.3	1.7	5.0	Increase
	Winter	2.5	1.6	3.7	Increase
Sahelian Region	Spring	3.6	2.0	5.9	Increase
	Summer	3.3	1.5	5.6	Increase
	Autumn	3.5	1.8	6.0	Increase
	Winter	3.5	2.4	5.7	Increase
West Africa	Spring	2.6	1.4	4.5	Increase
	Summer	2.4	1.1	3.8	Increase
	Autumn	2.6	1.5	4.5	Increase
	Winter	3.2	2.0	6.0	Increase
South Africa	Spring	2.7	1.6	5.4	Increase
	Summer	3.0	1.5	5.1	Increase
	Autumn	3.2	1.9	5.2	Increase
	Winter	2.7	1.8	4.7	Increase

Values for each region were calculated by averaging the relevant values for each country within the region, weighted by the area of the country. Countries included in each region *Fennoscandi*a: Finland, Norway, Sweden; *Iberia*: Portugal, Spain; *Sahel Region*: Gambia, Mali, Mauretania, Niger, Senegal; *West Africa*: Benin, Côte d'Ivoire, Ghana, Nigeria, Sierra Leone, Togo.

Table 3.5 Summary of changing climate from the present until the 2080s from two climate scenario models covering the UK (UKCIP) or Europe (ACACIA).

Variable	UKCIP	ACACIA
Temperature		
Mean Temperature	+2˚C to +5˚C	+0.8˚C to +3.2˚C
Spring Timing	1-3 wks earlier	-
Extreme Summer Temperatures	Increase	9-10x Increase
Extreme cold Winters	-	Disappear
Precipitation		
Mean Precipitation	0% to –15%	Variable
Summer Precipitation	Decreased	0% to +8% (N) 0% to –15% (S)
Soil Summer Moisture	-40%	Decrease
Winter Precipitation	Increased	Increased
Extreme Winter Precipitation	Increase	-
Snowfall	-30% to –90%	-
Other		
Sea-level Rise	-2 to +58 cm (NW) +26 to +86 cm (SE)	+5 to +90cm (NW) +35 to +140cm (SE)
Extreme Sea Levels	Increase	-
Gales	-	Increase

Figure 3. Predicted changes in seasonal temperature and rainfall for the UK between the present (1961-90) and the 2080s (2070-2099). Data are derived from an ensemble of four climate models and four emissions scenarios (Mitchell *et al.* 2003) and each symbol represents a different SRES marker scenario (see text). The cross-hair indicates the mean change averaged across all scenarios. The same scale has been used on each graph to facilitate comparison.



4. CLIMATE IMPACTS ON MARINE MAMMALS

Global climate change will affect the physical, biological and biogeochemical characteristics of the oceans and coasts. Large-scale and regional impacts of climate change on the marine environment that have been observed and are predicted include an increase in temperature, a rise in sea levels, changes in ocean circulation, a decrease in sea-ice cover, changes in salinity, increases in CO_2 concentrations, changes in rainfall patterns, changes in climate pattern/variability, an increase in storm frequency and storm surges, an increase in wind speeds and changes in wave conditions, and extreme weather events (FRS 1998; Hansen *et al.* 2001; IPCC 2001a; Sear *et al.* 2001; Hulme *et al.* 2002; FRS 2003; ICES 2004).

The effect of climate change on the marine environment therefore has the potential to have, and in some cases has already had, a considerable impact on the marine ecosystem and species. These effects include changes in abundance, distribution, timing and range of migration, community structure, the presence and species composition of competitors and predators, prey availability and distribution, timing of breeding, reproductive success and, ultimately, survival (IWC 1997; Tynan and DeMaster 1997; Harwood 2001; Würsig *et al.* 2002). Migratory marine species, by travelling large distances and being subject to a wide range of environmental influences are particularly likely to be affected by climate change at some point of their life cycles. While some species may increase in abundance or range, climate change will increase existing risk of extinction of some more vulnerable species. The geographical extent of the damage or loss, and the number of systems affected, will increase with the magnitude and rate of climate change (IPCC 2001a).

Uncertainties about the nature and degree of future climate change make it impossible to know exactly how weather, ocean circulation, and biological productivity will be affected (for example, Weaver and Zwiers 2000). Effects on the marine environment are especially difficult to predict because of the complex interactions between ocean processes and climate, and will vary greatly between areas. Therefore, predictions of the effects on species and populations are speculative (Würsig *et al.* 2002). The impacts of climate change will depend on the time and geographic scale of the environment, as well as on the longevity, generation time, and geographic distribution of the species (Würsig *et al.* 2002). For example, large but ‘slow’ (in the order of decades or centuries) shifts in the climate have occurred throughout the Earth’s history, and these have driven the evolution of adaptive characteristics, population discreteness, and extinctions (Würsig *et al.* 2002). However, of most concern is the impact of rapid or localised changes in climate, especially on species that depend on limited patches of specific habitat types, such as ice and land-breeding seals, coastal whales and dolphins, and dugongs and manatees (Harwood 2001; Würsig *et al.* 2002).

Marine mammals include the order Cetacea (mysticetes (baleen whales) and odontocetes (toothed whales, dolphins and porpoises)), the order Sirenia (dugongs and manatees), and many members of the order Carnivora: the polar bear *Ursus maritimus*, the sea otter *Enhydra lutris* and marine otter *Lutra felina*, and the pinnipeds (true seals, sea lions, fur seals and walruses). Marine mammals are found in just about all ocean habitats, as well as several rivers and inland seas. In the open ocean marine mammal species may be thought of as ‘surface dwellers’, that spend most of their entire lives within about 200 m of the surface, or ‘deep divers’, that routinely dive to depths below 500 m. Several species are semi-pelagic occurring in areas between shallow and deep water, often at the edge of the continental shelf or some other underwater feature. Many marine mammals are coastal, with baleen whales, odontocetes, pinnipeds, sirenians, sea otters and marine otters all having coastal species.

4.1. Range & Distribution

A species’ distribution is affected by a combination of demographic, evolutionary, ecological, habitat-related and anthropogenic factors, although in general prey availability (Forcada 2002). Species habitat preferences are generally thought to relate to prey availability, which may in turn be determined by physical oceanographic features. Therefore the habitat preferences of marine mammals are often defined by physical and chemical characteristics of the water, which define water masses and current boundaries where prey accumulates. For example some species, such as Heaviside's *Cephalorhynchus heavisidii*, Commerson's *Cephalorhynchus commersonii* and Peale's *Lagenorhynchus australis* Dolphins, are associated with cold-water currents and Blue Whales *Balaenoptera musculus* are often found in areas of cool upwelling waters (Forcada 2002; LeDuc 2002). Therefore, although marine mammals are observed widely across the world's oceans, distribution within their overall range is often patchy, with some areas being used more frequently than others. These 'preferred' areas are probably particularly important for survival and reproduction, and it is changes to these areas that are most likely to affect the distribution and abundance of marine mammals (Harwood 2001).

The range of marine mammals can generally be related to water temperature, Table 7 of the Appendix outlines the temperature range preference of marine mammal species and if the species have been recorded in the UK or UK Overseas Territories. For example, Bowhead Whales *Balaena mysticetus* and Narwhals *Monodon monoceros* are found only in Arctic waters, Atlantic White-beaked Dolphins *Lagenorhynchus albirostris* are found in cold temperate waters, and species such as Spinner *Stenella longirostris* and Pantropical Spotted *S. attenuata* Dolphins are found in tropical waters (Mann *et al.* 2000). A species range may be limited in some cases because a species is not adapted for living in certain environments. For example, tropical delphinids may not range into higher latitudes due to limitations on their abilities to thermoregulate in colder water or find food in different habitats. Competition, either from closely related species or from ecologically similar species, may also exclude a species from a particular region in which it could otherwise survive, i.e. competitive exclusion (Forcada 2002). However, whether the relationship between the range of many marine mammal species and water temperature is direct, with species only being able to survive within specific temperature ranges, or indirect with temperature affecting competitive abilities of ecologically similar species, is unknown in most cases.

4.2. Migration

The basic driving forces for migration are ecological and biological factors, such as seasonality, spatiotemporal distributions of resources, habitats, predation and competition (Alerstam *et al.* 2003). Within a species range, there may be regular changes in their distribution as their biological and ecological requirements change (Forcada 2002). The triggers for migration may relate to changes in day length but, as the timing of migrations can vary from year to year, prey abundance may also be an important factor, and temperature and sea ice formation can also be influential (Stern 2002).

Most baleen whales (mysticetes), such as Blue, Grey *Eschrichtius robustus*, Fin *Balaenoptera physalus*, Sei *Balaenoptera borealis*, Northern and Southern Right Whales *Balaena glacialis* and *B. australis* and Humpback Whales *Megaptera novaeangliae*, undertake long seasonal migrations between tropical calving grounds in winter and high latitude feeding grounds in summer. For example Grey Whales are highly migratory with an annual migration covering up to 15,000-20,000 km between summer feeding grounds in Arctic or sub-arctic waters and winter breeding grounds in temperate or sub-tropical southern waters (Jones and Swartz 2002). Bowhead Whales also migrate, but their longitudinal movements are equal to or greater than their latitudinal movements, and they never leave Arctic waters. The migration or seasonal movements of Bryde's *Balaenoptera edeni* and Minke *Balaenoptera acutorostrata* Whales are often less well defined and predictable than other migratory baleen whales (Forcada 2002).

Baleen whale migrations have generally been regarded as a response to the need to feed in colder waters and reproduce in warmer waters. Explanations for such long-range migrations have included (i) direct benefits to the calf, for example increase in survival in calm, warm waters, (ii) evolutionary reasons, i.e. leftover from times when continents were closer together, (iii) the possible ability of some species to supplement their food supply from plankton encountered on migration or on calving grounds, (iv) reducing the risk of killer whale predation of new born calves in low latitudes and (v) species with a large body size (and lower mass specific metabolic rates) are able to make the long migrations that allow them to take advantage of warmer, and predator free, waters (Thain and Hickman 2000; Bannister 2002; Stern 2002).

The movements of toothed whales (odontocetes) vary more in scale, depending on geographic areas and species, with most movements thought to be made in response to prey availability (Forcada 2002). For example, some Sperm Whales *Physeter macrocephalus* undertake long seasonal migrations similar to those of baleen whales, between high latitude feeding grounds and warmer water breeding areas (Whitehead 2002). Large seasonal movements often occur in oceanic odontocetes, for example *Stenella* species and Common Dolphins *Delphinus delphis*. Coastal Bottlenose Dolphins *Tursiops truncatus* exhibit a full spectrum of movements, including seasonal migrations, year-round home ranges, periodic residency and occasional long-range movements (Wells and Scott 2002). Bottlenose Dolphins living at the high-latitude or cold-waters extremes of the species' range may migrate seasonally, for example along the Atlantic coast of the United States (Wells and Scott 2002). North-south and inshore-offshore seasonal movements have been observed in several odontocete species, including Harbour Porpoise *Phocoena phocoena* (Northridge *et al.* 1995; Anderson *et al.* 2001; Bjørge and Tolley 2002).

Dispersal and migration is common in several pinniped species. Sea lion species tend to live in warmer areas where food resources are more constant, thus there is less dispersal from breeding sites. However Phocidae species (true seals) that live in higher latitudes, which are more dependent on ice cover and seasonally changing prey, tend to have a wider dispersal. For example, Northern *Mirounga angustirostris* and Southern Elephant *Mirounga leonina* Seals spend between 8 and 10 months at sea each year, with long-distance migrations from breeding and moulting sites to feeding areas (Forcada 2002). Polar Bears *Ursus maritimus* undertake seasonal migrations, and these long-range movements are generally related to ice cover and seal distribution (Forcada 2002). Sirenians, such as Florida Manatees *Trichechus manatus latirostris*, also embark on seasonal movements in which water temperature is a major determinant factor (Reynolds and Powell 2002).

Shifts of species range occur when mobile or migratory animals, such as pelagic fish and marine mammals, move or migration destinations change and these movements can track climatic fluctuations (IPCC 2001a). Ranges of migratory or mobile species can be very sensitive to climate and individuals can show an immediate response in their migratory destinations. Therefore, as with climatic data, a long time series is required to distinguish year-to-year variation from long-term trends (IPCC 2001a; Walther *et al.* 2002).

Migration and the range of marine mammals have evolved within constantly changing environmental conditions. Species have adapted to historic changes in climate. However, many of these changes, such as the retreat of the polar front in the Pleistocene, occurred at a rate that allowed species to adapt. Although marine mammals are capable of adapting to environmental changes, it is unclear if they will be able to adapt at the rate of climate change predicted in the near future (Stern 2002). The effects of climate change on migratory as well as resident species are likely to be through changes in distributions of prey in both time and space and, ultimately, how this affects reproductive success and survival (Stern 2002). Wild species have three possible responses to climate change: (i) change geographical distribution to track environmental changes; (ii) remain in the same place but change to match the new environment, through either plastic response, such as shifts in phenology (for example timing of growth, breeding etc.) or genetic response, such as an increase in the proportion of heat tolerant individuals; or (iii) extinction (IPCC 2001a).

4.3. Potential effects and impacts of increasing temperature

The potential impacts of climate change on marine mammals can be (i) direct, such as the effects of reduced sea ice and rising sea levels on seal haul-out sites or a species tracking a specific range of water temperatures in which they can physically survive, and (ii) indirect, such as the potential impacts on reproductive success through the effects on the distribution and abundance of prey or the structure of prey communities at specific locations. In this section, examples of observed effects relating to climate that may give an indication to the possible impacts of climate change are given, where possible, for mysticetes (baleen whales), odontocetes (toothed whales, dolphins and porpoises), pinnipeds (seals, sea lions and walruses), sirenians (manatee and dugong) and polar bears, based on published accounts and reports.

4.3.1. Potential Direct Effects

The most likely direct effects of changes in water temperature on marine mammals are shifts in species ranges as species track preferred or required temperature conditions. Baleen whales are less likely than other marine mammals to be directly affected by an increase in temperature because of their mobility and thermoregulatory ability, although calves may be more susceptible than adults (IWC 1997). The majority of baleen whales, such as the Blue, Grey and Fin Whales, migrate large distances and experience temperature variations between their polar feeding grounds and tropical breeding grounds. However, several species have a more restricted distribution for example Bowhead Whales are found only in the polar waters of the Arctic and may be uniquely heat intolerant (IWC 1997; Bannister 2002) (see Appendix I for generalised distribution of Mysticetes).

Toothed whales (odontocetes) are more likely to be directly affected by changes in water temperature than baleen whales, as several species are limited in the range of water temperature they inhabit, for example, Belugas *Delphinapterus leucas* are restricted to polar and cold temperate waters in Arctic Seas. As water temperatures change, species that inhabit specific ranges of water temperature would be expected to shift their geographic ranges to track preferred or required temperature conditions. However, for several species there may be physical limits to their ability to track these changes. For example, the endangered Vaquita *Phocoena sinus*, whose distribution is limited to the warm waters at the northern end of the Gulf of California, and river dolphins, Baiji *Lipotes vexillifer*, Ganges River Dolphin *Platanista gangetica*, Boto *Inia geoffrensis* and Tucuxi (*Sotalia fluviatilis*), may be particularly vulnerable. Some individuals in a population may also be more susceptible, for example finless porpoise *Neophocaena phocaenoides* calves (IWC 1997). Increased variation in sea temperature, especially in coastal areas may also be important, for example a mass mortality of Bottlenose Dolphins in the Gulf of Mexico has been linked to an unusual cold water event (IWC 1997).

Changes in water temperature will also directly affect pinnipeds and sirenians. For example, the distribution of the manatee is influenced by temperature, with waters colder than 20°C increasing the manatees' susceptibility to cold stress and cold-induced mortality. Therefore increase in sea temperature (i.e. extension of 20°C isotherm) could lead to an increase in range directly related to changes in temperature (Reynolds and Powell 2002; Würsig *et al.* 2002).

4.3.2. Potential Indirect Effects

The direct and indirect effects of climate change on prey species can have several indirect effects on marine mammals, including changes in distribution, abundance and migration, community structure, susceptibility to disease and contaminants, and reproductive success. Climate change may also indirectly affect marine mammal species through competition with other marine mammals.

Marine mammals and baleen whales in particular, require dense patches of prey, such as crustaceans (copepods, euphausiids or krill, amphipods, shrimp), cephalopods (squid) and schooling fish (such as Herring *Clupea harengus*). Therefore the distribution, abundance and migration of baleen whales reflects the distribution, abundance and movements of these prey dense patches, which have been linked to oceanographic features including fronts, eddies and primary productivity. These factors, and hence the formation of dense prey patches, can be affected by several factors including temperature. For example, the distribution of feeding whales, such as North Atlantic Right Whales, can be predicted by surface temperature and bathymetric variables, such as depth and slope, due to their effects on prey distribution. Changes in plankton distribution, abundance and composition have been linked to climate changes (see Section 6.1), therefore marine mammals, such as baleen whales, that depend on plankton species will be affected by these shifts in distribution and changes in abundance.

The distribution, abundance and migration of odontocetes are strongly influenced by prey distribution. For example, in the Faeroe Islands where there is a long history of traditional drive harvest of Long-finned Pilot Whales *Globicephala melas*, (catch statistics are available for almost 300 years), peaks in catch rates are correlated with periods of warmer temperatures and the occurrence of their main prey, the Pelagic Squid *Todarodes sagittatus*. The occurrence of the Pelagic Squid may be influenced by temperature directly, or indirectly through effects on hydrography or productivity, which in-turn influences the distribution and abundance of the Pilot Whales (Bjørge 2002). Temperature can directly and indirectly affect the biology, distribution, abundance and migration of several fish and cephalopod species (see Section 6.1), which in turn will affect the distribution and abundance of marine mammals that feed on them.

For example, changes in species distribution have also been related to increases in temperature, indirectly through the effects on prey. During the 1982-83 El Niño event, near-shore Bottlenose Dolphins expanded their range from southern to central California and have stayed in the new northern range well after the warming event subsided in the mid-1980s. It is believed that movement of prey, rather than water temperature itself may have caused the range expansion (Wells and Scott 2002) (Wells *et al.* 1990)). Bottlenose Dolphins off the north-east coast of Scotland are at the northern limit of their distribution. There is evidence of a recent range expansion, the causes of this are unknown, but they may be related to changes in prey abundance and/or distribution (Wilson *et al.* 2004.). A recent expansion in range of fur seals in the sub-Antarctic Indian Ocean has been related to climate and the effects on prey. For example, the re-establishment of Antarctic fur seals on Heard Island in the past 50 years coincides with warmer temperature, glacier recession, and hypothesised improved food supplies (Shaughnessy and Green 1998).

Shifts in a species range may be in response to climate change directly or indirectly as a result of changes in prey distribution or availability, and/or interactions with other species (Davis *et al.* 1998). Changes in the cetacean community of north-west Scotland have been related to recent ocean warming. There has been a decline in the relative frequencies of strandings and sightings frequencies of White-beaked Dolphins, a colder water species and a relative increase in strandings and sightings of Common Dolphins, a warmer water species (MacLeod *et al.* 2005). The results suggest a possible range expansion of Common Dolphins and a decrease in range of White-beaked Dolphins, which may be due to the direct effects of changes in temperature or indirect effects, such as competitive exclusion. This has potentially serious implications for White-beaked Dolphins, which are generally found in cold water less than 200m deep around north-west Europe, as their ability to respond to climate change by tracking suitable habitat may be restricted. This may lead to a decline in abundance or the species' distribution becoming fragmented (MacLeod *et al.* 2005).

Climate related changes in cetacean community structure have also been associated with El Niño events. During the 1982-83 El Niño, when near-bottom spawning Market Squid (*Loligo opalescens*) were absent from the southern California area as were the Short-finned Pilot Whales *Globicephala macrorhynchus* that normally feed on them (Shane 1994). The absence of Pilot Whales was followed several years later by an influx of Risso's Dolphins *Grampus griseus* feeding on the returned Market Squid. The Risso's Dolphins may have taken advantage of the temporarily vacant niche left by the pilot whales, apparently as a result of the El Niño event (Shane 1995).

Changes in temperature, through the effects on prey availability, can have potentially serious impacts on the reproductive success of marine mammals. For example, a decrease in the North Atlantic Right Whale a decrease in calf survival has been related to the effects of climate variability on prey abundance (Greene and Pershing 2004). Female Fin Whales, in years of great food abundance at the summer feeding grounds, might produce a calf in consecutive years, whereas in poor years the cycle can be extended to three years. In female Fin Whales, there appears to be a close correlation between food abundance, body fat condition and fecundity (Lockyer 1981). It is thought that ovulation is suppressed if a certain threshold level of body weight or fat is not attained. Similar strategies have also been observed in terrestrial animals, for example Red Deer *Cervus elaphus* (Boyd *et al.* 1999). Calving intervals and the sex-ratios of calves in Humpback Whales have been related to maternal condition; females in a 'superior' condition had a calving interval of 3 or more years and the sex-ratio of their calves was biased towards males (Wiley and Clapham 1993).

Observations of sea surface temperature and the abundance of Sperm Whale calves near the Galápagos Islands suggest that females have a lower rate of conception after periods of warm sea surface temperature, usually caused by ENSO events. Although the relationship between increased sea surface temperature and the abundance of calves is tentative, it is supported by poor foraging success of female and immature Sperm Whales during warm conditions when primary productivity is suppressed (Whitehead 1997). Therefore any increase in temperature as a result of global warming and/or the frequency and duration of El Niño events could have serious implications for populations such as Sperm Whales in the Galápagos Islands (Whitehead 1997).

Differences in reproductive success have also been related to prey availability in odontocetes, pinnipeds and sirenians. For example in Harbour Porpoise from the Bay of Fundy, changes in the growth and age of sexual maturity have been linked to changes in prey availability (Read and Gaskin 1990). In Antarctic Fur Seals *Artocephalus gazelle* the duration of pregnancy is longer and birth dates later in years associated with reduced prey availability (Boyd 1996). Reproductive failure, especially in the form of high juvenile mortality affected several seal colonies, including Galápagos Fur Seals *Artocephalus galapagoensis*, during the major El Niño year of 1982. This massive recruitment failure was attributed to shifts in prey distribution, as at least some lethal and sub-lethal effects were linked to starvation (Würsig *et al.* 2002). For sirenians there appears to be considerable potential plasticity of life history parameters in response to food availability, with food shortages probably causing sirenians to reproduce later and less often (Boyd *et al.* 1999).

Breeding in many species may be timed to coincide with maximum abundance of suitable prey, either for the lactating mother or the calf at weaning. Therefore, any changes in the environmental conditions that determine prey abundance may cause a mismatch in synchrony between predator and prey, either in time or location. Migratory species that travel long-distances between feeding and breeding areas may be particularly vulnerable to this mismatching. The uncoupling of phenological relationships has important implications for trophic interactions (see Section 6.2). Changes associated with climate change that cause mismatches in the food chain, and the effects on prey species, are likely to have serious implications from marine mammals.

Increased susceptibility to disease, starvation and the exposure to contaminants have been related to changes in prey type or reduced prey availability (Thompson *et al.* 1997; Geraci *et al.* 1999; Geraci and Lounsbury 2002; Würsig *et al.* 2002). For example, marked inter-annual variation in food availability, diet composition and body condition of Harbour Seals *Phoca vitulina* were associated with physiological responses, such as differences in haematological parameters. Differences observed in leukocyte counts could have resulted from immuno-suppression, for example because of differences in prey nutrient or contaminant levels (Thompson *et al.* 1997).

Insufficient prey availability results in the use of blubber reserves and the associated mobilisation of any accumulated contaminants, such as organochlorines, organobromines and polyaromatic hydrocarbons (Aguilar *et al.* 1999; Reijinders and Aguilar 2002). The majority of persistent organic pollutants and toxic elements have the potential to cause immune, reproductive and endocrine disrupting effects (Helle *et al.* 1976; Fuller and Hobson 1986; Reijnders 1986; Kuehl *et al.* 1991; Aguilar and Borrell 1994; de Swart *et al.* 1994; Kuehl *et al.* 1994; Kuiken *et al.* 1994; Borrell *et al.* 1996; ICES 1998; O'Shea *et al.* 1998; Brouwer 1999; Cole *et al.* 1999; Jepson *et al.* 1999; WWF 1999; Ross *et al.* 2000; Hoffman *et al.* 2001; Learmonth 2001; Reddy *et al.* 2001).

The frequency and severity of toxic algal blooms are likely to increase as a result of nutrient enrichment (increased rainfall and run-off) and increased temperature. Fatal poisonings have occurred in cetaceans, pinnipeds and manatees (Geraci and al. 1989; Hernández *et al.* 1998; Geraci *et al.* 1999; Scholin *et al.* 2000; Domingo *et al.* 2002; Geraci and Lounsbury 2002; Gilmartin and Forcada 2002). Changes in precipitation, pH, water temperature, wind, dissolved CO_2 and salinity can affect water quality in estuarine and marine waters, and some marine disease organisms and algal species are strongly influenced by one or more of these factors. Climate change has the potential to increase pathogen development and survival rates, disease transmission, and host susceptibility (Harvell *et al.* 2002).

Higher temperatures may also stress organisms, increasing their susceptibility to some diseases, especially if they are at the upper end of their thermal tolerance (Lafferty *et al.* 2004). Climate change is expected to affect the range and migratory patterns of many marine mammals, which in turn could lead to a spread of viruses and the introduction of novel pathogens. In the past two decades there has been an apparent increase in large-scale mortality events such as morbillivirus infections which caused massive die-offs of Striped Dolphins in the Mediterranean Sea and seals in Europe, although the actual causes are not fully understood (Kennedy *et al.* 1992; Aguilar and Raga 1993; Cebrian 1995; Kennedy 1996; Geraci *et al.* 1999; Harvell and al. 1999; Kennedy 1999; Van Bressem and al. 2001; Domingo *et al.* 2002; Geraci and Lounsbury 2002).

4.4. Potential Impacts of Rising Sea-Levels

Cetaceans, both baleen whales and odontocetes, are unlikely to be directly affected by rises in sea levels, although important habitats for coastal species and species that require coastal bays and lagoons for breeding, such as Grey and Humpback Whales could potentially be affected (IWC 1997). Pinniped haul out sites for breeding, nurseries and resting are likely to be directly affected. For example, rising sea levels could eliminate already scarce haul-out sites of the Mediterranean Monk Seal *Monachus monachus*, especially by the flooding of caves that provide the only refuges for some groups (Harwood 2001; Würsig *et al.* 2002).

The construction of sea wall defences and protective measures for coastal habitats against increasing sea levels could potentially impact coastal marine species and possibly interfere with migration routes. For example, in Florida between 1974 and 1996 about 4% of Manatee deaths were due to crushing and drowning in flood gates or canal locks. Dams or other structures have also obstructed the normal migration routes of Manatees along rivers in South America and West Africa (Reynolds and Powell 2002).

4.5. Potential Effects of Changes in Ocean Currents

The range of marine mammals that are associated with fronts between waters masses, such as the Antarctic convergence in the southern Ocean, could be directly affected by changes in ocean currents and the positions of associated fronts. In the Southern Ocean the Antarctic convergence, an oceanic front between cold southern polar waters and northern temperate waters, is an important physical feature that defines the normal southern extent of the distributions of most tropical and temperate marine mammals. The ocean temperature can change by as much as 10^oC across the Antarctic convergence, which may only be a few miles across (Boyd 2002). The segregation of male and female sperm whales is associated with the Antarctic convergence, with only male sperm whales found within the Southern Ocean during summer, and females and young males remaining north of the polar front throughout the year (Boyd 2002).

Changes in ocean mixing, deep water production and coastal upwelling will have profound impacts on the status, sustainability, productivity and biodiversity of the coastal zone and marine ecosystem (IPCC 2001a). Changes in ocean currents will directly affect the distribution, abundance and migration of plankton, many fish and cephalopod species (for example, Planque & Taylor 1998, Waluda *et al*. 2001, Walther *et al*. 2002), which in turn will affect marine mammals. For example, in the Barents Sea fluctuations in the influx of Atlantic water affects the location of the polar front and water temperature. This influences the distribution and species composition of the primary and secondary production, with subsequent effects on the distribution and diet of Minke Whales (Bjørge 2002).

4.6. Potential Effects of a Decrease in Sea Ice Cover

4.6.1. Potential Direct Effects

Seals that rely on ice for breeding are likely to suffer considerable habitat loss with a decrease in sea ice extent, particularly vulnerable may be species that are confined to inland seas and lakes, such as the Caspian Seal (*Phoca caspica*), the Baikal Seal (*Phoca siberica*, and subspecies of the Ringed Seal (*Phoca hispida lagodensis* and *P. h. saimensis*) which will be limited in their ability to track the receding ice cover (Harwood 2001).

During the breeding season, the ice on which pinnipeds haul out must be thick enough and persist long enough for completion of the critical stages of birth, feeding of the pups, and in many cases, completion of their annual moult (Burns 2002). Ice characteristics can affect the distribution and activity patterns of pinnipeds, with pack-ice offering a more constant substrate than fast-ice, which is highly variable with season. For pinnipeds that reproduce in fast ice, the duration of lactation and rearing of their young strongly depends on ice conditions (Forcada 2002). Ice-breeding pinnipeds in the Arctic include Ringed Seals, Bearded Seals *Ergnathus barbatus*, Harp Seals *Pagophilus groenlandicus*, Hooded Seals *Cystophora cristata*, Ribbon Seals *Histriophoca fasciata*, Spotted Seals *Phoca largha*, some populations of Grey Seal *Halichoerus grypus* and Walruses *Odobenus rosmarus* (Burns 2002). Ringed Seals, Bearded Seals and Walruses, which rely on suitable ice substrate for resting, pupping and moulting, may be particularly vulnerable to changes in sea ice extent (Tynan and DeMaster 1997). For example earlier spring break-up of ice together with lower snow depths suggest a continued low pup survival of Ringed Seals in western Hudson Bay (Ferguson *et al.* 2005). Antarctic ice-breeding species include the Weddell Seal *Leptonychotes weddellii*, Ross Seal *Ommatophoca rossii*, Crabeater Seal *Lobodon carcinophaga* and Leopard Seal *Hydrurga leptonyx* (Boyd 2002) (see Appendix I for list of breeding sites of pinnipeds).

Polar Bears require ice as a solid substrate on which to hunt and rear their offspring. The distribution of Polar Bears is probably a function of the distribution of ice conditions that allow them to hunt and travel most efficiently, especially in areas of ice floes, between foraging areas and areas where they give birth and rear their young. Therefore any changes in the extent and type of ice cover are expected to affect the distributions, foraging and reproductive success of Polar Bears (Tynan and DeMaster 1997; Forcada 2002). In western Hudson Bay there has been a significant decline in the condition of adult male and female Polar Bears, along with an overall decline in the proportion of independent yearling cubs between 1981 and 1998, during which period the break up of the sea ice has been occurring earlier. Observations suggest that the decline in physical and reproductive parameters of polar bears in western Hudson Bay reflect the earlier break up of the ice causing the bears to come ashore in poorer conditions (Stirling *et al.* 1999).

Open water areas, such as annually recurring polynyas (areas within the pack ice that are almost always clear of ice) driven by upwelling or wind, variable shore leads or cracks, or tidal- and wind-driven openings in the sea ice are critical for several marine mammal species, such as Walrus, Belugas, Narwhals and Bowhead Whales (Heide-Jørgensen and Laidre 2004). Although global warming has reduced sea ice formation in the Arctic this trend is not uniform and any changes in the timing and distribution of these important open water areas will have direct and severe implications for the marine mammals dependent on them (Tynan and DeMaster 1997; Heide-Jørgensen and Laidre 2004; Laidre and Heide-Jørgensen 2005).

4.6.2. Potential Indirect Effects

Changes in the extent and concentration of sea ice may alter the seasonal distribution, geographic ranges, patterns of migration, nutritional status, reproductive success, and ultimately the abundance and stock structure of some species (Tynan and DeMaster 1997). Melting ice-sheets in the Arctic will reduce ocean salinities, which in turn may cause highly variable shifts in the distribution and biomass of major constituents of Arctic food webs. These changes in the distribution and abundance of prey will also strongly affect more mobile whales such as the Bowhead, Belugas and Narwhals, as well as species such as pinnipeds and polar bears (Tynan and DeMaster 1997; Laidre *et al.* 2004). For example, periods of decline in the production of Ringed Seals, and consequently Polar Bears, have been linked with ice conditions, possibly as a result of a reduction in regional productivity causing poor nutritional condition in the seals (Tynan and DeMaster 1997).

Large baleen whale species that undertake long distance migrations from tropical breeding grounds to high-latitude feeding grounds close to the ice edge may be at risk as the polar ice caps retreat. The longer migration paths that will be required will increase the costs of movement and reduce the duration of the feeding season (Stern 2002). Species, such as the Grey Whale, that use the Arctic for summer feeding grounds are likely to experience disruptions in the timing and distribution of their food sources (Tynan and DeMaster 1997). Migratory species within the Artic will also be affected, for example the migrations of Belugas and Narwhals are both linked to the spring production of ice algae and ice-edge productivity (Tynan and DeMaster 1997). Warming in the Arctic will cause changes in species compositions, with a tendency for poleward shifts in species assemblages and loss of some polar species (Tynan and DeMaster 1997).

In the Southern Ocean, climate change is likely to produce long-term, perhaps irreversible, changes in the physical oceanography and ecology. Projected reductions in sea-ice extent are likely to alter under-ice biota and spring bloom in the sea-ice marginal zone and are likely to cause profound impacts to all levels in the food chain, from algae to krill to the great whales (Fraser and Hofmann 2003). Marine mammals which have life histories that tie them to specific breeding sites, such as Weddell, Ross, and Crabeater seals, are likely to be severely affected by shifts in their foraging habitats and migration of prey species associated with a decrease in sea ice extent. For example, the growth and survival of seal pups are directly influenced by krill abundance. Declining krill abundance in the region of the Antarctic Peninsula during the 1990s has been linked to low winter sea ice extent (Boyd 2002; Fraser and Hofmann 2003).

4.7. Potential Impacts of Changes in Salinity

The salinity of the surface waters of the open ocean varies between 32 practical salinity units (psu) in the sub-arctic Pacific to 37 psu in subtropical gyres. At the coastal and polar limits of the ocean and in marginal seas, processes such as local precipitation and evaporation, river runoff and ice formation can result in salinities of less than 10 and greater than 40 psu. Many marine mammals have adapted to tolerate variations in salinity (Fiedler 2002). Therefore variations in salinity related to climate change are unlikely to have a direct physiological effect on marine mammals. However, changes in salinity, for example with changes in river inputs/run-off and melting ice, will influence the distribution and abundance of prey through effects on stratification and circulation and possibly also due to limited salinity tolerance (Fiedler 2002). This is an area in which very little work has been done to date.

Changes in salinity, for example with changes in river inputs/run-off and melting ice, will influence the distribution and abundance of prey through effects on stratification and circulation and possibly also due to limited salinity tolerance, for example cephalopod species may be particularly sensitive to changes in salinity (Boyle 1983, Fiedler 2002). Shifts in the phytoplankton community structure, from diatoms to cryptophytes, in the near shore coastal waters along the Antarctic Peninsula have been linked to glacial melt-water runoff and reduced surface water salinities. This shift in phytoplankton community structure directly affects the zooplankton assemblage. Antarctic krill do not graze efficiently on cryptophytes due to their small size, and an increase in the relative abundance of cryptophytes will cause a shift in the spatial distribution of krill. This in turn will affect higher trophic levels in the food web as krill is an important prey species for several seabird and marine mammal species (Moline *et al*. 2004).

4.8. Potential Impacts and effects of Changes in Weather Patterns

4.8.1. Rainfall

More intense precipitation events and flash floods will result in increased run-off. Thus increased nutrients into coastal waters, combined with increase in water temperatures could cause an increase in toxic algal blooms (see 4.3.2). Increased run-off may also cause an increase in pollutants, including sewage, with potential effects on coastal species. The effects of eutrophication play an important role in phytoplankton seasonal and community dynamics in the southern North Sea (Edwards *et al*. 2001). Changes associated with changes in rainfall patterns, for example decreases in salinity in coastal waters, will affect the distribution and abundance of prey species, with consequences for their predators.

Changes in rainfall patterns are likely to lead to an increased demand for freshwater in some areas, resulting in the regulation of water flow through the use of dams and dredging. These are major barriers to the migration of freshwater species of river dolphins (family Platanistoidea and the Tucuxi). Such activities have already created small isolated populations and rendered some areas of otherwise suitable habitat completely inaccessible. Flood control will result in loss of shallow water habitats that are often used extensively during rainy seasons by river dolphins (Harwood 2001).

4.8.2. Storm Frequency, Wind Speed and Wave Conditions

Increases in tropical cyclone peak wind intensities, mean and peak precipitation intensities are likely over some areas, based on projected changes, which would lead to increased coastal erosion and increased damage to coastal ecosystems, such as coral reefs and mangroves (IPCC 2001a). Changes in prevailing ocean wave height and directions and storm waves and surges can be expected to have serious impacts on coasts as they will be superimposed on increasing sea-levels (IPCC 2001a). Pinniped haul-out sites for breeding and nurseries are likely to be vulnerable to any changes in storm frequency and wave conditions.

4.8.3. Climate Patterns and Variability

Warm events associated with the ENSO are predicted to increase in frequency, which would result in a decline in plankton biomass and fish larvae abundance, and adversely impact fish, marine mammals, seabirds and ocean biodiversity (IPCC 2001a).

The indirect effects on marine mammal species of climate change associated with El Niño events include (i) changes in cetacean species composition, for example, after the 1982-83 El Niño short-finned pilot whales appeared to be replaced by Risso's dolphins (Shane 1994, 1995), (ii) changes in species ranges, the range expansion of bottlenose dolphins along the Californian coast during and after the 1982-83 El Niño event (Wells *et al*. 1990), and (iii) effects on reproduction, for example reduced fecundity or calf survival in sperm whales of the eastern tropical Pacific during and after an El Niño event in the late 1980s (Whitehead 1997), and high juvenile mortality in seal colonies, such as Galápagos fur seals during the El Niño year of 1982 (Würsig *et al*. 2002). There is also some indirect evidence for environmental effects on reproduction in female Dusky Dolphins *Lagenorhynchus obscurus* during the 1982 to 1983 El Niño event off Peru. The deposition of poorly calcified dentinal growth layer groups in the teeth of pregnant and lactating female dusky dolphins during the period of El Niño and reduced prey availability, indicated nutritional stress (Manzanilla 1989; Boyd *et al*. 1999).

It is possible that overall climate change will have similar effects to short-term El Niño events, although, the effects of global climate change could be more gradual and potentially more subtle. However, it is possible that the severity of El Niño events is exacerbated by present climate change trends (Würsig *et al*. 2002). Potential changes in the frequency, intensity, and persistence of climate extremes (e.g. heat waves, heavy precipitation and drought) and in climate variability (e.g. El Niño

Southern Oscillation) are emerging as key determinants of future impacts and vulnerability (IPCC 2001a).

The NAO can influence, directly and indirectly, the recruitment, growth, distribution, abundance and survival of several fish, cephalopod and plankton species (see Section 6.8.3). Changes in prey abundance and distribution as a result of the NAO are likely to have direct and indirect effects on marine mammal species in the North Atlantic. For example, long-term inter-annual variation in the number of Sperm Whale strandings on the North Sea coast may be related to ocean climate, with a weak but statistically significant positive association between North Sea strandings (1563-1999) and the (three-year lagged) winter NAO index. It appears that a link could operate through changes in the distribution of the whales' main prey (squid) and consequent shift in Sperm Whale migration routes (Pierce & Boyle 2003; Pierce *et al.* In prep).

In addition to El Niño-Southern Oscillation variability, the persistence of multi-year climate-ocean regimes and switches from one regime to another have been recognised, and changes in recruitment patterns of fish populations have been linked to such switches (IPCC 2001a). Similarly, changes in the survival of marine mammals and sea birds are also related to inter-annual and longer term variability in several oceanographic and atmospheric properties and processes, especially in high latitudes (IPCC 2001a).

4.9. Summary of the potential effects of climate change on marine mammals

Direct effects of changes in temperature include shifts in species ranges, some may expand and some may contract, however, species with restricted ranges, for example, polar species, the Vaquita and river dolphins, may be particularly vulnerable. More information is needed on potential direct physiological effects of increased temperature on marine mammals and the possible consequences of this. Indirect effects of changes in temperature include the effects of climate change on prey availability affecting the distribution, abundance and migration, community structure, susceptibility to disease and contaminants, reproductive success, and ultimately, survival of marine mammal species. Changes in the range and abundance of competitors and predators will also affect marine mammals to varying degrees depending on the species and location. Management and conservation measures need to take into account the potential changes in species' range by creating protected areas for the remaining and predicted habitat.

Rising sea-levels will directly affect pinniped haul-out sites. The Mediterranean Monk Seal may be particularly vulnerable as it is reliant on a small number of caves or narrow beaches for breeding and these sites could easily be destroyed or rendered unusable by rising sea levels and increased storm frequency. Remaining, as well as potentially suitable breeding sites as conditions change need to be protected. The construction of protective measures for coastal habitats against rising sea levels could have several implications for coastal marine mammals, including habitat degradation, effects on prey, direct mortality and obstructions to migration. Detailed environmental impact assessments are required that take into account the current and possible future impacts on marine mammals.

Changes in ocean currents, upwellings and fronts could affect the distribution of marine mammals either directly if the limits to their range are defined by the changes between two water masses, or indirectly as a result of changes in the distribution and occurrence of prey associated with currents, upwellings and fronts. Protective measures could include flexible no-take zones that follow changes in prey distribution rather than fixed areas.

Marine mammals, particularly those that rely on ice or the environment close to the ice edge, are vulnerable to the direct effects of a decrease in sea ice cover. Seals and polar bears that rely on ice for breeding are likely to suffer considerable habitat loss. Large baleen whale species that undertake long distance migrations from tropical breeding grounds to high-latitude feeding grounds close to the ice edge may be at risk as the polar ice caps retreat. The longer migration paths that will be required will increase the costs of movement and reduce the duration of the feeding season. Changes in sea extent and salinity will affect all species associated with the ice edge, either directly or indirectly through spatial and/or temporal changes in prey availability.

The potential effects and impacts of changes in salinity, pH and CO_2 on marine mammals are not fully understood and require further research, although prey species, especially cephalopods may be particular sensitive. Changed rainfall patterns and increased run-off, as well as changes in temperature, salinity, pH and CO_2, could potentially increase toxic algal blooms. Fatal toxic algal blooms have occurred in cetacean, pinniped and manatee species. Improving water management and discharges could help to elevate the potential risks of increased eutrophication and toxic algal blooms.

However, the greatest threat to marine mammals probably comes from changes in their food resources as a result of climate change. For example, many species appear to rely on particular sets of environmental conditions to concentrate their prey. If climate change affects the geographic distribution of these oceanographic conditions, this could have serious consequences for reproduction and survival.

For populations that are already under threat (for example from low numbers i.e. due to past whaling; severely affected by by-catch and/or pollutants; restricted to a limited distribution; dependent on critical habitats for breeding or feeding), the effects (direct and/or indirect) of climate change may become important.

4.9.1. Adaptation: Implications of climate change for the management and conservation of marine mammals

Management and conservation measures need to take into account the potential changes in range and changing requirements of marine mammals. The adverse effects on breeding habitat may be reduced by creating protected areas for the remaining habitat, if it can be identified. However, the main method for adapting to change in the wider environment will be to manage human impacts on the resources required by marine mammal species through some form of ecosystem based management.

One way to protect marine mammals would be to designate marine protected areas (a.k.a. 'no-take zones') for the prey of marine mammals as well as marine mammal species. However, the ideal location of such areas is likely to change over time, and this will require different legislation than those currently used. For example, there needs to be a degree of flexibility in the establishment of protected areas for marine mammals, such as Special Areas of Conservation (SAC), to take into account the potential shift in range and needs of marine mammals with climate change.

However, protective and conservation measures will not be able to solve many of the problems faced by marine mammals as a result of climate change and therefore the mitigation of greenhouse gases to prevent temperature increase may be the only solution.

4.9.2. Knowledge gaps and future research

Marine mammals are large, long-lived warm-blooded animals that show considerable behavioural plasticity. This plasticity allows many species to respond to environmental changes within a single generation, and these species are unlikely to be affected physiologically by moderate changes in the physical characteristics of their environment. Their apparent reliance on behavioural responses to environmental changes, some of which can be transmitted culturally, means that low genetic diversity – which has been demonstrated for some species – does not necessarily affect their ability to respond to such changes. However, the limits to this plasticity are not known.

One of the greatest threats to marine mammals probably comes from changes in their food resources, as a result of climate change. Many prey species such as fish, cephalopods and plankton appear to rely on, and are influenced by, particular sets of environmental conditions. Any changes in the geographic distribution of these oceanographic conditions as a result of climate change will affect the abundance and distribution of prey species. This will ultimately affect the availability to marine mammals, which in turn would affect their distribution and migration, and could have serious consequences for reproduction and survival. More information is required to determine the potential impact of climate change on the timing and extent of population movements, distribution, abundance, recruitment, and species composition of prey. The theoretical basis for identifying and tracking areas where the prey of marine mammals should be protected is limited, and more information is required on the factors affecting prey availability and prey quality.

Future data needs to include the continued monitoring or establishment of long-term stranding and sightings records of marine mammals, especially in areas at the northern and southern limits of species. The range of migratory and resident species can be very sensitive to climate and individuals can show an immediate response, for example in their migratory destinations. Therefore, as with climatic data, a long time series is required to distinguish year-to-year variation from long-term trends (IPCC 2001a, Walther *et al*. 2002). These data are needed to (i) detect changes in the community structure, abundance or distribution of species, (ii) compare with long-term records of other marine species such as plankton, fish, cephalopods and environmental variables, and (iii) detect any changes in cause of death, i.e. the presence of 'new' diseases, etc.

The establishment of regular marine mammal monitoring programmes in areas where information is limited, especially areas that are known or thought to be important for breeding and/or feeding and on migration routes, is essential. The regionally distinctive effects of climate change make it difficult to predict the potential impacts on most species, therefore more information is required on a regional scale to determine critical habitat, diet, etc. This is especially true for populations that are already under threat: those with reduced abundance due to past whaling, by-catch and/or pollutants; restricted to a limited distribution; dependent on critical habitats for breeding or feeding. More information is required for species, such as beaked whales (Ziphiidae), for which very little is known about their distribution, abundance, migration and diet, and for which therefore, the potential effects of climate change or any other potential threat are difficult to predict.

In general, more information and research is needed on the direct effects of temperature change on marine mammals, for example the effects on blubber thickness and the potential consequences; the potential impacts of changes in salinity, pH and CO_2; habitat use and requirements for almost all species; competition interactions between marine mammal species, and the effects of climate change on the spread and survival of diseases. The effects of climate change are unlikely to be isolated therefore further information is required on the potential effects of synergetic interactions, for example the effects of changes in prey availability combined with the effects of increased stress due to changes in temperature etc. The impacts of climate change on marine mammal species and populations also need to take into account the threats and pressures, such as habitat degradation/destruction, by-catch, pollution, noise, etc., already faced by many marine mammals. Currently there has been very little done to model/predict future climate change scenarios on marine mammals and determine the potential effects and impacts.

5. CLIMATE IMPACTS ON MIGRATORY MARINE TURTLES

5.1. Direct effects and impacts of an increase in temperature

Turtles are directly affected by an increase in temperature. Trends towards earlier nesting by sea turtles has been linked to an increase in sea temperature, for example, median nesting date of Loggerhead Turtle *Caretta caretta* on Florida's Atlantic coast has become approximately 10 days earlier (between 1989 and 2003) and is significantly correlated to the 0.8°C increase in sea surface temperature over this period (Weishampel *et al.* 2004). The nesting and mating of Green Turtles *Chelonia mydas* on Ascension Island have also been related to prevailing environmental temperature, with nesting usually occurring in the warmest months of the year (Godley *et al.* 2002a). The internesting interval within a season, i.e. the period between consecutive clutches being laid, is also affected by temperature, with shorter internesting intervals with increased temperature. Therefore water temperature will have a strong influence on the length of time a female takes to lay her full complement of clutches within a season, reducing her time spent at nesting grounds (Hays *et al.* 2002).

Sex determination in sea turtles is dependent on the temperature during incubation of the eggs, with warm temperature resulting in the production of more females. Therefore global warming has the potential to drastically alter their sex ratios (Godley *et al.* 2002b; Hays *et al.* 2003; Glen and Mrosovsky 2004). In Ascension Island Green Turtle nests, a pivotal incubation temperature (when a 50:50 sex is produced) of 28.8°C has been determined, and based on nest temperatures the overall sex ratio of hatchlings is estimated to be 75% female (Godley *et al.* 2002b). In Green Turtle nests at Ascension Island there has been a general warming, with a mean increase in estimated nest temperatures for different months of between 0.36 and 0.49°C for the last 100 years (Hays *et al.* 2003). On Antigua air temperatures have increased by 0.7°C over the last 35 years and nesting season temperatures for Hawksbill Turtles *Eretmochelys Imbricata* are already above the pivotal incubation temperature (Glen and Mrosovsky 2004). At Loggerhead Turtle nesting sites in Northern Cyprus, sand temperature was found to be highly correlated with mean daily air temperature and mean nest temperature, and the mean incubation temperature is likely to be above the pivotal incubation temperature and therefore producing a sex ratio biased towards females (Godley *et al.* 2001).

Hatchling survival has also been found to be significantly correlated with incubation temperature, for example in Loggerhead Turtle nesting sites in Northern Cyprus, nests experiencing very high temperatures exhibit low hatchling success (Godley *et al.* 2001). On Ascension Island low hatchling success at some sites has been linked to temperatures exceeding the maximum for successful embryonic development, leading to heat stress and embryo mortality (Broderick *et al.* 2001). Incubation temperatures also influence body size, with higher temperatures producing smaller Green Turtle hatchlings on Ascension Island (Glen *et al.* 2003). Higher temperatures will produce predominantly smaller females, while cooler temperatures may produce larger hatchlings in addition to a higher proportion of males. The survival of small females may be compromised, with their fitness with respect to digging, crawling and swimming likely to be reduced (Broderick *et al.* 2001).

Climate warming may also increase the incidence of disease in sea turtles. Reports of disease of sea turtles have greatly increased over the last three decades. Fibropapilloma tumours in Green Turtles are hypothesised to grow more rapidly in warm water and the prevalence of this disease has increased since the 1980s (Lafferty *et al.* 2004). Temperature changes are also likely to result in range shifts and distributional changes in abundance for many turtle species.

5.2. Direct impacts of a rise in sea level

Sea turtles are likely to be directly affected by an increase in sea levels due to the loss of egg laying beaches. Under a predicted sea-level rise of 0.5 metres, GIS-based elevation models indicated up to 32% of the beaches used by nesting sea turtles in the Caribbean could be lost via 'coastal squeeze' – the loss of coastal habitat between the high-water mark and hard coastal defences, such as sea-walls

(Gill *et al.* 2004). The construction of sea wall defences and protective measures for coastal habitats against increasing sea levels, as well as changes in the development and use of coastal areas, will directly affect egg-laying beaches and possibly interfere with migration routes of marine turtles.

5.3. Changes in ocean currents

Fronts, eddies and currents are important for the migration and foraging of sea turtles, therefore any changes in ocean currents as a result of climate change could have serious implications for their migration and foraging, and could potentially result in range shifts and distributional changes in abundance for many turtle species. In the central North Pacific, satellite telemetry of Loggerhead Turtles indicate that they generally occupy seas surface temperatures between 15-25°C and were associated with fronts, eddies and geostrophic currents, such as the Transition Zone Chlorophyll Front and the southern edge of the Kuroshio Extension Current. Olive Ridley Turtles *Lepidochelys olivacea* in the central North Pacific were found to occupy warmer waters, primarily south of the Loggerhead Turtles, generally in the range of 23-28°C and were associated with major ocean currents, such as the southern edge of the Kuroshio Extension Current, the North Equatorial Current and the Equatorial Counter Current (Polovina *et al.* 2004).

5.4. Changes in storm frequency, wind speeds and wave conditions

Increases in tropical cyclone peak wind intensities, and in mean and peak precipitation intensities are likely over some areas, based on projected changes, and would lead to increased coastal erosion and increased damage to coastal ecosystems, such as coral reefs and mangroves (IPCC 2001a). Changes in prevailing ocean wave height and directions and storm waves and surges can expect to have serious impacts on coasts as they will be superimposed on increasing sea-levels (IPCC 2001a). Egg laying beaches of sea turtles are likely to be vulnerable to any changes in storm frequency and wave conditions.

5.5. Summary of the potential effects of climate change on marine turtles

The potential effects of climate change on marine turtles include the direct loss of nesting beaches; earlier nesting; reduced internesting intervals; reduction in the time spent at nesting sites; shifts in range and changes in migration, distribution, abundance and prey availability. Impacts associated with climate change include the effects on sex ratios of hatchlings; decrease in hatchling success; reduced body size of hatchlings, affecting their digging ability, fitness and survival, and an increase in the incidence of disease in adult turtles.

A further consideration is the impact of anthropogenic factors, particularly harvesting (either of eggs or adults), which represent both a direct threat, but also one that is likely to shift in regional importance with changing distributions of turtles and changing pressures on coastal communities.

The greatest threats to turtle populations stem from habitat degradation, as a result of rising sea-levels, increased storm frequency and coastal developments, such as sea-wall defences, at nesting beaches and feeding areas (particularly of coral reefs and sea-grass communities), and understanding the consequences of such degradation and reducing it are of primary importance in conserving turtle populations. The nature of this degradation, and its impact on turtle populations, may shift with climate change, and research and conservation policies need to be flexible to adapt to such changes.

5.5.1. Adaptation: Implications of climate change for the management and conservation of marine turtles

Protective measures for marine turtles need to include the protection of current and potential nesting beaches and minimising human induced habitat degradation, such as coastal developments. The nature of this degradation, and its impact on turtle populations, may shift with climate change, and research and conservation policies need to be flexible to adapt to such changes. Reducing the threats faced by sea turtles, such as egg harvesting, egg predation, fishing, by-catch, pollution, marine debris, boat traffic and light pollution, also need to be addressed at both global and local levels.

As for all marine species, climate change is likely to result in range shifts and distributional changes in abundance. This will result in a shifting regional focus for conservation (e.g. turtles are becoming much more frequent in UK territorial waters).

However, protective and conservation measures will not be able to solve many of the problems faced by marine turtles as a result of climate change, and therefore the mitigation of greenhouse gasses to prevent temperature increase may be the only solution.

5.5.2. Knowledge gaps and future research

A potential impact of climate change on turtle populations would be through increased temperatures changing sex-ratios, under extreme scenarios the possibility of single sex populations may arise. It is unclear to what extent turtle populations can adapt to these changes.

Further information is required to determine what drives seasonality of nesting. Long-term monitoring is required at Ascension Island where baseline data has already been collected and at other UK overseas territories. Monitoring is fundamental to determine if turtles can naturally adjust their phenology in response to warmer years and hence identify whether human intervention is required.

Patterns of habitat utilisation and migration are areas that require further research to determine the potential effects of climate change. For example, how will changes in ocean currents affect migration and the ability of turtles to return to nesting beaches?

6. CLIMATE IMPACTS ON MARINE FISH, CEPHALOPODS AND PLANKTON

6.1. Direct effects of an increase in temperature

Temperature can directly affect the age of sexual maturity, timing of spawning, incubation time, growth, and survival of certain fish species. The distribution, abundance and migration of several fish species are also related to temperature. Examples of effects of increased temperature include, an increase in the abundance of warm water pelagic species, Anchovy *Engraulis encrasicholus* and Sardine *Sardina pilcharadus* in the north-western North Sea since 1995 which appears to be related to rising sea temperatures (Beare *et al.* 2004a). Trawl data suggests that the North Sea is experiencing waves of immigration by exotic, southern species, such as Red Mullet (*Mullus surmeletus*), Anchovy, Sardine, Lesser Weever *Echilichthys vipera* and Bluemouth *Helicolenus dactylopterus*. Abundances of species such as Poor Cod *Trisopterus minutes*, John Dory *Zeus faber*, Horse Mackerel *Trachurus trachurus*, Mackerel *Scomber scombrus*, Tub Gurnard *Trigla lucerna* and Red Gurnard *Aspitrigla cuculus* have also increased. These species with southern biogeographic affinities have shown a sudden, almost exponential, increase in the North Sea since the mid-1990s (Beare *et al.* 2004b). There is evidence that the warming of the North Atlantic is responsible for the northward extension of the ranges of several warm water fish species, causing increasing numbers of southern immigrant species to appear off the Cornish coast of the UK. The increasing number of immigrant species is significantly correlated with temperature increases in the North Atlantic over the last 40 years (Stebbing *et al.* 2002).

The spatial distribution of Whiting *Merlangius merlangus* in the northern North Sea is positively correlated to sea surface temperature in winter and spring. The higher Whiting abundance in relatively warmer water may reflect the direct influence of North Atlantic waters entering the northern North Sea (Zheng *et al.* 2002). Changes in the migratory pattern, size of fish and year class strength of Norwegian Spring-spawning Herring *Clupea harengus* appear to be linked to temperature. Strong year-classes are more frequent during warm periods and when the stock is large the Norwegian Spring-spawning Herring tend to migrate over longer distances than in poorer years. It also appears that during these periods some of the year classes move further north than usual. This may reflect the effect of northward currents on the larvae and early feeding that takes place during warmer periods (Sissener and Bjørndal 2005).

For most cephalopods embryonic development and hatching, growth (including gonad maturation), timing of migration and range are influenced by temperature, as well as food availability (Boyle 1983). The changes in abundance of Squid *Loligo forbesi* in Scottish waters have been related to climate variation. Abundance in coastal waters was correlated with several annual environmental indices, including the winter North Atlantic Oscillation index, the average sea surface temperature and sea surface salinity in the northern North Sea. With sea surface temperature having an influence on recruitment strength (Pierce and Boyle 2003).

The timing of Veined Squid *Loligo forbesi* migration reflects North Atlantic climate variation. In the English Channel the eastward migration of Veined Squid is earlier when water in the preceding months is warmer, with the higher temperatures and early arrival corresponding with warm (positive) phases of the North Atlantic Oscillation. The timing of the squid peak abundance advanced by 120-150 days in the warmest years compared to the coldest. The extent of the squid movement was closely linked to sea bottom temperature. Results indicated that squid responded to temperature changes independently of time of year, suggesting that water temperature and indirectly, climate fluctuations, play important roles in determining the timing and extent of squid movement in any given year (Sims *et al.* 2001). Seasonal changes in water mass characteristics and location have been linked to seasonal changes in migrations of Patagonian Longfin Squid (*Loligo gahi*) on the Falkland shelf. The 5.5^{o}C isotherm limits the distribution of *L. gahi* into deeper water in all seasons: the squid are associated with the warmest possible water layers for its distribution on the feeding grounds (Arkhipkin *et al.* 2004).

Changes in plankton distribution, abundance and composition are related to climate, including temperature (Southward *et al.* 1995; Planque and Taylor 1998; Ducrotoy 1999; Heath *et al.* 1999a; Heath *et al.* 1999b; Edwards *et al.* 2001; Beare *et al.* 2002; Edwards *et al.* 2002; Beaugrand 2003; Reid *et al.* 2003a; Edwards and Richardson 2004; Moline *et al.* 2004). For example, large-scale changes in the biogeography of calanoid copepod crustaceans have recently been detected in the north-eastern North Atlantic Ocean and adjacent seas. Strong biogeographical shifts in all copepod assemblages were found, with a northward extension of more than 10^{o} in latitude of warm-water species associated with a decrease in the number of colder-water species. These changes reflect regional increases in sea surface temperature in recent years (Beaugrand and Reid 2003).

Extensive changes in marine communities in southwest Britain and the western English Channel have been linked to climate variation. From 1920 to 1960 there was warming period, after 1961 and markedly from 1970 there was a period of cooling and since 1981 there has been a warming trend. Warm water species increased in abundance and extended their range during periods of warming, while cold-water species declined or retreated, with the reverse occurring during the cooler period. Marked changes in plankton community structure occurred, the distribution of both plankton and intertidal organisms was affected, with latitudinal shifts of up to 120 miles and associated increases or decreases in abundance were 2-3 orders of magnitude (Southward *et al.* 1995).

6.2. Indirect effects and impacts of an increase in temperature

Species abundance is also indirectly affected by temperature through the effects on prey species. The potential uncoupling of phenological relationships has important implications for trophic interactions, altering food-web structures and leading to changes in the ecosystem. The recruitment success of higher marine trophic levels is highly dependent on synchronization with plankton production. Observations indicate that the marine pelagic community responds to climate changes and that the level of response differs throughout the community and seasonal cycle. For example, during summer, seasonality has advanced collectively for meroplankton by 27 days, dinoflagellates by 23 days, copepods by 10 days, and non-copepod holozooplankton by 10 days over the 45 year study period. Diatoms had the largest within group variation in phenology, with particular taxa occurring both earlier and later during the spring and summer blooms. Phenology of the plankton groups during summer showed positive correlations with sea surface temperature. Although many plankton organisms appear to be responding to climate warming, the response varies considerably between the pelagic assemblages. These differences in response have led to a mismatch between successive trophic levels and a change in synchrony of timing between primary, secondary and tertiary production (Edwards and Richardson 2004).

The link between climate change and the cascade effects on trophic levels has been observed in phytoplankton, zooplankton and Salmon *Salmo salar* in the northeast Atlantic. Climate change appears to be an important parameter influencing the dynamic equilibrium of pelagic ecosystems in the northeast Atlantic. If temperatures increase as predicted, there is expected to be a marked change in the organisation of pelagic ecosystems from phytoplankton to fish. As a result the decline in abundance of salmon returning to home waters will continue, particularly at the southern limit of their spatial distribution, for example, Spain and France (Beaugrand and Reid 2003).

The synchrony between predator and prey are particularly important for several fish species. For example, the growth and survival of cod larvae *Gadus morhua* depend on synchronous production with their main prey, the early stage of zooplankton (Stenseth *et al.* 2002). The decline in Cod recruitment in the North Sea has been linked to rising temperatures affecting the plankton ecosystem (O'Brien *et al.* 2000; Beaugrand *et al.* 2003).

Migration patterns and spatial distributions of large pelagic fish, such as Bluefin Tuna *Thunnus thynnus* can be altered indirectly through climate-induced changes in prey abundance (Walther *et al.* 2002).

6.3. Rise in sea level

A rise in sea level is likely to affect most coastal habitats, although the extent will vary with location and type of coastal habitat. Many coastal areas are already experiencing increased levels of sea flooding, accelerated coastal erosion, and seawater intrusion into freshwater sources, and these process will increase with climate change and rises in sea levels (IPCC 2001a). Low-latitude tropical and subtropical coastlines are highly susceptible to climate change impacts (IPCC 2001a). Coastal ecosystems such as coral reefs and atolls, salt marshes and mangrove forests, and submerged aquatic vegetation will be directly impacted by sea-level rise (IPCC 2001a). These areas are important nursery grounds for many fish and invertebrate species, including migrants.

6.4. Changes in ocean currents

Changes in ocean mixing, deep water production and coastal upwelling will have profound impacts on the status, sustainability, productivity and biodiversity of the coastal zone and marine ecosystem (IPCC 2001a). Changes in ocean currents will directly affect the distribution and abundance of plankton, many fish and cephalopod species and their migration.

The distributions of many marine species are associated with fronts between waters masses. Any changes in ocean currents could alter the position of these fronts and hence the distribution and migration of marine species. For examples in the Barents Sea the influx of Atlantic water fluctuates affecting the location of the polar front. The geographical position of the polar front and the water temperature of the Barents Sea influence the distribution and species composition of the primary and secondary production, with subsequent effects on the distribution and year/class strength of fish species. In years with large influx of Atlantic waters, conditions are favourable for the establishment of strong-year classes of boreal fish species such as Herring *Clupea harengus* and Cod *Gadus morhua*. In years of reduced influx of Atlantic waters, Arctic fish species, such as {Polar Cod *Boreogadus saida* and Capelin *Mallotus villosus* are favoured (Bjørge 2002).

Recruitment in fish populations is strongly influenced by climate variation. For example, variation in the atmospheric climate over the Bering Sea, through interactions with ocean currents, influence transportation of juvenile Walleye Pollack *Theragra chalcogramma* away from adults, affecting the intensity of cannibalism and, consequently, year class strength. Fluctuation in the recruitment of Walleye Pollack affect the whole ecosystem of the Bering Sea food web as they are an important prey species for other fish, birds and marine mammals (Walther *et al.* 2002).

In upwelling systems, fish production appears to be determined by enrichment, concentration and retention processes, which are in turn controlled by climatic factors. An increase in temperature should intensify upwelling causing a reduction in the concentration and retention processes, and therefore resulting in a decline in global fish production including migratory fish (Walther *et al.* 2002).

Interannual variation in the interaction of the Brazil and Falklands Currents in the inferred hatching areas during the early life stages is an important in influencing the population size of the Argentinean Shortfin Squid *Illex argentinus*. The most favourable conditions for successful recruitment appear to be a low proportion of the inferred hatchling area occupied by frontal waters coupled with an increased predominance of favourable sea surface temperature. This situation relates to the strength of the interface between the Brazil Current and the cooler Falkland Current/shelf-slope waters. It is possible that an extended or stronger frontal region may act as a barrier to egg mass and larval transport within the area of the Brazil-Falkland Current confluence (Waluda *et al.* 2001). Any changes in these ocean currents and fronts as a result of climate change could therefore influence the distribution and abundance of the Argentinean Shortfin Squid.

Copepod abundance in the central North Sea has been linked to the position of the Gulf Stream. Results suggest that the timing of the spring phytoplankton bloom on the European Shelf and the start of seasonal stratification is related to the latitude of the Gulf Stream off the US coast (Planque and Taylor 1998). The predicted weakening of the Gulf Stream with climate change, (Hulme *et al.* 2002), could therefore potentially affect plankton abundance which in turn will affect the species which rely on them.

6.5. Effects of a decrease in sea ice cover

Alterations in the sea-ice extent will affect the productivity of ice-edge systems and may affect the distribution and density of species associated with the ice-edge, such as Arctic Cod *Boreogadus saida* and the pelagic amphipod *Parathemisto libellula*. Cryopelagic fish such as the Arctic Cod are adapted to feed under ice, where they rely on crustaceans associated with ice and surrounding water. The timing of the phytoplankton bloom in the Arctic is also influenced by the break-up and melting of ice. Therefore regional and seasonal changes in the sea extent are predicted to lead to changes in distribution and migration of the Arctic Cod which will in turn affect the distribution and migration of marine mammals (see Section 4.6.2) (Tynan and DeMaster 1997).

The extent of sea ice has a significant effect on Antarctic Krill *Euphausia superba*. Sea ice is critical to Krill as larval Krill, unlike adults, cannot endure long periods without feeding and therefore winter survival depends on the availability of under-ice algae. Studies indicate that cohort strength in Krill is correlated to sea ice conditions during the preceding winter and Krill abundance has decreased in the northern western Antarctic Peninsula during the last decade (Fraser and Hofmann 2003). This in turn will affect higher trophic levels in the food web as Krill is an important prey species for many marine species (Moline *et al.* 2004).

6.6. Changes in salinity

Changes in salinity, for example with changes in river inputs/run-off and melting ice, will influence the distribution and abundance of prey through effects on stratification and circulation and possibly also due to limited salinity tolerance (Fiedler 2002). For example, shifts in the phytoplankton community structure, from diatoms to cryptophytes, in the near shore coastal waters along the Antarctic Peninsula have been linked to glacial melt-water runoff and reduced surface water salinities. This shift phytoplankton community structure directly affects the zooplankton assemblage, as Antarctic krill do not graze efficiently on cryptophytes due to their small size, an increase in the relative abundance of cryptophytes will cause a shift in the spatial distribution of krill. Changes in the spatial and temporal distribution and abundance of krill will have severe implications for marine species that rely on krill as their main prey (Moline *et al.* 2004).

6.7. Increase in oceanic CO_2 concentrations

Carbon dioxide accumulating in the atmosphere permeates into ocean surface layers, where it may impact on marine animals (Pörtner *et al.* 2004). There may be effects of elevated CO_2 partial pressures (hypercapnia) on acid-base regulation, calcification and growth, respiration, energy turnover and mode of metabolism. Acid-base parameters, such as pH, bicarbonate and CO_2 levels, are likely to affect metabolic function and therefore growth and reproduction. Sensitivity is highest in ommastrephid squid, such as *Illex illecebrosus*, which are characterised by a high metabolic rate and extremely pH-sensitive blood oxygen transport. Acute sensitivity appears to be less in fish with intracellular blood pigments and higher capacities to compensate for CO_2-induced acid-base disturbances than invertebrates (Pörtner *et al.* 2004).

An increase in CO_2 concentration in oceanic waters is causing a drop in the availability of carbonates, which are required by corals and molluscs and is resulting in reduced calcification rates. Changes in ocean chemistry resulting from higher CO_2 levels may have a negative impact on coral reef development and health, which would have a detrimental effect on the associated ecosystem (IPCC 2001a).

6.8. Changes in Weather Patterns

6.8.1. Rainfall

More intense precipitation events and flash floods will result in increased run-off. Increased nutrients inputs into coastal waters, combined with increases in water temperatures could cause an increase in toxic algal blooms and eutrophication. Eutrophication may play an important role in phytoplankton seasonal and community dynamics in the southern North Sea (Edwards *et al.* 2001), which in turn will affect marine fish and cephalopods.

Increased run-off may also cause an increase in pollutants, including sewage, with potential effects on coastal species. Changes in rainfall patterns and the associated changes, for example decrease in salinity in coastal waters, will also affect the distribution and abundance of prey species.

6.8.2. Storm Frequency, Wind Speed and Wave Conditions

Increases in tropical cyclone peak wind intensities, and in mean and peak precipitation intensities are likely over some areas, based on projected changes, and would lead to increased coastal erosion and increased damage to coastal ecosystems, such as coral reefs and mangroves (IPCC 2001a). Changes in prevailing ocean wave height and directions and storm waves and surges, can expect to have serious impacts on coasts as they will be superimposed on increasing sea-levels (IPCC 2001a). Coastal ecosystems such as coral reefs and atolls, salt marshes and mangrove forests, and submerged aquatic vegetation will be directly impacted by any changes in storm frequency and intensity (IPCC 2001a). These areas are important nursery grounds for many fish and invertebrate species.

6.8.3. Changes in climate patterns/variability

Large-scale patterns of climate variability, such as the El Niño-Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO), account for major variations in weather and climate around the world and have been shown to affect marine species and fish stocks, thorough both direct and indirect pathways (Stenseth *et al.* 2002). Effects of short-term events such as El Niño events and North Atlantic Oscillation can provide a valuable insight into the potential effects of longer-term climate change.

Fluctuations in tropical Pacific sea surface temperature are related to the occurrence of El Niño, during which the equatorial surface waters warm considerably from the International Date Line to the west coast of South America. The Southern Oscillation is a global-scale ‘see-saw’ in atmospheric mass, involving exchanges of air between eastern and western hemispheres centred in tropical and subtropical latitudes. Warm ENSO events are those in which both negative SO and an El Niño occur together. Different phases of the ENSO shift the location of the heaviest tropical rainfall, and these changes in the heating of the atmosphere distort the flow of air over thousands of kilometres, producing anomalous cold and warm regions (Stenseth *et al.* 2002).

El Niño events have been linked directly and indirectly to massive die-offs of plankton, fishes (such as Anchovy and Hake), seabirds and marine mammals (Stenseth *et al.* 2002). Warm events associated with the El Niño-Southern Oscillation are predicted to increase in frequency, which would result in a decline in plankton biomass and fish larvae abundance, adversely impacting fish recruitment patterns and spatial distribution of fish stocks, with subsequent effects on marine mammals, seabirds and ocean biodiversity (IPCC 2001a; Stenseth *et al.* 2002).

The temporal and spatial population dynamics of zooplankton, *Calanus finmarchicus* and *Calanus helgolandicus*, have been linked to the North Atlantic Oscillation. Four types of mechanism have been proposed to explain the observed correlation, (i) changes in the volume of Norwegian Sea deep water where the overwintering population reside, (ii) changes in the transport of individuals from the Faeroe-Shetland channel into the North Sea, (iii) changes in food availability (phytoplankton productivity), and (iv) alteration of the competition balance between the two species (Planque and Taylor 1998; Beare *et al.* 2002; Stenseth *et al.* 2002; Beugrand and Ibanez 2004). Early stages of the *Calanus* zooplankton species are the main prey for larvae and early juveniles of many fish species throughout the North Atlantic and thus influence fish recruitment success and consequently the size of fish populations (Stenseth *et al.* 2002; Walther *et al.* 2002).

The changes in the abundance of squid (*Loligo forbesi*) in Scottish waters have been related to climate variation. Abundance in coastal waters was correlated with several annual environmental indices, including the winter North Atlantic Oscillation index, and the average sea surface temperature and sea surface salinity in the northern North Sea, with sea surface temperature affecting recruitment strength (Pierce and Boyle 2003).

Positive phases of the NOA affect the Barents Sea through increasing the volume influx of warm water from the southwest, cloud cover, and air temperature, all lead to increased water temperature, which influences fish growth and survival both directly and indirectly (Stenseth *et al.* 2002). Variation in sea temperatures driven by North Atlantic Oscillation variation have been linked to Cod recruitment both off Labrador and Newfoundland and in the Barents Sea (Stenseth *et al.* 2002).

6.9. Summary of potential effects of climate change on marine species

Climate change is likely to affect the timing and extent of population movements, distribution, abundance, and species composition or marine communities. Climate impact on individuals and populations may operate either directly through physiology (metabolic and reproductive processes) or indirectly through prey, predators, and competitors (Stenseth *et al.* 2002).

Climate change may lead to recruitment failure due to trophic uncoupling (i.e. match-mismatch). The mechanistic links and their consequences of climate variability through primary or secondary producers may be complex. The effects of climate may also depend on other ecological factors and interactions (Stenseth *et al.* 2002).

Delayed effects of climate are important, for example individuals born in a specific year may be larger or smaller than average depending on the climatic conditions in the year of birth. Climate also has differential influences on sexes and age-classes, for example young individuals may be more susceptible to climate variability (Stenseth *et al.* 2002).

Climate change may lead to a higher frequency of extreme events, which are often ecologically more relevant than fluctuations in the mean climate (Stenseth *et al.* 2002). For example, changes in the frequency of episodic events such as increased storm frequency may affect recruitment.

6.9.1. Adaptation: Implications of climate change for conservation and management

Fishing activities and fisheries management need to be able to respond to regional changes in local population abundance and distribution which may be driven by the timing of life-history events (such as spawning, migration etc.) and episodic events. The designation of marine protected areas (a.k.a. “no-take zones”) for marine species will need to be flexible to take into account the potential changes in their distributions over time and space, with climate change.

However, protective and conservation measures will not be able to solve many of the problems faced by marine species as a result of climate change, and therefore the mitigation of greenhouse gasses to prevent temperature increase may be the only solution.

6.9.2. Knowledge Gaps and future research

Further research is required to identify the migration patterns and mechanisms of many marine species and determine the potential effects of climate change.

Monitoring of plankton, fish and cephalopod recruitment and adult stocks, and understanding the relationship between them is fundamental to addressing the potential impacts of climate change on the marine ecosystem.

The effects of episodic events such as increased storm frequency on recruitment need to be examined. It may be useful to consider the development of proxy measure for storms that can be related to recruitment of potentially sensitive species.

There is an urgent need for modelling of future climate change that will provide scenarios of how this will affect upwelling areas and fronts. This will be an important requirement to help understand the potential effects of climate change on the distribution and abundance of marine species.

7. CLIMATE IMPACTS ON MIGRATORY BIRDS

Migratory bird species, because they rely on spatially separated sites and habitats, may be especially vulnerable to the impacts of climate change, as changes in any one of the sites used during the course of the annual cycle could have population impacts. Because of this use of multiple separate areas the impacts of climate change on migratory species are also particularly hard to predict accurately. For example, many of the migratory species occurring in the UK (and northern Europe) that winter in Africa, south of the Sahara are greatly impacted by the state of vegetation in Africa, which is very dependent on annual rainfall totals. A useful measure for monitoring annual variation in this is the Normalised Difference Vegetation Index (NDVI), which has been shown to influence populations of northern migrants (e.g. Møller 2004). Rainfall, and hence the NDVI, shows considerable geographic heterogeneity due to spatial variation in large-scale climate processes, such as the North Atlantic Oscillation (NAO) and birds migrating along more eastern flyways in Europe may be more affected than birds following the western European flyway (e.g. Bairlein & Hüppop 2004). Thus, climate change impacts will vary between regions, making specific predictions of impacts difficult. Given the scale and complexity of migratory systems, direct (experimental) evidence of the impacts of climate change independent of any other changes, is almost impossible to obtain, consequently much has to be inferred from other lines of evidence.

We first discuss the effects of climate change on distribution, phenology and demography of migratory bird populations before assessing their impacts on population size and potential mitigation and adaptation strategies.

7.1. Range & Distribution

It is has long been known that the distribution of biomes and habitats follows climate patterns closely, particularly isotherms, which are lines connecting points of equal temperature (e.g. Andrewartha & Birch 1954; Huntley 1991). Limits of animal distributions will also, consequently, follow climatic boundaries, and when these boundaries alter, distribution patterns are likely to alter too(e.g. Root 1988; Parmesan 1996). Weather is also well known to influence the occurrence of bird species (e.g. Lack 1954; Newton 1998), and this can lead to long-standing cultural associations, for example, Oriental Pratincoles *Glareola maldivarum* and White Storks *Ciconia ciconia* are both known as 'rainbirds' by ethnic people in dry areas of Australia and Africa respectively as their arrival presaged the coming of the rains (e.g. Sitters *et al.* 2004).

In the UK, Thomas and Lennon (1999) reported that, over the period 1972-1991, bird species had extended their breeding ranges northwards by an average of 18.9 km, a shift which they suggested was linked to increasing mean annual temperatures at the northern extent of the species' distribution, although there was no evidence for any northward shifts in the southern edge of their distributions. Climatic amelioration in the UK could help to explain the colonisation of the UK by new breeding species from the continent, such as Black Redstart (*Phoenicurus ochruros*), Cetti's Warbler (*Cettia cetti*), Golden Oriole (*Oriolus oriolus*), during the 20th century, and possibly, more recently, Little Egret (*Egretta garzetta*) (Burton, 1995; Moss, 1995; Musgrove, 2002), although such suggestions are currently speculative (Crick 2004). Root & Schneider (1993) found strong statistical correlations between the distribution and abundance of a majority of 148 wintering landbirds of North America and six-large scale environmental factors, mainly climatic variables. These studies are largely correlational, so it is difficult to ascribe with certainty the distributional shifts reported to climatic influences because of the potential influence of many other confounding factors. In an attempt to disentangle these different effects, Gates *et al.* (1994) used multivariate regression to model the national distributions of several species in the UK, in relation to both land-use and climatic factors. The latter factors were shown to have a strong influence on large-scale distribution, even after the effects of land-use were accounted for.

There is direct evidence that at least some migratory species are changing their ranges. The Blackcap is, generally, a summer visitor to Britain, though a few individuals have always over-wintered. The number of birds present over winter has increased markedly in recent years. These are generally thought to be birds from central European breeding populations that have evolved a new migratory strategy, facilitated by warmer UK winters, as the direction of migration is known to be a highly heritable trait in this species (Berthold & Helbig, 1992). There is also evidence that a few British birds may now also spend the winter months here, instead of migrating south to Iberia (Clark *et al.* 2004). Warmer winter temperatures undoubtedly facilitate the survival of wintering warblers such as the Blackcap, though the presence of increased garden feeding (Chamberlain *et al.* 2005) may also contribute by providing an extended, accessible food source. The incidence of wintering in the UK by other (mostly short-distant) migrant warblers, such as Chiffchaff *Phylloscopus collybita* has also increased, which may be more attributable to climatic factors as they do not feed extensively on garden feeders (e.g. Dennis 1993, 2000). Similarly, across Europe Kinzelbach *et al.* (1997) found a strong correlation between instances of Bee-eater *Merops apiaster* wintering north of the Alps between 1500 and 1900 and winter temperatures and Berthold (1998) summarises some more instances from central Europe.

A similar shift in wintering location has been observed for many wader species in the UK (Austin *et al.* 2000; Austin and Rehfisch 2005). However, because the isotherms in winter are oriented longitudinally instead of latitudinally, as in the summer, the birds have redistributed themselves largely from West to East. This difference strongly suggests that climate change is having impacts on the distribution of migratory birds. A higher proportion of wader species used to winter in the Southwest of Britain where climatic conditions during the winter were relatively mild due to the influence of the Gulf Stream. However, as mean winter temperatures have increased since 1960, such climatic constraints have eased and an increasingly large proportion of the wader population has wintered on the east coast where the quality of the feeding grounds is higher and the birds are nearer to their northern breeding grounds. This distributional shift is most pronounced for smaller waders, such as Dunlin, Sanderling *Calidris alba* and Ringed Plover *Charadrius hiaticula*, that incur greater thermodynamic costs in cold weather, which supports the hypothesis that changing climatic conditions are the main driver behind the distributional shift (Austin & Rehfisch 2005). There is also evidence that open coast waders are wintering closer to their breeding grounds, as winters have become milder between the 1984-85 and 1997-98 (Rehfisch *et al.* 2004). Changes in juvenile settlement may help explain these changes in distribution (Summers *et al.* 2005). Similarly the wintering area of Golden Plovers in continental Europe shifted further south between 1960 and 1985 (Piersma & Lindström 2004).

These shifts in wintering range are partly a consequence of (or at least reflect) reduced migratory behaviour. A number of wader species have been shown to travel shorter distances between summer and winter than previously (Soutullo *et al.* in prep.). This does not appear to correlate with any ecological variables, unlike for example, raptor species, which are travelling further probably because of a population expansion. Such changes in migratory behaviour may have more impacts than just on population size, for example, Ludwichowski (1997) showed a reduction in the mean wing length of Goldeneye *Bucephala clangula* breeding in northern Germany, as might be expected if they were travelling shorter distances, i.e. body size is evolving to adapt to changing environmental conditions.

Generally, range shifts are likely to have the greatest impacts on, and be of most concern to, species that occupy habitats that cannot shift in response to a warmer climate, i.e. tundra, arctic and montane habitats. The extents of these habitats are likely to be seriously reduced under warmer conditions (IPCC 2001), with a consequent effect on the population of birds (and other wildlife) inhabiting them. The loss of tundra habitats is particularly relevant for the CMS as almost all species using this habitat are migratory, many of which face additional pressures (e.g. Delany & Scott 2002). This is amongst the most likely impacts of climate change and will have particularly severe consequences for migratory species.

Range shifts may also occur on a smaller-scale than geographical expansion of areas occupied. The altitudinal limits of vegetation are broadly climatically determined, particularly in relation to thermal characteristics (e.g. Huntley 1991; Seppa *et al.* 2002), and altitudinal shifts in these will affect the distribution of animals dependent on these habitats; the CMS covers a number of such altitudinal migrants, where migration results in the crossing of national borders (mostly African and South American species). The best demonstration of such effects comes from the montane rainforest of Costa Rica (Pounds *et al.* 1999). The average altitude at which the orographic cloud base has been raised through climate warming (Still *et al.* 1999), resulting in the colonisation of previously cloud-forest areas by bird species from lower altitudes. While Pounds *et al.* (1999) provide evidence to suggest that such changes may have had deleterious impacts on amphibian species, cloud forest birds appear to have maintained their populations at present. Similarly, Archaux (2004) showed that there was no upward shift in bird communities in the French Alps between the 1970s and 2000 despite a 2˚C increase in mean temperature. There are concerns, however, that such upward altitudinal shifts in montane bird communities might occur in UK (Watt *et al.* 1998). Predictive models, such as MONARCH (Harrison *et al.* 2001), suggest high altitude species in Britain, some of which, like the Dotterel *Eudromias morinellus*, are migratory, will reduce in population size under current climate-change scenarios. It is worth noting that, montane areas may well have isolated populations of species that are commoner elsewhere and that loss of habitat for these populations may reduce the overall genetic diversity of such species. However, direct evidence for this is so far lacking, and disentangling the impacts of land-use to prove causation will be difficult.

Coastal species are likely to suffer from rising sea levels, which are predicted to have a huge impact on lowland coastal habitats in the UK, and low-lying areas elsewhere. Increases in sea level combined with ‘coastal squeeze’ (see 2.4.2), could result in the permanent inundation of mudflats (Pethick & Crooks 2000), with severe implications for both wintering and breeding wildfowl and wader species. Salt marshes are likely to be under threat as well (Pethick & Crooks 2000), with implications both for breeding species, like Redshank, and species that winter in these areas, including Twite *Carduelis flavirostris*. Some areas, particularly those in the tropics, will face an additional threat in the form of elevated rates of erosion that have resulted from increases in the strength and frequency of winds and storm events. Such effects are likely to be particularly important for the Caribbean Overseas Territories, though the impacts on population size are unknown at present.

Estuarine mudflats represent important feeding sites for wintering waders. If artificial barriers do not prevent retreat, as sea levels rise, so the shape of these estuaries may change (Austin & Rehfisch 2003), influencing sediment composition and therefore altering the species composition and density of the invertebrate populations on which the waders feed. If the sea were allowed to encroach unhindered, the densities of waders that prefer muddy estuaries, such as Redshank and Dunlin, is predicted to fall as substrates become sandier (Austin & Rehfisch 2003). However, an increase in the area of sediment may actually permit an increase in the total number of individuals that can be supported. Species that prefer sandy estuaries, such as Oystercatcher, would be predicted to increase in both density and number. In some areas where these important habitats would theoretically be able to move in land as sea levels become higher, the land is being developed by conservationists to facilitate this process, creating areas of managed retreat through ‘coastal realignment’ (Atkinson *et al.* 2004; Crick 2004). Such adaptation measures are likely to be necessary to prevent declines in the overall numbers of waders using British estuaries.

In summary, it has been demonstrated that the distributions of at least some migratory bird species are being altered by climate change, independently of other causes. These changes have affected both breeding and wintering areas, and the distance birds migrate between these areas. In general, the impact on populations of these changes is unknown, but in many cases it may be beneficial, with birds migrating shorter distances than previously. Populations of migratory birds that use climatically limited biotopes, such as montane areas and arctic tundra, will be severely impacted by climate change and such species should be of high conservation concern.

Amongst species listed on the CMS, members of the Charariidae will suffer the most severe impacts as most depend on coastal areas in winter and many (especially *Calidris* spp.) breed in tundra or upland areas. The UK holds internationally important numbers of several species and these must be a high conservation priority (Delany & Scott 2002; Norris *et al.* 2004). Coastal breeding seabirds, particularly on low-lying islands, such as many of the Caribbean Overseas Territories, may also be impacted, though the severity of these impacts have not been quantified at present.

7.2. Migration Phenology

The results of several studies investigating the spring arrival times of migrant species in temperate latitudes have shown that birds are reaching their breeding grounds progressively earlier in the season as the climate becomes warmer; though this pattern is not universal. This adjustment of arrival dates is necessary if birds are to compensate for advancements in the timing of peak prey availability that have also been driven by climatic change, it may also mean a longer breeding season for some species, though the impacts on population size of this are unknown. Furthermore, regional climates are changing at different rates and in some cases in different directions; if populations have adapted to use cues in one area to predict the timing (of arrival) in another, changing the relative phenology of these cues may result in maladaptive behaviour (Visser *et al.* 1998, 2004; Inouye *et al.* 2000; Walther *et al.* 2002).

The positive phase of the NAO is associated with areas of high pressure over southwestern Europe, resulting in increased temperatures and therefore possibly in more favourable conditions for flight and foraging along the migration route (Forchhammer *et al.*, 2002). Weather conditions on the migratory journey can have an effect on both the timing and ability of individuals to complete their migratory journey (Elkins 2004; Gauthreaux & Belser 1999), though the impacts on population size may be relatively limited, and of concern only for species with small populations.

A number of studies have shown that mean spring arrival dates of species breeding in Europe are advanced when the NAO is in a more positive phase during the previous winter and spring, i.e. when conditions are warmer (e.g. Forchhammer *et al.* 2002; Hüppop & Hüppop 2003; Vahatalo *et al.* 2004).

Analysis of arrival date information for migrants in the UK suggests that many species are indeed arriving earlier on the breeding grounds. Three studies found that between 26% and 72% of species recorded were arriving earlier in the spring (Loxton & Sparks 1997; Sparks, 1999; Sparks & Mason, 2001), with individual species arriving up to two weeks earlier over the past 2-3 decades (Sparks & Mason 2001). Similar advances in arrival dates of spring migrants have been seen in Europe (Lehikoinen *et al.* 2004) and North America (Bradley *et al.* 1999). Supporting the notion that these earlier arrivals are the result of climate change, where no (significant) change has been observed in local temperatures no advancement in arrival date has been observed (Inouye *et al.* 2000; Barrett 2002) and where local temperatures have become cooler, there has been a tendency for later arrival (Sparks & Braslavska 2001). In some cases where apparent timing of events in spring is occurring later, this is due to other factors operating, such as declining population size (Collinson & Sparks 2005).

The changes in arrival dates of migratory birds (typically 2days/1˚C) appear to be less than changes in the vegetation and invertebrate phenology (typically 6days/1˚C), creating some concern that differential responses could result in a disconnection of ecosystem processes (Sparks & Menzel 2002; Root *et al.* 2003; Sparks & Mason 2004; Visser *et al.* 2004). Changes in the timing of arrival seem to be greater among short-distance migrants, than long-distance migrants (e.g. Tryjanowski *et al.* 2002; Hubalek 2003). This might be expected if individuals assess departure time according to local conditions that are increasingly correlated with conditions on their breeding grounds, the closer the wintering (or staging) grounds are. However, not all studies find such a distinction between short and long-distance migrants (e.g. Hüppop & Hüppop 2003), rather, such differences may be related to the fact that early migrants in both groups show more pronounced changes than later species. Thus, the question of whether long-distance migrants are particularly vulnerable to climate change remains open.

A small, but important component of global warming comes from urban areas, which are well known to exhibit higher temperatures than the surrounding countryside, creating 'heat islands' (Karl *et al.* 1988; Parmesan & Galbraith 2004). Consequently, urban areas have experienced a greater degree warming and the timing of some spring events has advanced at a greater rate in these areas than the surrounding countryside (Roetzer *et al.* 2000; White *et al.* 2002). However, certainly for avian studies, most information is collected at larger scales than single cities, and integrates over a greater range of habitats, so urban anthropogenic warming is not the primary factor in causing the phenological changes discussed here.

Evidence for later departure of migratory birds from their breeding grounds, and earlier arrival on their wintering grounds is more scattered (Bairlein & Winkel 2001; Sparks & Mason 2004). Sparks & Mason (2001) observed that nine species displayed trends towards progressively later departures for the wintering grounds since the 1950s, whereas only one species was leaving the UK at a significantly earlier date than before. An analysis of data concerning the autumn passage of Willow Warblers *Phylloscopus trochilus* at Dungeness Bird Observatory in Kent (Marchant & Wernham 2003) revealed that departure dates were on average 5-10 days later over the period 1994-2000 than they had been between 1962 and 1968. There is also some evidence to suggest that winter migrants which travel relatively short distances within the UK, such as Merlin *Falco columbarius* and Hen Harrier *Circus cyaneus*, may also have advanced their arrival dates on the wintering grounds (Sparks & Mason 2004), but this trend is less consistent across species with many others displaying no advancement. However, data collected in the Swiss-French Alps between 1958 and 1999 (Jenni & Kery 2003) suggest that the influence of climate change on departure dates may be more complex, at least for some European populations as a significant trend for delayed departure was observed amongst short distance migrants (wintering in the Mediterranean region), particularly those which produce multiple broods, whereas departure dates of long-distance migrants tended to become earlier. Where these species breed in the Mediterranean this may result in the species becoming non-migratory, for example Common Buzzard migration through Gibraltar (a UKOT) has virtually ceased (J. Cortes pers. comm.).

Climate induced changes in habitat are likely to have impacts on staging, stopover ecology and fuelling in migratory birds. The impacts of these changes on population levels are speculative due to uncertainty in climate models with respect to geographical variation in climate change, and regional and species-specific changes are also probable (Bairlein & Hüppop 2004). Migratory fuelling generally occurs before crossing an ecological barrier, such as a large expanse of desert or water. For example the Garden Warbler *Sylvia borin* weighs 16-18g in the breeding and (northern) wintering seasons, but increases its body mass to 37g before crossing the Sahara desert (Bairlein 1991). As such large fat reserves carry high costs and risks (e.g. Witter & Cuthill 1993), appropriate timing and the amount of deposition are obviously important, so any changes in timing, or the cues used for timing may have a large impact. Migratory warblers crossing the Sahara and arctic breeding geese and swans staging in northern Europe are two groups, where such impacts may be evident. However, birds have quite a large capacity to respond to adverse conditions, so there may be a fair degree of 'buffering' in the system (Bairlein & Hüppop 2004); of course this means if the buffering capacity is exceeded, the eventual impacts may be much larger.

In summary, weather conditions *en route* are known to affect an individual's ability to migrate. Though very little work has been done on the population consequences of this, they are mostly assumed to be small. It has been demonstrated that birds arrive earlier in years with warmer springs, and that there has been a general trend for earlier arrival as average temperatures have increased. There is some evidence that species which migrate short distances have responded to a greater extent than long-distance migrants, which may mean long-distance migrants will suffer greater impacts from changing climates. There is only scattered evidence that departure from the breeding grounds is getting later,

7.3. Breeding Phenology

In addition to changes in migration phenology, changing climatic conditions have affected the breeding phenology of migratory and non-migratory species alike. This is, at least in part, related to changes in the phenology of food resources. For example, advancement in leaf emergence results in advancement of caterpillar emergence, as insect herbivores (prey for many avian species) must maintain synchronicity with their food source. However, birds do not use food abundance as a direct cue to time breeding, except in the case of species which breed opportunistically (Visser *et al.* 2002, 2004), rather they must rely on an indirect, or proxy, cue. Temperature is the cue most likely to be used, though it is unclear to what extent gonad development is directly related to ambient temperature (Visser & Lambrechts 1999; Dunn 2004). The question of what environmental cues birds use to time their breeding and how they respond to changes in these is one that merits further research (Dunn 2004).

Physiological development is likely to respond to changes in temperature at a different rate in invertebrates than vertebrates, so leading to a mismatch between the optimal timing for bird breeding (based on food availability) and the possible timing of reproduction (reflecting physiological constraints). There is some evidence for such mismatches in Great Tits, Pied Flycatchers (Buse *et al.* 1999) and Honey Buzzards *Pernis apivorus* (Garcia *et al.* in prep.). However this pattern can vary on quite a small spatial scale in response to local ecological factors (Lambrechts *et al.* 1999; Visser *et al.* 2004), so the overall impacts are unclear. Should asynchrony develop, breeding success, and potentially survival of adult birds, may be seriously impaired. The consequences of this extend not just to timing of breeding schedules but also to moult, the timing of which is heavily dependent on the timing of breeding (Coppack *et al.* 2001), which may have carry-over effects for processes on the wintering grounds too.

Crick *et al.* (1997) demonstrated that the laying dates of around one-third of 65 breeding species studied in the UK have advanced, on average, by nine days in the last twenty years. These species were not limited by taxonomic group and included both migratory and resident species exhibiting a range of ecologies. More detailed analysis of the data over a longer, 57 year, period indicated that laying dates were significantly related to either spring temperatures or to spring rainfall for 31 of the 36 species studied (Crick & Sparks 1999). Furthermore, it was possible to demonstrate that the recent advancement of laying dates for seven of these species could be explained solely by climatic trends. The evidence for this relationship is particularly compelling as many species displayed a trend towards later laying as spring temperatures decreased up to the 1970s, only advancing their laying dates when this temperature trend was reversed during the following decades. Laying date advancements since the 1970s have also been reported from long-term studies of individual populations (e.g. McCleery & Perrins 1998; Slater 1999). Earlier laying in warmer years has also been reported for species in Europe, North America and Japan, with 79% of 57 species showing a negative relationship between laying date and air temperature (Dunn 2004). There is thus good evidence that changes in laying date are driven by changes in climate.

Sanz (2002), in a meta-analysis of the effects of the NAO on laying date in Blue Tits (75 study sites) and Great Tits (92 study sites) across Europe showed that there is much regional variation in the relationship, with effects being greater (more negative) in more western populations for both species and greater in northern populations of Blue Tits and southern populations of Great Tits. Similarly, Visser *et al.* (2003) found different responses between tit populations, though some of this variation could be explained by changes in the degree of multiple brooding in the population. Thus, the magnitude of effects of climate change are likely to be both species and geographically specific.

In summary, many bird species are breeding earlier. There is some evidence that in some species this may lead to a mismatch between the timing of breeding and timing of peak prey availability. It is unclear, at the moment, how many species will be impacted in this way (though it is most likely to apply to single-brooded species which forage on seasonally abundant prey), and how severe these impacts will be. This is an area that merits further research. There is good evidence that warmer springs are enabling birds to commence breeding (measured as date of first egg) earlier; this trend can be expected to continue.

7.4. Demographic Variables: Survival

Adverse weather conditions can influence the survival rates of bird species directly, or indirectly (Table 7.1). The rate of heat loss from the body increases as temperatures decrease and wetting of feathers by rain reduces the effectiveness of the plumage as insulation. In cold, wet conditions birds therefore have to invest more energy in maintaining their body temperature, and individuals failing to meet these increased costs may die. This is true particularly of resident passerine species in the UK (Peach *et al.* 1995; Thomson *et al.* 1997; Robinson *et al.* in prep), but also applies to migratory species, such as the coastal waders: Redshank (Insley *et al.* 1997) and Red Knot (Wiersma & Piersma 1994). This latter study found that the survival rates of first-year Redshank were lower in cold winters and in very wet winters, possibly due to increasing thermoregulatory costs in this relatively exposed environment. Under warmer climates, such effects are likely to become less severe, with beneficial consequences for the survival of individual birds.

The majority of bird species are limited in the amount of energy they are able to store as fat reserves, principally because excess weight increases the energetic cost of flight (Alerstam 1990; Gosler *et al.* 1995), as well as leading to increased predation risk (escape flight ability is impaired). Body weight (and hence condition) is thus maintained in an extremely dynamic fashion, with a number of factors influencing the bird's fattening decisions. Short, unexpected periods of adverse conditions can disrupt the delicate balance of trade-offs, causing large-scale mortality over very short periods of time. Clark (2004) found that the number of dead, ringed individuals of several migratory wader species, including Redshank, Grey Plover *Pluvialis squatarola* and Dunlin *Calidris alpina* increased during winters with periods of extreme cold. Severe storms can also have a direct impact on an individual's survival; for example, Lens & Dhondt (1992) reported the death of 62% of their study population of Crested Tit *Parus cristatus* after a severe storm in Belgium. The effect of tornadoes and hurricanes may be similarly devastating (Askins & Ewert, 1991; Wauer & Wunderle, 1992). Seabirds are also vulnerable to periods of severe adverse conditions, which can result in large mortality events, with many dead individuals (representing a small proportion of the total mortality) being washed ashore (e.g. Browne *et al.* 2004). Migratory species may be particularly vulnerable to these when they undertake journeys through hurricane belts, in areas such as the Caribbean, on a regular basis (Gauthreaux & Belser 1999).

.

Perhaps more pervasive are the indirect effects of climate and weather on survival, primarily through influencing the abundance and availability of the food supply. Just as changes in climate affect bird populations, so they affect the abundance of their prey populations. This might involve changes in range (Parmesan *et al.* 1999), or the rate of growth and thus in timing of emergence (Kimerle & Anderson 1971). Where bird populations vary in synchrony with their prey this climate change may cause relatively little problem directly, though it might disrupt the timing of other events in the migratory cycle. For example, the departure of arctic-breeding geese from wintering areas in northern central and western Europe is dependent on the quality (primarily protein content) of food plants. As a result of regional increases in temperature in Europe coupled with a slower advancement of spring phenology in arctic shallow waters, the stopover arrival of geese in these areas does not match the (relatively) delayed vegetation growth. There is an even bigger mismatch on the arctic breeding grounds where these species may arrive much to early for successful breeding (J. Stahl, pers. comm.), though the population consequences of this are poorly understood. Where a mismatch between bird populations and their prey population occurs, adverse consequences can arise, and there is some evidence that this is already occurring as a result of climate change (reviewed by Visser *et al.* 2004 and see above).

Importantly, climatic and weather conditions influence the quality, availability and accessibility of prey, lowering survival through reduced intake rates. Such factors may be more important in the non-breeding period when many populations, particularly those which winter in the northern hemisphere, may be food-limited. Extended periods of frost or snow cover may prevent ground-feeding birds from foraging, leading to increased rates of mortality and hence a reduction in population size. Survival rates of many passerines that spend the winter in Britain are known to be related to winter weather conditions (e.g. Peach *et al.* 1995; Robinson *et al.* 2004 see Table 7.1) and this appears to be related to the accessibility of food sources (Robinson *et al.* in prep.). Waterbirds, many of which are migratory, such as the Grey Heron *Ardea cinerea*, are particularly susceptible to decreases in food availability during spells of cold winter weather when areas of open water freeze over (Besbeas *et al.* 2002) and low temperatures and high rainfall in winter adversely affect the foraging success of many migratory shorebirds (e.g. Goss-Custard 1970; Pienkowski 1983; Insley *et al.* 1997). Climatic conditions also influence prey availability (and quality) for seabirds, this has been demonstrated to have effects on productivity (see below), but may also impact on survival. Survival of Emperor Penguins *Aptenodytes forsteri* in Terre Adélie, Antarctica decreased during a relatively warm period (Barbraud & Wiemerskirch 2001). High sea surface temperatures during this period were associated with poor krill *Euphausia superba* production, resulting in reduced populations of fish and squid (which prey on the krill) and hence poorer foraging success for the penguins. A warming climate is likely to increase the survival rates of many species in Britain, but increasing sea surface temperatures are likely to have adverse impacts on the survival of many seabird species.

Although resident birds in the UK, and elsewhere in temperate and boreal latitudes may face harsh conditions in the (boreal) winter, migratory species that spend the non-breeding period in the southern hemisphere may also suffer from adverse climatic conditions. For those spending the winter in southern Africa, rainfall may be particularly important and droughts during the winter months can lead to a serious reduction in the extent of the insect-rich wetland habitats in which many migrants, such as Sedge Warbler *Acrocephalus schoenobaenus*, forage (Peach *et al.* 1991; Marchant, 1992). The survival rates of adult Sedge Warbler (Peach *et al.* 1991), Swallow and Common Whitethroat (Baillie & Peach, 1992) have all been demonstrated to increase with the amount of precipitation falling on their wintering grounds. Similarly, survival of Sand Martins *Riparia riparia* is related to rainfall in the southern Sahel, through which the birds pass on their northwards migration (Szep 1995). The ability to cope with poor conditions on migration varies between individuals. For example, Jones (1987) showed that smaller bodied Sand Martins appeared to survive poor conditions in the Sahel better than big bodied individuals.

Migratory species also require clement conditions on stopover sites in order to successfully complete their journey. Climatic conditions on the northward, spring journey are likely to be particularly important. This is for two reasons. Firstly, there is a greater evolutionary imperative to arrive early on the breeding grounds, as the first arrivals secure the best breeding territories and hence increased reproductive success (Kokko 1999). Secondly, mortality on the spring migration has less chance to be compensated for by other mortality factors than on the autumn migration. Mortality during the winter is often significant, and is likely to be density dependent, so that many individuals that die in the autumn may have died in the winter anyway, even if they had survived the autumn migration period. Habitats *en route* may present major ecological barriers for migrating birds and adverse weather conditions or changing climates can increase the hazards greatly. For example, periods of low rainfall result in poor berry crops on shrubs, such as *Salvadora persica*, in the Sahel, which represent an important food source for migrating warblers (Stoate & Moreby, 1995). Changes in wind direction and strength could also have a major impact on the physical condition of migrants (Piersma & Jukema 1990; Butler *et al.* 1997). For trans-Saharan migrants, predicted increases in temperature and decreases in rainfall over the Sahel region will have negative impacts on survival and probably also population size, as was seen in 1968/69, when whitethroat *Sylvia communis* populations crashed; an event from which numbers still have not recovered. The Caribbean OTs are used as stopover and wintering areas by several species migrating between North and South America, maintaining sufficient habitat for these species is likely to be the key requirement.

There is increasing evidence that infectious diseases can influence the dynamics of bird populations, and can limit population growth in some cases (Newton 1998; Hochachka & Dhondt 2000; Tompkins *et al.* 2002). Changes in weather conditions may lead to shifts in the rate of reproduction of pathogens, or in the distribution of vectors carrying these pathogens (Faustino *et al.* 2004). For example, Epstein (2001) suggested that warm winters and spring droughts might have contributed to the spread of West Nile Virus through avian populations in Europe and North America. The distribution and incidence of other avian diseases, such as malaria, may also be dependent on climatic variables although little information is currently collected on diseases in wild bird populations and there are insufficient historical data to allow the assessment of trends in infection over time.

In summary, weather conditions, particularly in winter, are known to have an impact on bird survival. The trend towards warmer conditions in the northern hemisphere is likely to decrease mortality due to adverse conditions, however, warming in the southern hemisphere, coupled with a tendency towards lower rainfall is will have impacts on over-winter survival for many UK long-distance migrant landbirds. To what extent density dependence in population processes will counteract these effects is unclear at present; this is an area that merits further research, and one for which much data is likely to be available, at least for commoner species. Stopover sites on migration are key periods for migrating birds as they are times of great physiological stress, changes in conditions experienced and in food resources present could have substantial effects, either beneficial or detrimental, depending on the type of change. The impacts of climate change will be species-specific, depending on their ecology, although groups such as long- or short-distance migrants may show similar patterns of impact. The role of diseases in population ecology, has recently begun to be realised and should be the subject of further research.

7.5. Demographic Variables: Productivity

Climatic conditions have been shown to influence productivity in a number of ways (Table 7.1). Firstly, young chicks may be particularly susceptible to chilling (hypothermia) due to their small size and undeveloped plumage (as may incubating adults under especially severe conditions). In warmer climates, e.g. the Mediterranean, they may also be susceptible to hyperthermia (i.e. heat stress). Secondly, climatic conditions can also influence the amount of food that parents are able to collect for their offspring.

The proportion of juveniles in the post-breeding population of a variety of passerine species has been demonstrated to increase with temperature (Sokolov, 1999). Several studies of the migratory Pied Flycatcher *Ficedula hypoleuca* in Europe have identified a positive relationship between fledging success and temperature (Jarvinen, 1989a, Eeva *et al.* 2002) and warm, sunny weather in June is also associated with increased survival rates of Spotted Flycatcher *Muscicapa striata* offspring (O'Connor & Morgan, 1982). Conversely, wet weather in summer has been linked to increased chick mortality for species such as Capercaillie *Tetrao urogallus* (Moss *et al.* 2001; Summers *et al.* 2004), Black Grouse *T. tetrix* (Summers *et al.* 2004), Grey Partridge *Perdix perdix* (Panek, 1992) and the migratory Corncrake *Crex crex* (Tyler & Green, 2004), possibly because their chicks leave the nest soon after hatching and are particularly susceptible to wetting when foraging in damp vegetation. In at least one case, climate change appeared to be causing a population decline (Moss *et al.* 2001). Similarly, in North America, productivity of both neotropical migrants and temperate wintering species (including some short-distance migrant species) were positively related to temperature, though via different mechanisms (Nott *et al.* 2002). For neotropical migrants, weather conditions on the wintering grounds prior to spring departure were important, whereas for temperate winterers, climatic effects on insect populations on the breeding grounds were more closely related to productivity. Low temperatures reduce the activity levels of invertebrates (Davies & Green, 1976; Avery & Krebs, 1984), as do periods of high rainfall (Foster, 1974; Morse, 1989**),** limiting the amount of food that insectivorous species are able to collect for their offspring. Both Pied Flycatcher (Siikmaki, 1996; Eeva *et al.* 2002) and Willow Warbler nestling stage failure rates have been found to increase during wetter breeding seasons (Leech & Crick, in prep). These two species are migratory, but similar patterns apply in resident species too (Evans *et al.* 1997; Bradbury *et al.* 2003). With a predicted increase towards wetter summers, it is possible that productivity of some species may decrease (particularly nidifugous species, though most of those studied are not migratory), however, such impacts will depend very much on the timing of rainfall in relation to young being in the nest, and may vary regionally.

Wet summers are associated with poor breeding success for migratory raptors such as Peregrine *Falco peregrinus* (Norriss, 1995; Leech & Crick, in prep) and Merlin *Falco columbarius* (Leech & Crick, in prep) that hunt other bird species on the wing, as heavy rain may both reduce the activity levels of their avian prey species and reduce visibility (Ratcliffe, 1980). However, the influence of rainfall on the survival rates of nestlings is not necessarily always negative. For example, Schmidt *et al.* (1992) found that the fledging success of Nuthatch *Sitta europaea* chicks increased with rainfall in March and April, and Leech & Crick (in prep) found a similar relationship for Carrion Crow *Corvus corone* suggesting that wet springs may actually result in increased food availability later in the year when the chicks have hatched. Thus, changes in productivity in response to climate changes are likely to be species specific. The density dependent nature of population processes mean it is unclear whether such changes in productivity will affect overall population sizes.

The relationship between climate and breeding success has been well documented for seabirds. Many studies have identified significant relationships between sea surface temperatures, which determine the abundance of plankton and therefore of fish species and, consequently, the reproductive success of seabird species across the world's oceans (e.g. Thompson & Ollason, 2001; Durant *et al.* 2003; Jenouvrier *et al.* 2003; Smithers *et al.* 2003). The distribution of marine invertebrates is often sensitive to sea temperature (usually measured at the surface) and climate change has caused both a warming of temperatures and a shifting of currents (and hence the spatial balance of areas of warm and cold water). This causes a shift in invertebrate distribution, which can affect bird foraging success, and hence productivity. Kitaysky & Golubova (2000) studied breeding auklets *Aethia cristata* and *Cyclorhinchus psittacula* and puffins *Lunda cirrhata* and *Fratercula corniculata* in the Okhotsk Sea. The auklets feed largely on (macro-)plankton, while the puffins feed primarily on fish (which feed on meso-plankton). Macro-plankton were more abundant during years when cold water predominated, whereas meso-plankton were more abundant when warm water pre-dominated. Similarly the breeding success of auklets was greater in cold-water conditions, that of puffins in warm-water conditions. It is unlikely another environmental variable would explain such contrasting patterns so parsimoniously. Consequently climate change is likely to lead to changes in the seabird community, but such changes will be depend on species-specific aspects of ecology.

Of course, seabird reproductive success will also be impacted by fishing activities. Frederiksen (2004) investigated the role of changing water temperature and fishing activity in determining breeding success, and hence population size, in a UK colony of Kittiwakes and showed that both factors played an important role, supporting the correlative study of Aebischer *et al.* (1990). There is thus good evidence that, for seabirds, many of which are migratory in the sense of crossing national boundaries, climate change is influencing reproductive success. It is difficult to disentangle the relative importance of changing sea temperature and pressures from fisheries but both contribute to the observed changes in productivity. Changes in Kittewake productivity associated with climate change have already been observed, and are predicted to intensify under current scenarios (Frederiksen 2004), similar patterns are likely to be seen in other species.

Populations of waders breeding in the high Arctic are all migratory, and many spend the winter in UK coastal areas. The implications of earlier arrival and breeding of northern waders are currently unexplored (Rehfisch & Crick 2003). However, earlier phenology may be beneficial if it provides waders with greater opportunities for multi-brooding or clutch replacement after failed breeding attempt. Furthermore, earlier breeding may provide juveniles and post-breeding adults with a longer period to grow and improve their body condition before migrating south at the end of the summer. However, there is the possibility that warmer temperatures may lead to increases in high latitude precipitation, such that snow cover is retained for longer. Thus, waders that attempt to arrive earlier on their breeding grounds may be faced by prolonged snow cover that could affect their survival. Furthermore, increased snow cover and delayed melt could delay their breeding, which may be detrimental given the short 'window of opportunity' that they have for breeding at high latitudes before temperatures start to fall again. The mistiming of arrival in relation to delayed snow melt can also affect high altitude populations, such as in Colorado, where American Robins *Turdus migratorius*, arrived 14 days earlier in 1999 compared with 1981 due to warmer temperatures at lower altitudes, but the interval between their arrival and the date that bare ground is first exposed has actually grown by 18 days due to greater snowfall and later snowmelt (Inouye *et al.* 2000). In addition, if the climate becomes more variable (Hulme *et al.* 2002), then periods of extreme (and detrimental) weather may increase early in the season, causing greater stress on new arrivals and causing increased nest losses. Furthermore, climatic conditions not only influence the abundance of insects, and therefore the availability of food with which to provision the offspring, but also affect the size of the lemming (*Lemmus* spp. and *Dicrostonyx* spp.) populations in the tundra (Summers & Underhill 1987; Soloviev & Tomkovich, 2003). In years when lemmings are scarce, avian and mammalian predators such as skuas *Stercorarius* spp. and Artic Fox *Alopex lagopus* turn their attention to the contents of nests, reducing the breeding success of the ground-nesting wader species. Thus, predicted warmer climates are likely to have severe negative impacts on wader populations, most of which are migratory, particularly those that breed in the Arctic.

Climate change may also influence adult condition at the start of the breeding season. Even if individuals are able to survive unfavourable winter conditions while on passage or on return to the breeding grounds, they may be left with depleted energy reserves that are insufficient to allow successful breeding during the following season. Reductions in the number of individuals attempting to breed may also have a negative influence on the size of the population. Ambient temperatures during the laying period have been found to positively influence the clutch size of a number of passerine species, including the migratory Pied Flycatcher and Redstart (Järvinen 1989b; Winkel & Hudde 1997; Leech & Crick, in prep.) and increased clutch sizes have been reported as a consequence of a trend towards warmer temperatures and earlier arrivals (Järvinen 1996; Winkel & Hudde 1997). In addition, Nager & Zandt (1994) observed that Great Tits laid larger eggs in warmer temperatures, which are likely to have increased hatching success and chick survival (Järvinen & Vaisanen 1983; Both *et al.* 1999). Bryant & Stevenson (2000) showed that temperature acted as a constraint on egg-laying in the Great Tit due to conflicts with daily metabolism, so increased egg sizes are likely irrespective of calendar date of laying. Sanz's (2002) meta-analysis of Blue and Great Tit populations showed no trend towards increased clutch size, suggesting that the breeding season has just become earlier rather than 'extrapolating' earlier (i.e. following the relationship that currently exists between laying date and clutch size, and hence producing a larger clutch size at an earlier date, Crick 2004). This highlights a general problem with understanding the mechanisms of climate change - the relationships we observe now may not hold under changed climatic conditions. Understanding the mechanisms behind the relationships will be important if we are to accurately assess the impacts of a changing climate.

In summary, there is good evidence that changes in productivity have occurred as a result of changes in climate. In northern temperate regions, at least, productivity for many species is expected to increase, however, the density-dependent nature of population processes does not mean an increase in population size, as survival may decline in response to the increased competition between a greater number of individuals. There is evidence that productivity of open ground nesters may decrease in response to increased precipitation, though the timing of such events will be critical in determining the severity of impacts on population size. Changes in productivity in response to climate change are particularly well documented in seabirds, and such changes appear to be independent of other factors, such as fishing pressure. Reductions in seabird productivity seem to be driven by declines in prey distribution in response to warming sea temperatures.

7.6. Impacts on Population Size

The size of all populations is essentially controlled, at a fundamental level, through the balance of two demographic rates: the rate at which new individuals are born into the population, and the mortality rate, i.e. the rate at which old individuals leave the population (e.g. Newton 1998). A number of detailed population studies have shown that reasons for changes in population size, either in the long-term or short-term fluctuations, can be explained by understanding variation in these demographic rates (e.g. Peach *et al.* 1994, 1999; Goss-Custard *et al.* 1995; Potts 1996; Siriwardena *et al.* 2000; Crick *et al.* 2002; Atkinson *et al.* 2003; Frederiksen *et al.* 2004; Robinson *et al.* 2004). These studies cover a range of taxonomic groups and life-history strategies, and both migratory and resident species. The size of local populations may also be augmented or reduced by dispersal into or out of the population, though this is not a consideration when dealing with entire species or distinct populations, as CMS does. However, movement of populations during periods of cold weather, especially prevalent in migratory waterbirds (Baillie *et al.* 1996; Austin & Rehfisch 2005) might complicate assessments of population size, particularly where regional assessments are made, for example in the site designation process (Atkinson *et al.* 2004).

There have been a number of studies looking at the effects of local climatic variables on changes in bird populations (Table 7.2). These have mostly investigated the effects of mean temperature or precipitation, or a related measure, on either time-series of population size, or annual changes in numbers. All of these studies are of birds from European or North American breeding populations and only four relate specifically to species covered by CMS (all on Appendix II, see below).

There is a clear difference between migratory and resident birds in the climate variables found to be most closely related to changes in population size. Whereas population change in resident species appears related mostly to winter climate, particularly winter temperature, changes in breeding population size of migratory species seem to be mostly related to changes in spring rainfall. This is primarily the annual variation in rainfall in the Saharan and Sahel regions of Africa, over which many passerines migrate northwards. This reflects the Afro-European bias of studies, but clearly climatic conditions on the migratory journey are very important in determining population size.

Four species included in the analyses in Table 7.2 appear on Appendix II of the CMS. Two, Garden Warbler *Sylvia borin* and Sedge Warbler, are representative of the Muscicapidae (which as listed includes the (sub-)family, Sylviidae) and both migrate in the winter to sub-Saharan Africa. Populations of both are affected by spring rainfall on their northward journey, and such rain is likely to be important for many of the trans-Saharan species in this family. It can take populations many years to recover from severe climatic events. For example, the numbers of Whitethroat breeding in Britain have been significantly reduced (> 90%) following a period of drought in the Sahel (Winstanley 1974). Numbers still have not recovered to their former levels, despite the drought event occurring in 1968. It is unclear as to whether spring conditions will have such an impact on the remaining migratory members of this family that spend the winter in the Mediterranean basin. Numbers of breeding Wigeon *Anas penelope* in Iceland, which migrate to Britain in winter from northerly climes, were related to the date of water becoming ice-free on their breeding lakes (Gardarsson & Einarsson 1997). It is unclear, though, whether this simply represented dispersal elsewhere, possibly into a non-breeding population and so whether the observed change in numbers on the study lakes was related to the overall population size, or simply reflected a redistribution elsewhere. It would appear that the decline in the numbers of many species of Britain's internationally important wader populations (Rehfisch *et al.* 2003a,b) is a result of a change in their distribution (Rehfisch *et al.* 2004; Austin & Rehfisch 2005) that has extended to Continental Europe (Maclean, Austin & Rehfisch in prep.). Numbers of Golden Plovers *Pluvialis apricaria* breeding in upland England were related primarily to temperature on the wintering grounds (Yalden & Pearce-Higgins 1997) increasing two years after warm and moist winters, presumably because juveniles survive better (Forchhammer *et al.* 1998). Similar changes are likely to be exhibited by many of the migratory Charadriidae listed by CMS, particularly for those that winter in northern temperate latitudes.

The studies analysed in Table 7.2 involved correlations with average climatic variables. Variability in climate is also important, with bird populations being affected by climatic extremes, both in summer and winter. For example, George *et al.* (1992) found numbers of breeding grassland passerines, some of which were migratory, greatly reduced in a drought year in central North America. In this case, the breeding population recovered the following year indicating some buffering by the population in the long-term trend. In contrast, following a drought in the Sahel in the spring of 1962, numbers of Whitethroat *Sylvia communis* fell dramatically (Winstanley 1974) and have yet to recover (Baillie *et al.* 2005). Such non-linear responses are likely to be common in response to changing climates, with populations being buffered to some extent to normal annual variability, but not so to extreme events.

Most climate scenarios predict an increase in weather extremes, of temperature and precipitation as well as storm events, so such ‘one-off’ impacts may be become more frequent, although largely unpredictable, and short-lived, may have long-lasting repercussions for populations, as evidenced by the Whitethroat example.

Climate change may, of course, impact both productivity and survival and the relative magnitude of these impacts will determine the overall change in population size. For example, Emperor Penguins *Aptenodytes forsteri* breeding in Antarctica suffer reduced survival as a result of warmer sea temperatures decreasing food supply (see above), but also have increased hatching success, because of reduced travel times over the pack-ice (Barbraud & Wiemerskirch 2001). However, the impacts on adult survival were greater in demographic terms than the increased productivity, so colony size was declined. In general, impacts on either (or both) productivity and survival will be required for climate change to have an impact on population size, which at the international level is the key conservation measure. (At the national level, changes in range without, necessarily, a change in overall numbers may also be important for national conservation strategies.) However, due to the density-dependent nature of population processes, it is very difficult to predict change in population size, even from knowledge of productivity and survival rates, without a knowledge of the strength of density dependence (Green 1999). This is an area that strongly merits further research.

In summary, there have been a number of studies looking at the impact of local weather, mostly temperature and precipitation variables, on population size. For migratory species, most effects relate to variation in spring rainfall on migration in the Sahel. While this partly reflects a publication bias, it does underscore the importance of this region for migratory birds and the severity of impacts likely from the predicted reduced rainfall in this region. Populations are also susceptible to extreme climatic events, and may take many years to recover in numbers. Although the frequency of extreme climatic events is predicted to increase, the species-specific nature of these impacts means that general predictions are not possible.

7.7. Climate Change and Migratory Bird Species

Table 11 of the Appendices details the threats to bird species listed on the Appendices of the CMS from both climate change impacts and other, anthropogenic, threats. The climate change threats are to some extent speculative, but are thought to be plausible based on knowledge of the species’ current ecology, distribution and habits.

Of the 300 species, 251 (84%) occur in one of the four most vulnerable habitats (coastal, wetland, tundra or montane) to changed climatic conditions. Of these, 233 (93%, 78% of the total) occur in coastal or wetland habitats, highlighting the importance of these types of site for migratory species. The 73 (24%) species that occur in tundra or montane habitats are likely to be particularly vulnerable, as these habitats have a relatively limited geographical space in which to spread under warmer climate scenarios, which suggest a latitudinal or altitudinal shift in the occurrence of these habitats.

Climate change scenarios suggest changes in a wide range of climate related phenomena that have the potential to impact on populations of migratory birds listed on the CMS (specific examples from Appendices I and II are given). These include:

- Increased storm frequency: likely to affect the productivity of species nesting in low-lying coastal areas, particularly on tropical islands, such as the Caribbean UKOTs e.g. Short-tailed Albatross *Diomedea albatrus*. It may also affect the ability of landbirds to complete their migratory journeys, though the population impacts of this are likely to be small. The extent of threat to CMS listed species is relatively small, with only 7% potentially suffering impacts based on current knowledge of their species ecology.
- Lowered water tables: will reduce habitat availability for aquatic species, such as Baikal Teal *Anas formosa* and reduce food availability for terrestrial species that forage in such areas such

as Chestnut Seedeater *Sporophila cinnamomea.* Additionally, such wetland areas provide critical staging habitat for many migratory species, such as Aquatic Warbler *Acrocephalus paludicola*, and habitat loss may compromise their ability to complete their migratory journeys. This is the most prevalent climate-related threat to species listed on the Appendices of the CMS with around 40% of species potentially impacted based on a knowledge of the species ecology.

- Higher drought frequency: a forecast greater incidence of droughts will particularly affect those species that use seasonal wetlands, such as many waterfowl. Increased droughts are likely to extend the width of the deserts that present significant barriers to some migrants, particularly passerines such as Aquatic Warbler. Taken together with lowered water tables, around half of species (53%) listed on the CMS are likely to suffer some impacts from this factor.
- Altered prey distribution: changing climate will impact on species that are prey for birds as much as birds themselves; changes in prey distribution have the potential to impact severely on the populations of many species. Such changes have perhaps been best demonstrated for seabirds. Analogously, prey may shift in timing that might impact on bird populations, though it is uncertain how widespread and significant these impacts might be at present. At least 25% of species on Appendices I & II of the CMS are likely to be affected, but this is likely to be a substantial under-estimate.
- Sea level rise: will reduce habitat availability of species that nest or forage in low-lying coastal areas, particularly where 'hard' sea-defences are put in place. This may be particularly problematic for migratory species as many important stopover areas are in such coastal habitat, often as a relatively limited number of discrete sites. Migratory waders, such as Spoon-billed Sandpiper *Eurynorhynchus pygmeus*, and waterfowl, such as Lesser White-fronted Goose *Anser erythropus*, may be particularly This is particularly relevant to the UK, which hosts internationally important numbers of several wader and waterfowl species, both in winter and on passage. The impacts of sea level rise will be restricted to coastal species, which represent about a fifth (18%) of the species listed on the CMS Appendices.
- Habitat shifts: Changing climate will lead to shifts in vegetation zones; this will affect many bird species who nest and winter in such habitats. Arctic and high montane species, many of which are migratory, are the most likely to be affected in this way. Migratory species may be particularly affected if the length of the migratory journey increases, though there is limited evidence that this will be a significant factor currently. Around a fifth (17%) of species are likely to be affected by shifts in habitat.

Based on current knowledge of each species, ecology, distribution and habits, only 35 (12%) species were identified which did not face specific threats due to climate change (mostly as a result of large population sizes), though about half of these occur in the threatened habitats previously identified. This scale of threat is comparable to that resulting from anthropogenic causes, which have been identified to affect 80% of the species listed (see Table 7.3). Of climate change impacts, changes in water regime are most pervasive (affecting 53% of species), reflecting the importance of wetland sites for migratory species. A mismatch in the timing of prey abundance and the bird's breeding season has the potential to affect most insectivorous species, though as discussed above the actual effects on population dynamics are still unclear. Changes in range of prey species are likely to affect species that have restricted ranges, or which use a limited range of habitats. Climate induced habitat shifts are again likely to affect species with limited range, or particular habitat requirements (perhaps because of other, anthropogenic influences).

Good knowledge of the specific potential impacts of climate change is restricted to relatively few, well-studied species. We discuss a representative selection of these in the Case Studies (summarised in Table 7.4). The six species discussed were to illustrate the potential range of effects likely to be important to avian populations. Where possible, we have used these Case Studies to make more general comments about the potential impacts of climate change.

7.8 Adaptation to Climate Change

Although the threats to bird populations from climate change are severe, there has been very little attempt to adapt to climate change impacts explicitly, though measures taken to counter other conservation threats will undoubtedly be beneficial (Gitay *et al.* 2002). Often, significant improvements in conservation status are likely to be achievable through mitigation of anthropogenic impacts, which allow many populations greater capacity to adapt to climate change impacts, without explicit targeted measures. One example is the use of habitat corridors, which although controversial (Simberloff *et al.* 1992), do appear to provide some conservation benefits (Levey *et al.* 2005).

Perhaps the best example of adaptation to climate change threats comes from the U.K. in the form of managed realignment of coastal defences (Atkinson *et al.* 2004). Many migratory wader species, such as the Redshank (see Case Study) rely on low-lying coastal areas that are threatened by rising sea-levels, particularly where immovable sea-defences are employed to protect land for human use (Norris & Atkinson 2000; Norris *et al.* 2004). In some cases it is more economic to realign the coastal defences than to increase them to prevent further encroachment. Such provision of sites may also be required under EU habitat legislation and to provide compensation for habitats destroyed by human development activities. Assessment of the success of these schemes is difficult, both because of their long-term nature, and because biological monitoring has been poor (Atkinson *et al.* 2004).

Overall, the UK experience of creating mudflats through managed realignment is encouraging. Biologically active mudflats have formed at all sites that were sufficiently low in the tidal frame and, on two sites at least, within 5 years invertebrate and bird faunas have developed that were similar, although not identical, to those found on ‘natural’ mudflats. However, some realignment sites may develop habitats that are unsuitable for particular species, e.g. species that rely on large bivalves such as Eurasian Oystercatcher *Haematopus ostralegus*. Managed realignment also tends to take place at relatively small sites higher in the tidal frame and the large-scale creation of mudflats at lower elevations is untested in the UK. The creation of saltmarsh is more difficult and, even after many decades, vegetation communities may be different from those of surrounding areas (e.g. Burd 1994).

7.9. Birds as Indicators of Climate Change

Birds make good indicators of environmental change (Furness *et al.* 1993). They share a number of features: they are easy to identify; they are relatively high in the food chain, thus they integrate events and processes further down the chain; they are relatively well-studied and understood (as this review demonstrates) and there are (often) pre-existing baseline data; they have a relatively long lifespan, meaning they integrate the effects of environmental stress over time allowing long-term effects to be measured, but possibly obscuring shorter term perturbations. The presence of density-dependent processes does mean that there is some (probably variable) buffering in population size, which might obscure any impacts, but, conversely, any impacts that are observed will, consequently, be that much more serious.

Because of these features, changes in bird populations have been proposed as monitors of the extent of climate change. In the UK, amongst a suite of 34 indicators, two phenological variables (arrival date of Swallows) and egg-laying dates in two species (Robins *Erithacus rubecula* and Chaffinches *Fringilla coelebs*) have been suggested as suitable indicators, together with an index of Wren population size (Cannell *et al.* 1999). All three of these variables have been demonstrated to be closely related to ambient temperatures. Wintering waders also have been suggested as an indicator of the effects of climate change on wintering populations of migrants (Rehfisch & Crick 2003; Rehfisch *et al.* 2004; Rehfisch & Austin 2005). Waders are likely to be particularly useful indicators as the phenological shifts expressed by species in northerly latitudes are greater than those further south (Root *et al.* 2003) and Arctic species tend to show range-size contraction (Parmesan & Yohe 2003). In a European context, the survival rates of bird species has also been proposed as a possible indicator of climate change (EEA 2004) because the survival rates of many species, have been shown to be related to temperature (Baillie 1992; Frederiksen 2002; Robinson *et al.* in prep.)

7.10. Summary

7.10.1. Impacts of Climate Change on Birds

Birds represent the group in which the impacts of climate change on migratory species are perhaps best documented. Changes in range and the timing and direction of migratory routes have changed recently, and there is good evidence that this is due, in large part, to a changing climate, especially increases in winter temperature. For many temperate species, these impacts may be beneficial, but for high arctic and montane species (a high proportion of which are migratory) the impacts will be severe as the area of suitable habitat is likely to decline markedly.

There is good evidence that the timing of migration, and of breeding is changing in response to climate changes, particularly an increase in spring temperatures. An earlier commencement to the breeding season may have beneficial effects if it allows more breeding attempts, however, it may also lead to asynchrony with prey populations, which will have severe negative impacts. Migratory species are particularly vulnerable in this regard, since they are constrained by the timing of their migration. However, the population impacts of such phenological change are unclear and are a key research gap.

Survival of many bird species is linked to climatic conditions, in particular winter weather. For temperate migrants, increasing winter temperatures are likely to improve survival, and there will be fewer mass mortality events, which, until recently, were not infrequent, particularly amongst waders. Trans-equatorial migrants, particularly those which winter in Africa south of the Sahara, on the other hand, might be expected to see a decline in survival rate, if precipitation declines as predicted. The increased desertification of the Sahel, a key stopping off point before crossing the Sahara Desert on the northward migration will reduce the number of birds able to make the return migration, and is a key conservation concern.

There is also good evidence for changes in productivity in relation to changing climate. However, these changes vary between species groups. Amongst many species productivity is related to temperature, and is showing a long-term increase over the last few decades, at least in the UK, although in some species it is difficult to determine whether this is a density dependent response to population declines. Some ground-nesting species may be adversely impacted by increased precipitation, but predictions are difficult since the timing of precipitation will be critical. Increased sea surface temperatures are causing shifts in plankton communities, which are having adverse impacts on seabird productivity.

Overall, there are many studies showing that changes in weather conditions can have impacts on population size, with spring weather conditions in the Sahel region of Africa being particularly critical for migratory species. Climate change will affect populations through a combination of impacts on productivity and survival, investigating the impacts of climate and density on these demographic variables must be a key research priority. This also applies to groups other than birds, though may be more difficult to achieve.

7.10.2. Key Conservation Priorities

Climate induced changes in habitat area, phenology and demography are likely to affect all bird species in the future, irrespective of their migratory status, but three key areas apply particularly to migratory birds:

- Increased drought frequency and desertification in the Sahel making the northward migratory journey more difficult for many passerine species (particularly migratory members of the Muscicapidae, listed on CMS Appendix II).
- Maintenance of a network of high quality wetland sites to allow many waders and waterfowl (listed on CMS Appendices I and II) to complete their migratory journeys. These are

threatened by sea-level rise and a reduction in water table level, as well as, in some cases critical, anthropogenic exploitation. In many cases this simply means making best use of existing measures. Compiling an inventory of these sites and their status for each flyway would be a useful step in assessing the coherence of the migratory network; much of this information is already available, but scattered in the literature.

- Loss of polar habitats (particularly tundra) as breeding habitat. Most of the species breeding in these areas are migratory, and many are listed on the CMS Appendices.
- The maintenance of key long-term monitoring schemes, as these are of utmost importance for the detection of new and unexpected impacts of climate change. Birds are perhaps the best monitored of taxonomic groups, being relatively popular and thus with monitoring schemes that take advantage of extensive volunteer participation. Changes in bird populations may act as an early warning system of changes that may also impact on other parts of the food chain and other taxonomic groups.

7.10.3. Key Research Priorities

The effects and impacts of climate change on populations are best documented and best understood for birds as a whole, but much more work is required to fully understand and accurately predict the impacts of a changing climate. Key research areas are:

- Understanding the mechanisms behind the observed responses to climate change to better implement adaptation measures.
- Understanding the strength and prevalence of density-dependent factors (and the role of population limiting factors more generally) in regulating population processes. This is necessary if accurate modelling and prediction of future population changes is to be achieved.
- Understanding the importance and need for genetic variability for populations to respond to climate change. Currently, very little is known in this area.

Table 7.1. Effect of weather variables on the survival and productivity of Resident (R) and Migratory (M) species.

Species	Status[1]	Season[2]	Variable[3]	Reference:
Survival				
Emperor Penguin	R	B	T	Barbraud & Wiemerskirch 2001
Grey Heron	M	W	T	Besbeas *et al*. 2002
Lapwing	M	W	T	Peach *et al*. 1994 Marcström & Masscher 1989
Redshank	M	W	T/R	Insley *et al.* 1997
Redshank	M	W	T	Clark 2004
Grey Plover	M	W	T	Clark 2004
Dunlin	M	W	T	Clark 2004
Swallow	M	W	R	Baillie & Peach 1992
Sand Martin	M	S	R	Szep 1995
Wren	R	W	T	Robinson *et al.* 2005
Dunnock	R	W	T	Robinson *et al.* 2005
Robin	R	W	T	Robinson *et al.* 2005
Song Thrush	R	W	T	Thomson *et al.* 1997 Robinson *et al.* 2004
Sedge Warbler	M	W	R	Peach *et al.* 1991
Whitethroat	M	W	R	Baillie & Peach 1992
Blue Tit	R	W	T/R	Robinson *et al.* 2005
Great Tit	R	W	T	Robinson *et al.* 2005
Treecreeper	R	W	R	Peach *et al.* 1995
Productivity				
Emperor Penguin	R	B	T	Barbraud & Wiemerskirch 2001
Southern Fulmar	M	B	T	Jenouvrier *et al.* 2003
Shag	R	B	T	Rinderf *et al.* 2000
Peregrine	M	B	R	Norriss 1995 Leech & Crick in prep.
Grey Partridge	R	B	R	Panek 1992
Black Grouse	R	B	R	Moss 1986 Summers *et al.* 2004
Capercaillie	R	B	R	Moss & Oswald 1985 Moss *et al.* 2001
Corncrake	M	B	R	Tyler & Green 2004
Spotted Owl	R	W, S	R	Franklin *et al.* 2000
Kittiwake	M	B	T	Rinderf *et al.* 2000; Frederiksen 2004
Guillemot	M	B	T	Rinderf *et al.* 2000
Puffin	M	B	T	Durant *et al.* 2003
Auklets (2 spp.)	M	B	T	Kitaysky & Golubova 2000
Puffins (2 spp.)	M	B	T	Kitaysky & Golubova 2000
Nuthatch	R	S	R	Schmidt *et al.* 1992
Redstart	M	B	T	Leech & Crick in prep.
Spotted Flycatcher	M	B	T	Morgan & O'Connor 1982
Pied Flycatcher	M	B	T	Jarvinen 1989 Eeva *et al.* 2002
Willow Warbler	M	B	R	Leech & Crick in prep.

[1] Status: R Resident/Sedentary; M Migratory.
[2] Season: A Autumn; B Breeding/Summer; S Spring; W Winter.
[3] Variable: R Rainfall/Precipitation; T Temperature.

Table 7.2. Effect of weather variables on local population size of Resident (R) and Migratory (M) species.

Species	Status[1]	Season[2]	Variable[3]	Reference:
Adelie Penguin	R		T	Wilson *et al* 2001
Night Heron	M	S	R	den Held 1981
Heron	R	W	T	Marchant *et al.* 2004
Purple Heron	M	S	R	Den Held 1981 Cave 1983
Squacco Heron	M	S	R	den Held 1981
Mute swan	R	W	T	Bacon & Andersen-Harild 1989
Wigeon	M	S	T	Gardarsson & Einarsson 1997
Buzzard	R	W	T	Kostrzewa & Kostrzewa 1991
Goshawk	R	W	T	Kostrzewa & Kostrzewa 1991
Goshawk	R	B		Kruger & Lindstrom 2001
Kestrel	R	W	T	Kostrzewa & Kostrzewa 1991
Prairie Falcon	R	W	R	Steenhof *et al.* 1999
Black Grouse	R	B	R	Moss 1986
Ptarmigan	R	B	T	Watson *et al.* 2000
Capercaillie	R	B	R	Moss 2001 Slagsvold & Grasaas 1979
Capercaillie	R	S	T	Moss 2001 Slagsvold & Grasaas 1979
Turkey	R	S	T	Rolley *et al.* 1998
Partridge	R	W	T	Rotella *et al.* 1996
Partridge	R	W	R	Rotella *et al.* 1996
Bobwhite	R	B	T	Lusk *et al.* 2002
Bobwhite	R	A	R	Lusk *et al.* 2002
California Quail	R	W	R	Botsford *et al.* 1988
Coot	R	W	T	Cave & Visser 1985
Golden Plover	M	W	T	Yalden & Pearce-Higgins 1997
N Spotted Owl	R	S	R	Franklin 2000
N Spotted Owl	R	W	R	Franklin 2000
N Spotted Owl	R	S	T	Franklin 2000
Swallow	M	S	R	Moller 1989
Sand Martin	M	B	T	Persson 1987
Sand Martin	M	W	R	Szep 1995
Dipper	R	W	T	Saether *et al.* 2000a
Wren	R	W	T	Greenwood & Baillie 1991
House Wren	R	S	T	Verner & Purcell 1999
Bewick's Wren	R	W	T	Verner & Purcell 1999
Galapagos Mockingbird	R		R	Grant *et al.* 2000
Medium Ground Finch	R		R	Grant *et al.* 2000
Catctus Ground Finch	R		R	Grant *et al.* 2000
Dunnock	R	W	T	Greenwood & Baillie 1991
Robin	R	W	T	Greenwood & Baillie 1991
Blackbird	R	W	T	Greenwood & Baillie 1991
Song Thrush	R	W	T	Greenwood & Baillie 1991 Robinson *et al.* 2004
Garden Warbler	M	S	R	Baillie & Peach 1992
Sedge Warbler	M	S	R	Baillie & Peach 1992 Foppen *et al.* 1999
various	M	S	R	Marchant 1992
Blue Tit	R	S	T	Slagsvold 1975
Blue Tit	R	W	T	Slagsvold 1975
Great Tit	R	W	T	Greenwood & Baillie 1991 O'Connor 1980

Species	Status[1]	Season[2]	Variable[3]	Reference:
Great Tit	R	S	T	Slagsvold 1975 Lebreton 1990 Orell 1989
Starling	R	W	T	Greenwood & Baillie 1991
Orange-crowned Warbler	M	B	R	Martin 2001
Red-faced warbler	M	B	R	Martin 2001
Virginia Warbler	M	B	R	Martin 2001
Grey-headed Junco	R	B	R	Martin 2001
Song Sparrow	R	W	T	Cave & Visser 1985

[1] Status: R Resident/Sedentary; M Migratory.
[2] Season: A Autumn; B Breeding/Summer; S Spring; W Winter.
[3] Variable: R Rainfall/Precipitation; T Temperature.

Table 7.3. Summary of threats faced by migratory species listed on the CMS. Based on Information in Appendix 1,Table 11. In each case the number of species affected is given.

Climate Change Impacts		**Anthropogenic Impacts**	
Lowered Water Tables	127	Hunting or Persecution	137
Increased Drought Frequency	84	Habitat Loss	132
(Water Tables and Drought)	(160)	Human Disturbance	76
Mismatch with Prey Abundance	73	Overgrazing	63
Sea Level Rises	55	Agricultural Intensification	22
Habitat Shifts	52	(Overgrazing and Intensification)	(70)
Changes in Prey Range	50	Direct Mortality	49
Increased Storm Frequency	20	Over-fishing / Long-lining	42
No Threats	35	Introduced Species	30
		No Threats	59
Total Number of Species	300		300

Table 7.4. Summary of the ecology, status, distribution and main response to climate change of each of the case-study species.

Species	**Migratory status**	**Habitat preference**	**Climate change impacts**
Sooty shearwater *Puffinus griseus*	Trans-equatorial pelagic migrant	pelagic and offshore water	ENSO intensification leads to less productive feeding grounds
Siberian Crane *Grus leucogeranus*	Eastern Palaearctic migrant	Freshwater wetlands	Taiga/Tundra vegetation changes, fluctuating water levels
Red Knot *Calidris canutus*	Global migrant	Northern tundra and estuaries	Loss of tundra, distribution changes
Common Redshank *Tringa totanus*	Palaearctic migrant	Wetlands, saltmarsh	Wetland loss, sea-level rise and coastal mudflats
Aquatic Warbler *Acrocephalus paludicola*	Trans-Saharan migrant	Fens and mires	Changes in hydrological regimes, Sahel drought
Pied flycatcher *Ficedula hypoleuca*	Trans-Saharan migrant	Oak woodland	Phenotypic miscuing

8. CLIMATE IMPACTS ON MIGRATORY BATS

8.1. Introduction

There are approximately 1100 bat species in the world (Simmons, in press). About 75% of bat species feed on insects, with most of the rest feeding mainly on fruit and flowers. A small number feed on small vertebrates, from fish to other bats, and three species from Central and South America feed on blood.

About 22% of bat species are considered threatened and a further 25% considered near threatened (Mickleburgh *et al.* 1992; Hutson *et al.* 2001; Hilton-Taylor, 2000). These figures may change following a current programme to reassess the conservation status of all the world's mammals through the IUCN's Global Mammals Assessment.

Bats have a number of features that place them particularly at risk of environmental change. These include their slow breeding rate (most bats only have one young per year) and the propensity of many species to aggregate into large colonies, particularly for the birth and nurture of the young.

Communal roosting, especially in caves, places bats at particular risk of the loss of the whole population from a wide area. Caves (or other underground roost sites) are subject to a range of threats, including mineral exploitation, sealing, incidental disturbances such as caving and tourism, and deliberate disturbance or harvesting of the bats themselves. Loss of mature trees with suitable roost cavities is also a threat to many species, and where bats have adapted to roosting in buildings their future may be affected by renovation or maintenance work or because they are unwelcome.

Throughout the world bats are strongly associated with forests and water, and populations are affected by the loss of these and other habitats or of key structural elements of the habitats. Agricultural development, industrial development and other pressures from increased human populations generally are common threats throughout the world. Other threats, such as over-exploitation for food and damaging practices for the control of vampire bats, are more regional threats.

The ecological services provided by bats have been poorly appreciated. Many species are regarded as pests of orchards and yet bats play a key role in the pollination and seed dispersal of plants grown or utilised by man. In many examples the vast number of insects consumed by bats often includes insects regarded as pests of agriculture or other products. The accumulations of guano under many larger bat colonies has long provided an important source of fertilizer for some societies. Increasingly bats are being incorporated into eco- and other tourism.

8.2. Migration in bats

While it is probable that many species of bats undertake regular seasonal movements (migration), the scale and extent of such movements is largely unknown. Such movements may be to avoid unfavourable climatic conditions and/or to take advantage of seasonably favourable energetic conditions. Most research has been carried out in temperate areas (where migration is likely to be more marked), but there have been some important studies in tropical areas. Traditionally, most data has come from the results of ringing (banding), although this has never been undertaken on the scale of bird-banding. Some recent studies have used more newly-developed approaches, such as analysis of DNA or stable isotopes, and it is likely that further technological advances will provide other opportunities to study bat movements in the future.

The most recent review of bat migration is that of Fleming & Eby (2003), which discusses in detail the ecological, behavioural, social and physiological effects of migration on bats. Important accounts of the interaction between arid zone plants and bats and the influence of that on migration can be found in Fleming & Valiente-Banuet (2002).

Various attempts to classify migratory bat species, e.g. as short-range (or sedentary), medium-range (or regional) and long range (Strelkov, 1969, 1997a, 1997b; Fleming & Eby, 2003) are based on the maximum distance that a species is known to move. Such classifications are complicated by several factors:

a. migration may be more pronounced in one sex (usually female) than the other.

b. only certain populations of a species may migrate.

c. the migration route and distance covered may vary depending on the differing flowering and fruiting pattern between years.

In temperate areas, where all bats are insectivorous, migration is usually between warm sites suitable for pregnancy and lactation and with adequate food supplies in summer, and cool sites for hibernation in winter (and this migration may not be north/south). Such regular movements may take bats from the roof of a building in summer to its cellar in winter, or to a location up to 2000 km from the summer roost. Winter aggregations may include individuals of a single species involved in short-, medium- or long-range movements. In Europe, populations of some species in north-east Europe are more likely to undertake longer migrations than populations of the same species in the north-west. Some species more or less consistently move only short distances and others regularly move long distances, giving some credence to the application of a classification of migration. However, it is clear that in Europe (where many range states are quite small in area) all species regularly make transboundary movements and hence fit within the definition of migration in the sense of CMS. Elsewhere in the world, even relatively long-range migration may not always take bats across national borders.

Available evidence suggests that most bats do not undertake long continuous movements; rather that the journey is interrupted at frequent intervals (perhaps daily) at ‘stopover’ points, with the bats resting and feeding to replenish energy requirements. Thus, the maintenance of suitable migration corridors, which include adequate stopover points, may be a more important conservation requirement for migrating bats than it is for many bird species.

In some temperate zone bat species, migration may be undertaken to allow wintering in areas that will allow feeding throughout the temperate winter period when insects are scarce, but this behaviour is rarely recorded and intercontinental migration is recorded in only one species, *Lasiurus cinereus* of North America. On the other hand, some tropical/subtropical species move into more temperate areas for parturition (e.g. some populations of *Tadarida brasiliensis*), or to take advantage of seasonally available food supplies (e.g. *Leptonycteris* spp, *Choeronycteris mexicana*).

Within the tropical or subtropical latitudes, migrations are still directed by changes in food supply and to allow the formation of large communal maternity colonies. In some cases, movements may be associated with retreating from seasonally arid areas to concentrate in moister areas where food supply may be more persistent. Similarly, although little studied as yet, altitudinal movements for the same reason are also recorded in a few species and suspected to occur in many more. In contrast, some African fruit bat species seasonally move into savannah habitat from wet forests; the wet forests may consistently provide a higher density of fruit, but in the wet season foraging in the savannah is still profitable. In some cases these movements are following a resource gradient (a flowering/fruiting corridor) and in years of particular abundance of food resources along the route, the bats may not complete the maximum route. In some cases, food resources may not follow a strict gradient, and resultant movements may be more erratic.

Some species are highly colonial during the period of parturition and rearing of young. These concentrations of bats may accumulate from very wide area and give a special vulnerability to catastrophic loss of bat populations. Similarly, ideal hibernation sites may aggregate large numbers of bats of a wide range of species from a wide catchment area. Where large aggregations are for breeding purposes, there is the potential for the influx to produce competition for local resources; where it is for hibernation purposes, there is little impact on local resources.

Where there is sex bias in migratory bat species it is generally more pronounced in females (e.g. *Nyctalus noctula*, *Pipistrellus nathusii* in Europe, *Miniopterus schreibersii* generally, *Tadarida brasiliensis* and *Leptonycteris* spp in Central and North America). However, in the African fruit bat, *Myonycteris torquatus*, migration is more pronounced in (principally immature) males. In *Lasiurus cinereus* both sexes winter in Mexico (and possibly further south) but as they migrate to the northern summer the sexes become geographically segregated.

Two conservation initiatives relate specifically to the migration of bats. CMS includes *Tadarida brasiliensis* in its Appendix I. The species was included when the Appendix was first created but no conservation action has yet been identified. The convention also includes all European species in Appendix II for the purposes of the Agreement on the Conservation of Populations of European Bats (Eurobats); initially this was all European species of Vespertilionidae and Rhinolophidae with the later addition of European Molossidae (*Tadarida teniotis*). With a change in geographical scope of the Agreement and changes in the known fauna and its systematics, the Agreement now covers a list of species identified in an Annex to the Agreement and which is updated at each Meeting of Parties. There are current attempts to develop bats Agreements elsewhere under CMS as well as to extend the species covered by its Appendices.

The only other similar initiative is the Program for the Conservation of Migratory Bats of Mexico and the United States (Programa para la Conservacion de Murcielagos Migratorios de Mexico y Estados Unidos de Norteamerica - PCMM). This was launched in 1994 as a partnership between the Institute of Ecology of Mexico's Universidad Nacional Autonoma de Mexico and Bat Conservation International, based in Texas, USA. Although not an intergovernmental programme, it has the support and participation of its host governments and is producing valuable results for conservation (Walker, 1995). Originally established for three threatened migratory species (*Tadarida brasiliensis*, *Leptonycteris curasoae* and *Leptonycteris nivalis*), the program has been extended to include Canada and some currently less threatened long-range migrants (such as *Lasiurus* spp and *Lasionycteris noctivagans*) and now includes all Mexican bat species. The importance of this programme has been highlighted in discussing the needs for integrated programmes of research, education and conservation of a wide range of pollinators (birds, bats, butterflies) in Mexico and USA (Withgott, 1999). Currently the programme is working to identify and conserve habitats along migratory corridors and to identify and protect key roosts along migratory routes.

8.3. Distribution of bats in UK and its Overseas Territories

Bats occur in the UK and its European territories, and in the Caribbean territories and Bermuda.

There are four records of one bat species, *Tadarida brasiliensis*, from the Falkland Islands (Hutson *et al*. in prep.). Some of the North American populations of this species are well known to be migratory and are the subject of intensive conservation programmes. There is also circumstantial evidence for migration in this species in the lower latitudes of its distribution, but the Falkland Islands are over 300 km south of the normal southern limit of distribution (and with a long sea crossing). Currently the habitat and climate on the Falkland Islands are not suitable to host a breeding population of this species (or probably any other bat species). *T. brasiliensis* is listed in CMS Appendix I.

No other UK Overseas Territory has bats recorded from it.

For the purposes of this report, the areas of Europe and the wider Caribbean (including Bermuda) are treated separately.

8.4. Bats in the UK and UK Overseas Territories of Europe

The bat fauna of the UK, of those territories with dependence to the Home Office, (viz. Channel Islands and Isle of Man), and the territories of Gibraltar and the Sovereign (base) territories of Cyprus are included here in discussions on Europe.

The European fauna currently comprises 47 recognised species in five families (Appendix 1, Table 13) where Europe is taken as the area recognised for the Agreement on the Conservation of European Populations of Bats (being mainland Europe South to the Mediterranean and including the independent island states of Malta and Cyprus, and East to include all of Turkey, the Caucasus states and Russian Federation west of 50°E) and the North Atlantic islands of Azores, Madeira and Canaries. Only one species, which just extends into the south-east corner of the region, is frugivorous, the rest are insectivorous.

The UK has 17 regularly occurring (breeding) bat species. Six other species have been recorded, either as fairly regular visits by migrant species or as occasional vagrant species, or as species of uncertain status.

Of the 47 European species, the Channel Islands have 10, Isle of Man has seven, Gibraltar six, and Cyprus 17.

In all, these faunas cover 29 bat species. Some of the relevant biological traits for these species are given in Appendix 1, Table 15.

8.4.1. Bat migration in Europe

Migrations of up to 2000km are undertaken by some species in Europe. The longer migrations are recorded for mainland species of *Nyctalus* and *Pipistrellus nathusii*. A number of other species can be considered as medium-range migrants (see Appendix 1, Table 15). No migrations are known which take bats outside of Europe (but see, for example, the notes under Gibraltar below). All data on bat migration in Europe is currently being assembled for a migration atlas of European bats through the European bats Agreement.

In general migration is Europe is between summer foraging or parturition sites and winter hibernation sites. Migration may not be in a strongly North-South direction and indeed, particularly for the short to medium-range migrants may be in any direction. Although only a medium-range migrant, the Bent-winged Bat is known to have regular migration routes with stop-over sites. The same is becoming evident for a few other species, such as *P. nathusii* and *M. dasycneme*. The only species where there is evidence of a bat species relocating to maintain foraging (rather than for hibernation) is the European Free-tailed Bat, which on some Mediterranean islands is only found in winter (J. Borg, pers. comm.).

The long-range migration of birds often includes very obvious difficulties in crossing large (and possibly expanding) hostile environments (e.g the Sahara crossing). Evidence suggests that bats generally migrate in short hops (i.e. the distance that can be travelled in one night) and hence the presence of hostile environments may not be so apparent but may be equally real.

Distribution maps for all European species were prepared in 2004 as part of the IUCN Global Mammals Assessment programme and these should be useful in monitoring changes. It should be noted that changes may occur at the southern as well as the northern limits of range.

8.5. Potential Impacts of Climate Change in UK and Europe

The following potential aspects of climate change are taken from Hulme *et al*. (2002) and Parry (2000) through reference to Robinson (this report).

8.5.1. Temperature changes

Bats are most diverse in the tropics with the diversity declining towards the higher latitudes and with very few species that are restricted to the higher latitudes. This decline is also apparent in the UK where all species occur in the south of the territory, but only three in the extreme north (Table 8.1). An increase in mean temperature in Britain might result in a number of species increasing their range northwards. It may also result in some species spreading into Britain (such as *Myotis dasycneme*, *Myotis emarginatus* and *Pipistrellus kuhlii*). Indeed, a colony of *P. kuhlii* was recently discovered on Jersey (Magris, 2003). Whether this southern European species was formerly overlooked or is a recent coloniser is uncertain. The species has also recently been added to the Guernsey list (P.Costen, pers, comm.; A.M.Hutson, pers. obs.).

Within Europe, most of the species are widespread already, and cover a fairly broad range of latitudes. Nevertheless there could be changes in bat community structures. In the Mediterranean region are species currently of restricted southern distribution, e.g. European Free-tailed Bat (*Tadarida teniotis*), Bent-winged Bat (*Miniopterus schreibersii*), some horseshoe bat species (*Rhinolophus* spp), and these may increase their range in Europe. There might also be movement into the area of groups not currently found in Europe, such as sheath-tailed bats (Emballonuridae) or mouse-tailed bats (Rhinopomatidae). There are two bat species that are more or less restricted to northern latitudes: the Parti-coloured Bat (*Vespertilio murinus*) and Northern Bat (*Eptesicus nilssonii*). The first is a medium-range migrant, the second more or less sedentary. These species may be affected by competition with southern counterparts spreading north and may be squeezed into the northern parts of their range. There may be increased competition for roosting or foraging sites.

There have been almost no studies of bats in relation to climate change in Europe. The recent expansion northwards of *Pipistrellus kuhlii* has been noted in the East from Ukraine, and in the West from France and Germany. The species was widely regarded as a Mediterranean species that also occurred in North Africa and tropical Africa and Eastwards through to south-east Asia. In Europe, although principally Mediterranean the species was found north to the southern tip of Crimea and mid-France (e.g. van den Brink, 1967; Corbet, 1978). Its spread in Ukraine from a northerly limit in 1985 of c.45°N to a northerly limit in 2001 of above 51°N is described by Zagorodniuk & Negoda (2001). In France it is now found widely to the coast of Normandy (Masson, 1998), and with a few records from Channel Islands (including one maternity colony) and from south coastal UK from Sussex to Cornwall. It is also now recorded north of the Alps in Germany (P. Boye, pers. comm.; Bogdanowicz, 2004). It has been suggested that this expansion is a response to climate change, but there has been no analysis to support this and no other species has shown such a rapid and marked expansion in range. Ilyin (2000) considered that the expansion of this species (and of *E. serotinus* and *E. bobrinskoi*) in southeastern Europe (parts of former USSR) could relate to climate change, but that this alone could not explain the expansion of *P. kuhlii*. *Hypsugo savii*, another largely Mediterranean species, is being found further north in parts of its range, e.g. Austria (Spitzenberger, 2001). Gazaryan (2002) studied Noctule Bats (*Nyctalus noctula*) in hibernation in trees in the Precaucasus in an area north of the Koban River, where retrospective data on climate suggests that these bats could not have hibernated until about 50 years ago. There is very little other data to suggest impacts of climate change in Europe, but it is possible that, in general, climate change effects in Europe are much weaker in bats than, for instance, in birds.

In general there might be increased migration where summer maternity sites and winter hibernation sites become separated. There might even be an increased shift towards migration to maintain foraging in preference to hibernation (as is of course the norm for more tropical and subtropical bats). There may be reduced migration where maternity sites and hibernation sites are brought closer together.

While it may be possible to suggest some direct effects of likely scenarios for climate change by the 2080s on bats in general or on individual species, there are likely to be much more serious and subtle indirect effects on natural roost sites in trees and on the insect food supply for bats. A key feature is the availability of roosts, particularly trees, caves and buildings and the extent to which that will be maintained through any climate change process. While there is unlikely to be a shortage of buildings as roosts, building structure varies around Europe and some structures favour some bat species more than others. A decline in the availability of over mature trees with suitable cavities (an already increasingly scarce resource) following climate change and resultant changes in species composition may be of particular concern. For instance, it is noted that beech trees may disappear from the south of Britain (Hulme *et al*. 2001/2).In a small survey of notified tree roosts in South-East England in the 1980s, 8.5% of 48 tree roosts were in beech trees, with oak (52%) being the only more commonly used tree (Hutson, pers.obs.). Many of the trees in this sample were in gardens and included a number of exotics, so the occurrence in nature may be much higher; indeed the incidence of bat roosts in beech trees was very much higher than that in most other trees for a study in the Netherlands (Limpens & Bongers, 1991); beech trees were also used by a wider range of species than most other trees.

While it is considered that the climate within most caves and mines is unlikely to change sufficient to affect bats, the extent to which the internal temperature is affected by warmer ambient conditions depends on the configuration of the cave and its entrance(s). Warmed caves may become more suitable as maternity sites, but less suitable as hibernation sites. More importantly, cave-dependent species that shift their range to the north may be constrained by not finding suitable caves (or other appropriate underground habitats) in their potential new locations. This is unlikely to be a serious issue in the UK, but could be in parts of mainland Europe. In such cases the bats may be unable to occupy such territories (e.g horseshoe bats) or may be required to make extended seasonal movements (e. g. *Myotis* spp, *Miniopterus*). Humphries *et al*. (2002) have discussed the bioenergetic constraints on range change through climate shifts for a small North American hibernating bat, *Myotis lucifugus*.

The reproductive cycle of temperate zone bats has become adapted to hibernation. Bats mate in autumn and winter, and spermatozoa are stored in the female reproductive tract until spring, when females arouse from hibernation, ovulate and become pregnant. Such a unique cycle has evolved to avoid the necessity for mate selection and mating when the animals are at their lowest body condition in spring. However, if such bats experience warm conditions and a supply of food in the second half of winter, they will arouse from hibernation prematurely, ovulate and become pregnant. Even winter parturition has been noted in Greater Mouse-eared Bat (*M. myotis*) in southern Spain. If winter is protracted, arousal will be delayed, and births will occur later (Racey & Entwistle, 2000). 'Early' springs in northern Europe are associated with reports of earlier births in June. Experimentally, by manipulating environmental conditions, the timing of births can be altered by up to three months. If bats experience periods of inclement weather associated with food shortages during pregnancy, they will become torpid, foetal development will cease, and the gestation period will be extended by the duration of torpor. This is unique to bats. Given the extreme dependency of these reproductive events on external temperatures and food supply, it could be predicted that the timing of reproductive cycles of temperate bats might be significantly affected by climate change. Arlettaz *et al*. (2001) demonstrated the importance of food availability to the timing of parturition in certain *Myotis* species. An earlier advent of spring (by 1-3 weeks) would presumably result in a shorter hibernation period and hence an earlier appearance of most bats on the wing and searching for insect food. If the food is available this may have no detrimental effect. It is presumed that the phenology in autumn would be similarly affected, with a longer period in autumn when insects are available being advantageous to the survival of bats born that year, if it allows them to achieve sufficient prehibernal fattening.

Whether this would affect summer phenology is being investigated through a project started two years ago in Scotland. Designed to relate to climate variation and change, the project collects data on bat birth dates and colony formation/dispersal for bats in the UK via forms on Scottish Bats website (I. Mackie, pers. comm.; see www.scotbats.org.uk).

An increase (up to tenfold) in the occurrence of extreme summer temperature events may cause problems for maternity colonies of bats in buildings through overheating and dehydration. It may also cause overall decrease, increased concentration, or other changes to the prey populations and species composition.

A decrease, or even the disappearance of extreme cold winters may result in a reduced period of hibernation, increased winter activity (when there may be limited food supply), reduced reliance on the relatively stable temperatures of underground hibernation sites. It may also have some impact on the internal climate of even larger caves and other underground habitats. The need or reliance on such places for hibernation varies between species. Thus as warming progresses, the underground sites will be abandoned for hibernation by, for example, some species of *Myotis* (e.g. *M. nattereri*) well before other species (e.g. horseshoe bats). Apart from the biological effect, this would be an important consideration in the use of counts in hibernation sites for population monitoring.

Even if climate change itself had minor effects on bats in Europe, it might be adding to existing threats and in some cases a critical effect in a highly developed region with fragmented habitats. Also key are a range of other features such as availability of suitable supplies of insect food and appropriate habitat, continuity of habitat features, and the broader scale continuity of migratory routes and stopping off points. Thus there would be a need to maintain and manage appropriately a network of suitable habitats (with particular emphasis on wetlands and woodland).

8.5.2. Precipitation in the UK

Predictions suggest a mean reduction in precipitation, with a significant summer decrease (by up to -15% in the south, but possible increase in the north by up to 8%) and a large decrease in summer soil moisture (up to -40%).

For a large number of bat species, wetlands, waterways, waterbodies and woodland provide key resources of insect biomass and diversity for feeding. Thus a decline in wet or moist areas is likely to affect bat populations and cause declines or behavioural changes (although it is worth remembering that many of the UK species also occur in drier Mediterranean habitats).

Any increase in summer storms may affect foraging opportunities during the pregnancy and lactation period. The most vulnerable period in a temperate zone bat cycle is during lactation, when heavy rain at dusk (such as a series of a few days when feeding is not possible) can cause late weaning (reducing chances of juvenile survival through the first winter) or even abandonment of young. However, drier periods in the migration and pre hibernation periods (especially September and October) could affect foraging at this crucial time.

Warmer wetter winters are likely to result in a reduced hibernation period with reduced reliance on underground habitats. However, there may be an increased risk of flooding of underground sites or other hibernation sites. Also, there may be indirect effects through disruption of normal hibernation or overwintering of adult insects and metamorphosis of insect prey through the winter period (reduced ability for a proper diapause by those insects that need it, increased occurrence of disease or other pathogens (e.g. viruses and bacteria) to overwintering larvae during wet warm winters). In particular, this might lead in spring to asynchronies with insect abundance at a time when bats are at their lowest body condition and need to fatten up quickly.

8.5.3. Other impacts in the UK

A sea level rise (to 1.4m in the South-East) is unlikely to be of major influence, except locally where there may be some loss of foraging habitat through inundation or salination of wetlands.

An increased incidence of gales, unless increasing to a considerable extent and over land, is unlikely to have any major effect (but might have some minor effect in increasing the occurrence of vagrant species). A marked increase in gales over land could have serious consequences in damage to roost sites (e.g. trees) and influence on foraging opportunities; The impact is likely to be greatest in summer.

8.5.4. Gibraltar and Cyprus

The Mediterranean UK overseas territories of Gibraltar and Cyprus SAFB are also expected to experience significantly increased land temperatures, especially in summer, indeed possibly to a greater degree than elsewhere (see Mitchell *et al*. 2004; Robinson, this report).

The single European fruit bat, *Rousettus aegyptiacus,* occurs widely in Africa through Arabian peninsula to South Asia. In Europe it occurs as isolated populations in south-west Turkey and Cyprus. Any potential spread may be constrained by human pressure (control by developers and fruit farmers). A cave dwelling fruit bat, with colonies up to 800 on Cyprus. The species is also naturalised (probably from escapes) in Tenerife.

The possibility of more southern species moving in to Europe cannot be excluded. Most of these would be similar to the existing fauna of southern Europe, but more exotic families of bats may spread, such as sheath-tailed bats (Emballonuridae), currently with one species recorded from one locality in eastern Turkey, or mouse-tailed bats (Rhinopomatidae). At the species level, species such as the recently recognised *Myotis punicus*, currently know from North Africa (principally Morocco), Balearic Islands and Corsica may spread further north to replace the related *M. myotis* in the southern parts of its range.

On islands such as Cyprus, it may be that there will be extra demand for the increased development of artificial water containments (e.g. reservoirs), which may have some benefit for bats in providing improved foraging areas.

It has long been argued that bats probably migrate across the straits of Gibraltar. The distance involved is not an obstacle to most species. Increased aridity in North Africa may reduce the advantages of such migration. In the late 1960s very large numbers of *M. myotis* (to 6000) and *Miniopterus* (to 5000) were reported from Gibraltar. These are far larger than current figures (e.g. largest group of *Miniopterus* about 150) and far larger than the territory could sustain. Some were summer maternity colonies that presumably largely foraged in Spain, others were winter aggregations for the hibernation period, but the importance of Gibraltar for migratory birds might also suggest the possibility of aggregations of bats at stopover sites for migration.

8.6. Bats of the UK overseas territories of the Caribbean

There is no recorded migration in bat species of the Caribbean UK OTs. In general the more serious effects of climate change are likely to be on the fruit and flower feeding bats of the family Phyllostomidae. Insectivorous bats (including those belonging to the family Phyllostomidae) and fish-eating bats (Noctilionidae) may be better able to withstand short periods of food shortage and may have increased foraging opportunity in the long-term. In general, cave-roosting bats will be better protected from roost damage than bats roosting in buildings or trees. Of the bat species considered here, again a higher proportion of the fruit and flower feeders favour caves as roost sites. The reproductive period (in particular the time between weaning and periods of food shortage) may be critical. Currently, the factor of most concern (by far) is hurricanes and other factors have been little considered. Predicted wind speed increases of up to 20% greater than today (Sear *et al*. 2001) would greatly exacerbate the issues raised here. It should be noted that in some territories, e.g. Montserrat, there is more immediate concern about volcanic eruption than the longer term potential influence of climate change.

Of the 22 species recorded from UK overseas territories (Appendix 1, Tables 12 and 14), 17 are unlikely to be transboundary migrants in the Caribbean. Nine species are Caribbean endemics, two of the non-endemics are known to undertake short-range migrations elsewhere, and six other non-endemics are regarded as generally sedentary species.

Five species are regular long-range migrants in North America. These are *Lasionycteris noctivagans*, *Lasiurus borealis*, *Lasiurus cinereus* and *Lasiurus seminolus*, and *Tadarida brasiliensis*. All these species are included in the Program for the Conservation of Migratory Bats of Mexico and the United States (Programa para la Conservacion de Murcielagos Migratorios de Mexico y Estados Unidos de Norteamerica - PCMM).

For *Lasionycteris noctivagans*, the Silver-haired Bat, migration is little known, but the species has reached TCI, Bermuda and north Mexico. The occurrences outside North America may be occasional vagrants rather than regular migrants, however, even in North America the species is believed to be widely under-recorded (Buden 1985, Van Gelder & Wingate 1961; Wingate in prep., Arita & Ortega 1998).

Of the three species of *Lasiurus*, *L. borealis*, the Red Bat, occurs from Chile and Argentina north to Canada and on Galapagos Islands (as *L. brachyotis*) and several islands of the Caribbean and can tolerate cold conditions (Mormann *et al*. 2004). On Bermuda, the species occurs only as a seasonal migrant (Van Gelder & Wingate, 1961; Wingate, in prep.). Elsewhere, e.g. Turks & Caicos Islands, island populations may include migrants as well as resident and non-migratory populations (A.M.Hutson & T.J.McCarthy, pers.obs.). Bat detector monitoring, or tissue analysis for DNA or stable isotopes, may establish any occurrence of migratory populations. For a species account see Shump & Shump (1982a). See also CMS report UNEP/ScC11/Doc.7.

L. cinereus, the Hoary Bat, occurs from Chile and Argentina north to Canada. It is not recorded so widely in the Caribbean as *L. borealis*, but otherwise has a similar distribution. On Bermuda the species occurs only as a seasonal migrant (Van Gelder & Wingate, 1961; Wingate, in prep.). The species is regarded by Fleming & Eby (2003) as possibly the only recorded truly intercontinental migrant, moving from much of North America into the subtropics and possibly the tropics (Findley & Jones 1964, Barclay 1984, LaVal & LaVal 1979, Cryan 2004). For a species account, see Shump & Shump (1982b). See also CMS report UNEP/ScC11/Doc.7.

L. seminolus, the Seminole Bat, is a lowland bat of south-eastern USA, with outlying records to the south from Veracruz (Mexico), and extreme south Texas, north to New York State and east to Bermuda. It occurs throughout Florida and so may also occur on islands to the north of the Caribbean. The species is very similar to other *Lasiurus* species in appearance and behaviour, especially similar to *L. borealis*. While there is no conclusive evidence of migration in this species, it is widely believed to do so. However, it is possible that the extralimital records are more the result of the known tendency for extensive wandering in young individuals of this species (Barbour & Davis, 1969). For a species account, see Wilkins (1987).

Tadarida brasiliensis, the Brazilian (or Mexican) Free-tailed Bat, is distributed from about 40°S in Chile and Argentina to the southern states of USA (to about 40°N) and on many Caribbean islands. There is no evidence of migration to/from Caribbean Islands, and the more south-easterly US populations are generally regarded as non–migratory. The species is rare on Cayman (Morgan, 1994), there is one subfossil record from TCI (Morgan, 1989), it has rarely been trapped on Montserrat, where there was one large colony in a cave but the current status is unknown since the cave collapsed in the early 1990s. Thus, although globally regarded as a threatened migratory species, the Caribbean populations (at least the UK OT populations) are probably of resident animals and not subjected to migratory pressures. The species is included in Appendix I of CMS and is discussed here as a case study. For a species account see Williams (1989); see also Hutson *et al.* (2001) (see also CMS report UNEP/ScC11/Doc.7 and CMS/ScC12/Doc.12).

8.7. Potential Impacts of Climate Change in the Caribbean Territories

8.7.1. Background

The UK Caribbean territories of Anguilla, British Virgin Islands (BVI), Cayman Islands, Montserrat, and Turks & Caicos Islands (TCI) all have bat populations and are discussed below.

There are no bats resident on the UK Overseas Territory of Bermuda (especially following the loss of the cedar forests as a result of scale insects in 1946-51), but four species regularly occur there, 900-1300 km from the US mainland. The species are *Lasiurus cinereus*, *L. borealis*, *L. seminolus* and *Lasionycteris noctivagans* (Van Gelder & Wingate, 1961). A further two species, *Eptesicus fuscus* and *Pipistrellus subflavus*, have recently been added from single specimens (D.Wingate, pers. comm.).

A total of 22 bat species is recorded from the UK OTs in the wider Caribbean (Appendix 1, Table 12). There is a clear need for better information on the status and populations of these species on most small islands. While there have been recent studies on Turks & Caicos Islands and on-going studies for some years on Cayman, the bat fauna of most of the other islands are poorly known – especially that of British Virgin Islands.

Many of the Caribbean island populations have been recognised as separate subspecies (in some cases more than one subspecies in the Caribbean). The validity of most of these subspecies needs verification including the use of modern techniques and some are certainly questionable. Nevertheless, it should be noted that the validity of any of these forms as distinct from mainland or other Caribbean forms, does not deny the possibility of migratory individuals of other subspecies occurring contemporaneously for part of the year.

The following potential effects of climate change in the Caribbean Overseas Territories are taken from Sear *et al*. (2001) and Gill *et al*. (2004). They are dealt with in what is considered to be their order of importance of likely influence on bats.

8.7.2. Increase in number and intensity of extreme weather events

There is likely to be an increased incidence and intensity (wind and precipitation) of hurricanes and storms resulting in damage to roosts (e.g. trees, buildings) and foraging (especially fruit and flower feeders through stripping of flowers and seeds/fruit).

Three regional post hurricane studies have been published. Gannon & Willig (1994) investigated the effects of Hurricane Hugo (18.ix.1989) on a study site on Puerto Rico with respect to three frugivorous bats (*Artibeus jamaicensis*, *Stenoderma rufus* and *Monophyllus redmani*) for three years pre- and three years post-hurricane. *A. jamaicensis* and *M. redmani* showed immediate declines, but recovered to pre-hurricane levels in two years. *S. rufus* showed a slower decline to c.30% of pre-hurricane levels and showed no signs of recovery after three years. In this latter species there was a marked absence of juveniles (40% pre, 17% immediately post-hurricane, declining to none) and decline of reproductively active females (93% pre and 17% post-hurricane). This is a strictly forest species normally with limited foraging and home range. Its decline may have been exacerbated by the increased opening of its habitat, exposure to wind and heat and decreased available fruit. Radio telemetry suggested home range size increased by up to 5-fold. *A. jamaicensis* is a larger species and stronger flier and it is suggested that dispersal may have partly explained its 'decline' (but note that this would not apply to *M. redmani*).

Following Hurricane Georges, which hit Puerto Rico in September 1998, Jones *et al*. (2001) examined, in 1999, areas that had been systematically studied between 1995 and 1998. They used systematic mist-netting and cave colony counts. From the mist-netting, small numbers of bats were caught and all species, especially *Erophylla sezekorni*, showed declines in abundance. Again, *S. rufus* was a rarely caught species before the hurricane and was not found post hurricane. Pre-hurricane the species composition had comprised nine species, five frugivorous, four insectivorous. The post hurricane sample included three frugivores and two insectivores. The principal cave counts also showed a marked decline of frugivores (*E. sezekorni* and *M. redman*i), but increases in insectivores (*Mormoops blainvillii*, *Pteronotus parnelli* and *quadridens*). There was also increased finding of skulls, mainly of the frugivores which was given as direct indication of mortalities associated with the hurricane. There was also indication that greater sensitivity to hurricane effects was occurring in larger bats and bat species with a wide geographical range.

Pedersen *et al*. (1996) used earlier data to examine the effects of Hurricane Hugo (1989) on the bat fauna of Montserrat four years after the event (August 1993-August1994). They still found a general 20-fold decrease in bat abundance compared with pre-hurricane. The composition had shifted from smaller frugivores to more omnivorous and larger frugivorous species. They attributed the decreases to fatalities during the hurricane, as well as starvation from removal of fruit and flowers, and defoliation. *A. jamaicensis* was reduced from 50% of captures to 17%, *Brachyphylla cavernarum* (basically a frugivore, but somewhat omnivorous) increased from 4% of frugivores to 45%, decreases were also apparent in other frugivores: *Monophyllus*, *Ardops* and *Sturnira*. On the other hand *Molossus* (aerial insectivore) and *Noctilio* (insect- and piscivore) were only marginally affected.

In the Old World, there is data (mainly for the large flying foxes, *Pteropus* spp) of the impact of cyclones from Guam, Samoa, Mauritius and Rodrigues, which all suggested reasonable recovery rates (given the general slow reproductive rate of bats). Recent work on Rodrigues discussed the dangers of carrying out counts too soon after the hurricane or cyclone, i.e. before the bat colonies have regrouped. The important ('keystone') role of these bats in pollination and seed dispersal on many islands should be recognised. There may also be the need for further work to establish the requirements for the structure and composition of forest reserves which may be important for their own survival and hence for the survival of the bats they may host.

8.7.3. Sea level rise

On TCI, sea-level rise is unlikely to affect the main central ridge, which is probably the prime foraging habitat. Flooding of lowlands associated with the ocean coast could have a serious impact in destroying foraging habitat and roost trees (especially if associated with damage to current coastal protection through damage to reef structure and erosion of beach heads). Reductions of foraging habitat may result in reduced populations or increased seasonal movement.

Sea level rise may also affect roost caves. On TCI some roost caves are partly flooded, with water levels probably being related to sea level. Such cave waters may have a fresh water lens, but may also have direct connections with sea water or indirect connection (through, e.g., rock porosity). A rise of water level of 0.5 – 1.0 m in the main cave on TCI (Conch Bar Village Cave, Middle Caicos) is unlikely to affect the bats' use of the cave (and indeed would not raise the water level to that which it appears to have been at some stage in the past).

8.7.4. Changes in temperatures and precipitation

While there hasn't been any study in the Caribbean, Scheel *et al*. (1996) modelled the impact of climate change (warmer and wetter) on the distribution and species composition of the bat fauna of Texas. The study predicted no extinctions within the state, but some profound changes in distribution and the potential addition of a number of species from the south. Tree-roosting bats and roost generalists expanded as forest and woodland spread. Again the maintenance of the co-location of fixed roosts, like caves, with suitable foraging habitat was considered a potential problem for some cave-dependent bat species. LaVal (2004) has studied changes in the bat fauna of study sites at 1350-1500m in Monteverde Cloud Forest, Costa Rica, over a 27 year period. A number of bat species were found to be gradually colonizing these higher elevations, but this seemed to be having little effect on indigenous high altitude species. Changes in bat distribution were not as evident as in other groups of animals. Sampling strategies may be partly responsible for some of the findings, but LaVal considers that global warming, forest clearance and an increase in the amount of secondary forest as contributory factors. Such results suggest that bats respond to climate change; to what extent individual species are flexible enough to cope with such changes, needs further investigation.

Rising sea temperatures might affect the Fishing Bat, *Noctilio leporinus*, where it feeds from sea water. Also rising temperatures might result in increased rainfall which would have severe effect on xerophytic habitats, such as that on TCI. Rapid loss of xerophytes and replacement with more ‘forest’ vegetation is likely to have immediate and deleterious effect on some fruit and flower feeding bats as their food plants are lost, but may have long-term benefit for insectivorous bats (especially if there were also increased freshwater habitats) and other frugivorous bats. Ultimately it may provide for increased populations of foliage and tree-dwelling species. In general changes may prove more beneficial for the common and widespread more adaptable species than for the specialised island endemics.

Declines in precipitation might result in a decrease in trees and open fresh water used by bats. This might result in an increase in nectarivores, possible decrease in frugivores, decrease in insectivores (and piscivores). Greater extremes of precipitation are predicted, with increased seasonality (generally wetter in the North Caribbean and Bahaman islands, and with precipitation increases in December to February outweighing decreases in June to August). Drought may affect territories such as Anguilla and perhaps TCI. Changes in cloud cover could influence roost temperature (in buildings and trees) or food availability. There may also be considerable influence from concerns about climate change, including socio-economic factors, such as the effects of construction of sea defences and other environmental management schemes and the perceived need to relocate human populations.

8.8. Summary and recommendations

Relatively little is known about details of migration in bats. However, a wide range of migration strategies are used by bats and it is likely that the phenomenon is much more widespread than currently recognized. Much of the research on bat migration has been carried out on relatively abundant and widespread species. Nevertheless, threatened species that are migratory can be identified, and there are very clear threats to some migratory species that are still widespread and relatively abundant. There are substantial gaps in our knowledge of bat migration in all regions and co-ordinated approaches to filling those gaps would help, particularly for the understanding of migration behaviour and routes.

Traditional bat banding programmes have not been widely used and have their limitations (Hutson, 1999). More recently, analysis of DNA or stable isotopes, and advances in radio or satellite tags offer further opportunities for migration studies. Trapping programmes have shown seasonal changes in community structures. Even visual or bat detector observations can also contribute to the understanding of bat movements.

A high percentage of the 1100 bat species are considered threatened and there are obvious instances where an intergovernmental collaborative approach to their conservation, such as through further CMS bats Agreements, would benefit greatly the conservation of the threatened migratory species as well as a range of other bat species and wider biodiversity.

There have been very few studies that investigate the likely effects and impacts of climate change on bats. The detailed data collection, study and conservation of bats are relatively new and with many immediate problems. It may be that addressing future issues has until now been regarded as something of a ‘luxury’, but current conservation initiatives should consider the long–term possible consequences of climate change. There is also the opinion in some quarters that the effects of climate change on bats may be generally weak and not a threat of extinction to many species, but that needs further investigation.

Some general priorities for migration research are:

a. further collation of available data on seasonal movements;

b. further effort to establish the threats associated with migration (including those associated with climate change);

c. further investigation of bat communities and their seasonal variation in relation to migration;

d. further investigation of migration and the associated requirements of particular key bat species.

In Europe to date, there have been no direct studies related to climate change with respect to bats even though climate change could have a marked effect on the bat fauna of Europe and might have severe impact on some species. Particularly in Europe, influences on the ability to adapt to range shifts will depend on availability and suitability of the range of roosts required at different times of year (in trees, buildings and other structures, or underground habitats), and the impact this may have on migratory patterns and needs, including for stop-over sites. The continuity of suitable habitat and foraging opportunity may also be a concern. Synchrony of breeding (and hibernation) in these colonial animals is important and changes in or loss of internal synchronies or changes in wider phenologies and mismatches or asynchronies with insect prey could have major impact. Even if the effects of climate change on bats are not particularly severe, they may exacerbate the other conservation problems of an already beleaguered group of mammals. The following areas may usefully be investigated:

a. use of available data to assess any existing evidence of impact of climate change;

b. use of available data to model likely impacts of climate change;

c. further assessment of likely impacts on;

    i. reproduction and other aspects of annual cycle;

    ii. separation of winter and summer sites and availability of suitable territory in between (including migration stopover sites as appropriate);

    iii. changes in community structure;

    iv. phenologies and any important synchronies involved with interactions with prey, roost availability, breeding and migration;

d. the increased establishment and co-ordination of long-term population and distribution monitoring that considers potential effects of climate change and can be related to that of other biota;

e. identification of suitable adaptation strategies to climate change, using flexible, multibenefit, integrated and potentially large-scale approaches.

Additional potentially useful areas of research or monitoring to assess the effects of climate change might include the incidence of multiple births (which is more frequent at higher latitudes within some species and as a matter of course in Parti-coloured Bat) and possibly the phenology of parturition and of colony formation and dispersal. Recent data on the progress in monitoring UK mammals can be found in Battersby (2005), which includes updates from the results of the UK's National Bat Monitoring Programme (Walsh *et al*. 2001). Within Europe there is a good network of NGOs, a regular European bat research conference and the intergovernmental Agreement for the conservation of bats (EUROBATS – see section 1.3.1). There are thus several possible mechanisms for considering different aspects of the affects of climate change on bats in Europe. Thus far, the matter has not been considered in any depth but would usefully now be placed on the agenda for bat research and monitoring programmes.

Outside Europe there have been a few studies of bats in relation to climate change, and these suggest that further research is urgently required. The UK Overseas Territories with bats are confined to the wider Caribbean, where, to date, regular migration to or from these island territories has only been recorded from Bermuda. The projected effect of climate change most likely to have impact on the bats of these territories is the increased intensity (and perhaps incidence) of hurricanes and storms. This is likely to affect particularly the fruit and flower feeding bats (which are mainly Caribbean endemics). Sea level rise may also be an impact on some low elevation islands, the reaction to concerns about climate change (such as development of coastal protection and relocation of human populations) may have considerable impact in some cases, and changes in temperature and precipitation are likely to have effect on particular specialist species indigenous to these small islands. Of particular relevance to the UK Overseas Territories is the need for studies on:

a. the collection of data on the distribution, abundance and migration of the bat fauna of territories where such information is lacking or poor (e.g. notably the British Virgin Islands);

b. the effects of hurricanes and tropical storms (for example, there are planned studies on Cayman Islands to assess the impact of Hurricane Ivan that hit the islands in 2004);

c. further effects of sea level rise on low lying islands, taking into account any influence of reduced coastal protection and effects on existing roosting and foraging territory, including socio-economic factors such as the impact of the construction of defences, or the relocation of human populations;

d. the effects of other influences on habitat and foraging potential through changes in temperatures and precipitation levels and patterns of their occurrence;

e. the relevant factors identified above for Europe regarding the assessment of existing data, the establishment of population and distribution (including migratory) monitoring, and the identification or development of adaptive strategies.

Table 8.1. Approximate limit of northerly range of the 17 UK bat species

Latitude	Species Reaching their Northerly Limit
50-52°N	*R.ferrumequinum*, *M.bechsteinii*, *M.myotis*, *P.austriacus*
52-54°N	*R.hipposideros*, *E.serotinus*, *B.barbastellus*
54-56°N	*M.brandtii*, *M.mystacinus*, *N.leisleri*, *N.noctula*
56-58°N	*M.nattereri*, *P.pygmaeus*, *P.auritus*
58-60°N	*M.daubentonii*, *P.nathusii*, *P.pipistrellus*

9. CLIMATE CHANGE AND MIGRATORY TERRESTRIAL MAMMALS

In comparison to birds and marine mammals, migration is a less common phenomenon in terrestrial mammals. The most familiar and well studied migrations in terrestrial mammals are those undertaken by herbivorous mammals that feed on seasonal grasses, such as Wildebeest, *Connochaetes taurinus* (e.g. Fryxell and Sinclair, 1988; Sinclair, 1995; Thirgood *et al.* 2004) and more generalist herbivores that live at higher latitudes, such as Caribou, *Rangifer tarandus* (e.g. Ferguson and Elkie, 2004). However, migratory movements have been recorded in a wide variety of terrestrial mammals including African Elephants (*Loxodonta africana*), Cougars (*Felis concolor*), Spotted Hyenas (*Crocuta crocuta*), Mountain Goats (*Oreamos americanus*) and Black-tailed Rabbits, *Lepus californicus* (Berger, 2004).

During migrations, terrestrial mammals may cover tens, hundreds or even thousands of kilometres as they move from one area to another. These migrations often follow similar routes every year and can occur in very large aggregations, up to a million or more animals in species such as Wildebeest (Thirgood *et al.* 2004). In addition, in some cases several species of mammal may migrate in consort, for example Wildebeest, Burchell's Zebra (*Equus burchelli*) and Thomson's Gazelle (*Gazella thomsonii*) in eastern Africa (Sinclair, 1995). However, there can be changes in the dependence on alternative migration routes over time (Thirgood *et al.* 2004) and while individuals may exhibit site-fidelity for specific areas between years during some parts of annual migratory movements, site fidelity need not necessarily occur during other parts (Ferguson and Elkie, 2004).

The reasons for migration are not always clear but may include movements between areas of seasonal food abundance, changes in availability of drinking water, avoidance of predators or access to food with essential minerals (Fryxell and Sinclair, 1988). In many cases, there may be no single, easily explained reason for observed patterns of seasonal movements and the migratory movements of an individual species may be the result of a combination of factors. For example, Caribou migrate both to reduce predation and to obtain seasonally available food (Ferguson and Elkie, 2004). Similarly, different factors may be responsible for different sections of annual migratory movements. For example, the main factor influencing northward movements of Wildebeest in the Serengeti-Mara ecosystem is thought to be rainfall and its effect on food or salinity (Wolanski *et al.* 1999). In contrast, the southward migration is thought to be the results of factors such as maximising energy consumption and nutrient availability (Fryxell, 1995; Murray, 1995). Finally, the reasons behind migration can be a result of interactions between a number of different variables and the decision to migrate may be the result of a trade off between two or more factors. For example, in Mule Deer (*Odocoileus hemionus*) migratory females use habitats with higher quality food than resident females. However, the benefit of such movements are traded-off against increased risk of predation during migration, which may explain why only some females migrate (Nicholson *et al.* 1997).

9.1. Climate Change And Effects On Migration In Terrestrial Mammals

Climate change has the potential to affect the movements of migratory terrestrial mammals in a number of different ways. Firstly, as climates change, patterns of seasonal growth in plants or rainfall are likely to change, leading to shifts in the locations of specific habitat types, known as habitat tracking (Jackson and Overpeck, 2000; Ackerly, 2003). This in turn may lead to a shift in the destination area for migratory animals at any particular time of the year, resulting in animals spending larger proportions of their time outside areas designated to protect them based on previous distributions. It may also change the distance animals are required to migrate or the route that they follow. Both of these may increase conflicts with humans, particularly if animal populations are enclosed by human populations. In addition, if total areas of suitable habitat decrease due to changes in climate or if distances animals are required to cover increase, this may increase stresses on animal populations due to density dependent effects or a reduction in available time to build up energy stores required for migration.

Changes in destination areas, migration routes or timing of migration may also result in the exposure of animals to higher densities of predators, parasites and/or diseases all of which could have a detrimental effect on animal populations. In addition, climate change could reduce the total amount of available food, the relative abundance of important food items required for nutritional reasons or a change in plant communities that may impact herbivores.

Finally, due to the presence of human populations, agriculture and development, potential shifts in migration routes or destination areas that would allow migratory animals to respond to climate change by tracking changes in the occurrence of suitable habitats may not actually be possible. Therefore, climate change may result in formally migratory populations of mammals becoming non-migratory and the animals would effectively become trapped in a particular habitat. Such a shift could have a number of impacts both for the animals themselves and the ecosystems on which they rely. Firstly, local areas may not be able to support as high a density of animals due to seasonal lows in food abundance or nutritional quality. This has been observed in sub-populations of Wildebeest in the Kruger National Park where the park's western boundary fence has severed a migration route, resulting in the decline of one sub-population (Whyte and Joubert 1988). Secondly, if formerly migratory populations as trapped in a local area, this can lead to habitat degradation as animals trample areas close to the edges of area where they become trapped while attempting their usual migratory movements. Again this has been observed when migratory movements are disrupted by the presence of fences, for example in the Okavango area of Botswana (Ringrose *et al.* 1997). Thirdly, resident animals may be more vulnerable to predator populations that could not track animals throughout their entire migration, resulting in a higher predation rate and a reduction in population size (Fryxell and Sinclair, 1988). A related effect may occur in predator populations. Predator populations in specific areas may rely on high abundance of prey that result from migratory populations moving into their hunting areas at specific times of the year to provide enough food to feed offspring or to build up sufficient energy stores to survive periods of lower prey abundance when only resident animals are available. Therefore, if migratory populations of prey are prevented from reaching certain areas by human populations, local populations of predators may decline due to this loss of high prey availability at critical times of the year. Finally, grassland ecosystems may require periods when grazing pressure is relatively low, to recover from the effects of grazing and to increase above ground biomass to counter higher grazing pressure at other times of the year (Fryxell and Sinclair, 1988). As migration temporarily reduces local grazing pressure, local ecosystems may not be able to cope with high levels of grazing throughout the year if formerly migratory populations become resident. This may result in local ecosystem collapse and may even result in further changes in local climate, such as changes in rainfall patterns (Sinclair and Fryxell, 1985).

However, determining which of these potential affects of climate change may apply to an individual migratory species will depend on having a detailed understanding of the factors that drive a species to migrate in the first place. Therefore, predicting the potential impact of climate change on migratory terrestrial mammals needs to be conducted on a case by case basis and may require a detailed study of the reasons for migration in each species before potential impacts specific to that species can be identified.

9.2. Climate Change And Other Aspects Of The Ecology Of Terrestrial Mammals

While climate change may affect the migratory behaviour exhibited by some terrestrial mammal species, it may also affect other aspects of their ecology, such as species range, life history parameters and competitive interactions between species. These potential effects will not be restricted to migratory species, but could potentially affect any species of terrestrial mammal.

For example, tracking of suitable environmental conditions may result in migratory and non-migratory species shifting their distribution in response to climate change. As local climates get warmer, species that favour cooler habitats may move to higher latitudes or higher altitudes. While this may not be a problem for widespread or generalist species, this may be a problem for specialist species, particularly those that specialise in living at high altitudes (e.g. Mountain Gorilla *Gorilla* *beringei beringei*) or latitudes (e.g. Polar Bear *Ursus maritimus*). The Mountain Gorilla is a technical migrant, in that it crosses trans-national boundaries regularly but within a relatively restricted geographical area that includes a boundary. The habitats where these species occur may simply disappear as local climates warm, resulting in the species extinction. This can also happen if tracking of suitable environmental conditions is blocked by barriers such as large bodies of water that terrestrial mammals cannot cross. However, not all species will exhibit a decline in distribution with climate change. Species that are adapted to warmer climates may in fact expand their ranges if temperatures increase. For example, rodents in Texas, USA, are predicted to increase their habitat-corrected range by an average of 2 to 3 fold with currently predicted global climate change based on a doubling of carbon dioxide in the atmosphere in comparison to the baseline values (Cameron and Scheel, 2001). Therefore, the effects of climate change are likely to be species specific and separate predictions may even be required for different populations of the same species.

Climate change may also directly affect terrestrial mammals through changes in environmental variables such as local rainfall, minimum winter temperature, maximum summer temperature and daily ranges in temperature. These may affect important life history parameters such as timing of birth, growth of foetuses and new-borns, winter mortality and population densities. For example, among Collard Pikas (*Ochotona collaris*) in the south-west Yukon, growth rates across different populations are greater in areas where the snow-free season is shorter, while high snow accumulation and late spring snowmelt results in a delay in the birth of calves (Franken and Hik, 2004). Similarly, Red Squirrels (*Tamiasciurus hudsonicus*) in the same area have advanced their breeding time by 6 days per generation over the last 10 years in response to increasing spring temperatures and food supply (Reale *et al.* 2003). In Moose (*Alces alces*), calf body mass is positively correlated with the length of growing season (days greater than 6°C) and, as a result, changes in the length of the growing season may affect moose population dynamics via offspring body mass by altering survival rates (Ericsson *et al.* 2002). In Soay Sheep (*Ovis aries*) on St. Kilda, variations in the local climate associated with the North Atlantic Oscillation (NAO) are linked to variations in a number of life history traits. For example, animals born after warm, wet, windy winters are lighter at birth, born earlier and matured later than animals born after cold dry winters, while high NOA winters before birth results in a lower juvenile survival. As well as affecting the ecology of juveniles, changes in local environmental conditions can also affect adults. For example, in the Soay Sheep study mentioned above, high NAO winters are also associated with an increase in adult survival and fecundity (Forchhammer *et al.* 2001). Similarly, in woodrats (*Neotoma* spp.) in New Mexico, USA, changes in body mass over time have been negatively correlated with both winter and summer temperatures and future climate warming is predicted to result in further declines in mean body mass. This change in body mass may, in turn, result in changes in many other ecological parameters closely linked to body mass such as fecundity, home ranges, predation risk and energetic requirements that may lead to large changes in the life history of woodrats (Smith *et al.* 1998). Any changes in life history parameters resulting from changes in local conditions may affect the viability of populations of terrestrial mammalian species. While some of these changes may be positive, others are likely to be negative. However, predicting the likely affects of climate change on the life history of individual mammal species will be difficult without a detailed understanding of the species biology and its responses to changes in local conditions expected under different climate change scenarios.

As well as directly affecting the distribution or life history parameters of terrestrial mammalian species, changes in local climates may also result in changes in interspecific interactions. Different species may respond differently to changes in the local environment, resulting in changes to the structure and composition of local mammalian communities, while competitive interactions between pairs or groups of species may also be altered so affecting the local occurrence of one or more species. Among resident species, for example, in tropical rainforest in Queensland, Australia, interactions between local climate and interspecific competition determine the relative proportions of different rodent species at specific locations (Heinsohn and Heinsohn, 1999). Similarly, increases in the range of the Greater White-toothed Shrew (*Crocidura russia*) in Switzerland is most likely to have been facilitated by ongoing climate change and has resulted in the local extinction of the Bicoloured White-toothed Shrew (*Crocidura leucodon*) at several locations as a result (Vogel *et al.* 2002). Such changes in interspecific interactions, particularly competition, are also likely to affect migratory species and may be almost impossible to predict in advance even with a full understanding of all species involved (e.g. Davis *et al.* 1998a, b; Harrington *et al.* 1999 .

9.3. Conclusions

Climate change has the potential to affect migratory terrestrial mammals in a number of ways. However, assessing which is most likely to affect individual species will require an intimate understanding not just of its migratory patterns but also the reasons why migrations are undertaken in the first place. In terms of the UK and its overseas territories, there are almost no populations of terrestrial migratory mammals due to the fact that these areas are primarily islands and that terrestrial mammals cannot easily migrate over large bodies of water. However, climate change may affect the occurrence, distribution and viability of non-migratory terrestrial mammals in a number of ways. In particular, species that currently have limited or fragmented ranges may be affected by a reduction in suitable habitat as local ecosystems respond to changes in climate. Other mammal species may also be affected due to influences of climate on life history parameters. As with migratory mammals, predicting the exact affects of climate change on individual terrestrial mammal species will require an intimate understanding of the species ecology and life history parameters as well as an understanding of how they may respond to changes in local climate.

9.4. Summary

Climate change is likely to affect the timing and extent of population movements, distribution, abundance and ecology of terrestrial mammals. These climate change impacts may operate in a number of ways. Firstly, climate change may lead to changes in patterns of rainfall and seasonal plant growth that may result in alterations in the routes, extent and/or destinations of migratory movements. This may be a particular problem for populations of animals where movements are restricted by human activities such as farming, fences or urbanisation. For example, fencing in the Okavango area of Botswana is known to affect the migratory behaviour of wildebeest and other species may react in similar ways if they find fencing or other anthropogenic structures blocking their way. Secondly, climate change may also lead to changes in ecological parameters such as reproductive success, survival and mortality that will alter local population dynamics and may affect the long-term survival of populations of species. For example, warmer temperatures can result in increased mortality and decreased pregnancy rates in Caribou. Finally, there may also be changes in the interactions between species, for example competitive abilities, that may change the structure of local mammalian communities. This has been observed in shrew species in Switzerland where changes in local climate have resulted in the replacement of one species by another in certain areas.

9.4.1. Adaptation

For some species of terrestrial mammals, for example Mountain Gorillas (*Gorilla beringei beringei*) that are technical migrants listed under the CMS, in that they cross national boundaries within relatively restricted areas, climate change may substantially alter their high altitude habitats detrimentally so that they lose suitable habitat. Given their restriction to certain mountain ranges, they will not be able to move to find other suitable habitats and may thus be threatened with extinction. Similarly, species at high latitudes may also lose suitable habitat with climate warming, perhaps the Polar Bear being the most extreme case. The only real solution to conserve such species is the mitigation of greenhouse gas emissions to slow or halt climate change. Efforts to enforce better conservation and protection measures within their ranges will be important to reduce additional potential ecological stresses on their populations.

For species that migrate longer distances, such as ungulates, range states may need to consider how to conserve these populations as they change migration routes into areas currently under other land uses. This may require a more flexible approach to the protection of habitats and the designation of sites used while on migration, in addition to a rapid response to the detrimental effects of fences and other barriers to migration. Such approaches and considerations will need to be included in current and future Agreements and Memoranda of Understanding completed within the CMS.

9.4.2. Knowledge Gaps

a. Identify the mechanisms underlying migration in terrestrial mammal species to understand better those that may be affected by climate change and whether the species are vulnerable to a lack of a suitable response to climate change.

b. Identify the effects of human land use on the ability of mammal species to alter their distribution, extent and routes of migration in response to climate change. This will need to be undertaken at a locally appropriate spatial scale and is likely to be population specific.

c. Monitor the effects of changes in climate on ecological parameters such as juvenile survival and reproductive success.

d. Monitor the effects of climate change in interactions between mammalian species.

e. There is a need to develop population models that are spatially and temporally explicit to understand the potential effects of climate change and to provide tools for developing scenarios of the impacts of climate change on terrestrial mammal populations.

10. CLIMATE IMPACTS ON TERRESTRIAL INVERTEBRATES

10.1. Introduction

In this section the definition of a migrant remains as a species which crosses international boundaries and in which an annual cycle is discernable. This conflicts with many uses of the word in the scientific literature for terrestrial invertebrates which include species undergoing range expansion, those whose poleward or uphill migration (e.g. Konvicka *et al.* 2003) is contained within a single country (even those the size of the USA), and those where evidence of a return migration is limited. In invertebrates, the annual cycle of migration may consist of several successive generations rather than the same individuals. Only in some situations can this be considered to be migration with a predictable trajectory and return phase (e.g. Riley *et al.* 1991). As with birds, the migrant status of species can be further complicated where an unknown proportion of the population consists of migrants, for example in the Large White Butterfly (*Pieris brassicae*) in the UK.

In broad terms, migration in invertebrates occurs because the destination provides better potential opportunities for breeding and feeding (resources) than the current location. The location of suitable resources may vary from year-to-year, even from month-to-month, so migration destinations can be quite dynamic and unpredictable, particularly the geographical range limits to which they move. In general, even given the undoubtedly large numbers of species involved, little is known about migrant invertebrates, particularly how climate and weather may affect their migratory behaviour. As a consequence, the brevity of this section reflects the scarcity of information. Where information is known, it tends to concern pest species, but for species not primarily considered as pests, most information is available (in descending order) on butterflies, moths, dragonflies, damselflies and hoverflies.

10.2. Pest species

One of the most familiar mass migration species is the Desert Locust (*Schistocerca gregaria*), which regularly erupts from areas that are becoming desiccated to find new areas for feeding. Like other pest species (e.g. armyworms, aphids) they have been well studied in countries with important agricultural economies. By their very description, pest species tend to be highly adaptable and occur in large populations. Climate change is unlikely to adversely affect them, although it may shift their distributional range. If anything such pest species may benefit from climate warming bringing more regions within their climatic tolerances (e.g. Cannon, 1998).

Species which are undergoing range expansion, for example polewards, without annual return phases do not qualify for migrant status in the sense used in this report. Such expansion will affect many species in the coming decades, including pests of arable agriculture and those affecting both animal and human health.

10.3. Species occurring in the UK Overseas Territories

Little or nothing is available in the searchable literature on migrant invertebrates in the UK Overseas Territories, even though they are known to occur in them. Gibraltar, which is an important migration crossroads for many vertebrates, also experiences invertebrate migration. Thus in a recent article (Bensusan *et al.* 2005), the lack of information on dragonflies and damselflies is reported, but the abundance of these species in an area with little open water and the lack of breeding records, suggest that the majority of these species are, in fact, migratory. Obviously some information will exist in the local literature, but it is beyond the scope of this project to locate all such evidence.

10.4. Changes to range and migration status

There is growing evidence of distributional shifts in invertebrates, for example butterflies (Parmesan *et al.* 1999) and dragonflies (Hickling *et al.* 2005). A northwards shift in distribution has been witnessed as climate warming makes more northerly areas more suitable for colonisation. Whilst this demonstrates the ability of invertebrates to exploit new territory as it becomes within the climate envelope of the species, it does not imply a change in the distribution of migrants *per se*. There is, however, evidence of recent changed residency status in two migrant butterfly species in England. The Clouded Yellow (*Colias croceus*) has recently started to overwinter in Dorset (Skelton, 1999), and the Red Admiral (*Vanessa atalanta*) has been doing so in increasing numbers across the country (Asher *et al*. 2001). The latter species has been gradually becoming more common in the north of the UK and its UK population has been rising steadily. These changes are unlikely to be isolated cases, but rather represent examples from a well-studied group of species, and are likely to be generally valid in migrant invertebrates.

10.5. Changes to phenology

The phenology of butterflies is changing across a wide geographical area (Roy & Sparks, 2000; Forister & Shapiro, 2003; Stefanescu *et al*. 2003). This will affect all species, both migrants and residents. Possible mismatches with foodplants at the appropriate quality stage are likely to be more serious for residents as they do not have the mobility to track foodplants as do the migrants. Phenological advances are likely to occur in a wide range of other species, particularly early season species.

10.6. Changes to population size

The abundance of migrant invertebrates in the UK appears to be influenced by temperatures (and desiccation) in source locations. A study of a 113-year series of Lepidoptera migrant numbers (Sparks *et al*. 2005) suggested a temperature influence on migrant incidence in the UK for 22 of the 27 species (9 butterflies, 18 moths). Thus a greater incidence of migrant numbers in the UK could be anticipated as the climate continues to warm. Such results are likely to have general applicability beyond the Lepidoptera. Fecundity, growth and survival of invertebrates, including migrants, are likely to be improved under climate warming (e.g. Virtanen *et al.* 1998; Willott & Hassall, 1998).

10.7. Are migrant invertebrates at risk?

One characteristic of migrant invertebrate species is that they are numerous, highly mobile and adaptable. They are thus likely to be less at risk that resident species that may be habitat specialists, exist at low populations or are immobile. In general, the adaptability of migrant invertebrates suggests that climate warming may be expected to benefit them, including those regarded as pests (Porter *et al*. 1991; Cannon, 1988). Desiccation in breeding areas is likely to be the greatest risk to migrants if species are in larval (i.e. relatively immobile) stages.

10.8. Further research

Undoubtedly many features of migrant invertebrates are recorded in the pest management (e.g. Drake, 1994; Westbrook *et al.* 1997) and in radar entomology (e.g. Niemenen *et al.* 2000; Feng *et al*. 2004) literature, but as yet little has been done linking movements and other features of these species to a changing climate. UK schemes monitoring invertebrate populations could undoubtedly yield more information on climatic influences on migratory species (e.g. Butterfly Monitoring Scheme, Rothamsted Insect Survey). Given its importance as a European crossroads, monitoring or exploiting data resources from Gibraltar would be highly desirable.

11. IMPACTS OF CLIMATE CHANGE ON MIGRATORY SPECIES: CASE STUDIES

In the main report, we discuss the potential impacts across species generally, highlighting specific examples of the impacts of climate change on individual species where appropriate. In this section, we have selected a representative range of species to illustrate the potential effects across taxa (Table 11.1). A brief background of their distribution, conservation status and ecology is presented followed by an account of the likely impacts of climate change. At least in part, predicted responses are made by reviewing evidence of changes that have already occurred, but in some instances, predictions are based on knowledge of the ecology and behaviour. The relative length of the texts reflects the differing amount of knowledge between taxonomic groups.

To illustrate the potential impacts of climate change on migratory marine mammals the Sperm Whale was selected as a case study, because (i) although a Toothed Whale (odontocete) the Sperm Whale undertakes long seasonal migrations, similar to most Baleen Whales, (ii) is listed on CMS Appendix I & II, (iii) although widely distributed, localised populations may be vulnerable, and (iv) it occurs around the UK and most UK overseas territories. To illustrate the potential impacts of climate change on marine turtles the Green Turtle was selected as a case study, because (i) the threats faced by Green Turtles are essentially the same for all marine turtle species, (ii) it is listed on CMS Appendix I & II, and (iii) it occurs in several UK overseas territories. The Atlantic Cod was chosen as being representative of marine fish, which may move extensively across territorial boundaries.

To illustrate the range of potential impacts of climate change on birds in more detail, several species have been selected as case examples. Not every likely effect is discussed for every species. In the interest of brevity, accounts focus on well documented or highly likely responses and each of the accounts examines a different type of response in detail. Thus although phenotypic miscuing could potentially affect all of the species considered, it is only in the account of Pied Flycatcher that this issue is considered in depth, as this is the one species where numerous studies have demonstrated that adverse affects have already occurred.

For terrestrial mammals, we selected three species or groups representative of different ecosystems. The large herds of mammals in sub-Saharan Africa roam widely across national boundaries following the available food supply and the threats faced apply similarly across many species, we therefore treat them as a group. Additionally, we present studies of the Saiga Antelope (temperate steppe) and Caribou (Arctic tundra), both of which have been relatively well studied. To illustrate a range of issues relating to the potential impacts of climate change on migratory bats, three case studies are offered. The species represent a range of distributions, foraging types, roost choice and status. Brief notes on their distribution, conservation status and ecology are followed by suggestions of the potential impacts of climate change.

Finally, we consider the only terrestrial invertebrate listed in the CMS Appendices, the Monarch Butterfly *Danaus plexippus*.

Table 11.1. Summary of species included as Case Studies and their occurrence on CMS and its subsidiary agreements.

	Species	Taxonomic Group	CMS Listing
11.1.	Sperm Whale *Physeter macrocephalus*	Cetacean (long-range migrant)	I & II
11.2.	Green Turtle *Chelonia mydas*	Marine Turtle (long-range migrant)	I & II
11.3.	Atlantic Cod *Gadus morhua*	Fish (short-range migrant)	None
11.4.	Sooty Shearwater *Puffinus griseus*	Bird (pelagic)	None
11.5.	Siberian Crane *Grus leucogeranus*	Bird (wetland migrant)	I & II; AEWA; MoU (1999)
11.6.	Red Knot *Calidris canutus*	Bird (Arctic migrant)	II; AEWA
11.7.	Common Redshank *Tringa totanus*	Bird (temperate migrant)	II; AEWA
11.8.	Aquatic Warbler *Acrocephalus paludicola*	Bird (migrant passerine)	I; MoU (2003)
11.9.	Pied Flycatcher *Ficedula hyopleuca*	Bird (migrant passerine)	II
11.10.	Saiga Antelope *Saiga tatarica*	Mammal (nomadic migrant)	II
11.11.	Sub-Saharan grassland herbivores	Mammal (seasonal migrant)	I & II
11.12.	Caribou/Reindeer *Rangifer taurandus*	Mammal (northern migrant)	None
11.13.	Pond Bat *Myotis dasycneme*	Bat (medium-range migrant)	II
11.14.	Brazilian Free-tail Bat *Tadarida brasiliensis*	Bat (long-range migrant)	I
11.15.	Straw-Coloured Fruit Bat *Eidolon helvum*	Bat (long-range migrant)	II (candidate)
11.16.	Monarch Butterfly *Danaus plexippus*	Insect (long-range migrant)	II

11.1. SPERM WHALE Physeter macrocephalus

Migratory species: Yes
CMS Listing: Appendices I & II
Threat status: Vulnerable
Distribution: Worldwide (polar to tropical waters), occurs UK & UKOT waters

11.1.1. Background

11.1.1.1. Distribution

Sperm Whales are distributed worldwide in tropical, temperate and sub-polar seas of both hemispheres. They occur throughout the deep waters (usually 500-2000 m) of all the world's oceans and confluent seas, including the Mediterranean, from the edge of pack ice in both hemispheres to the equator, especially in the Pacific (Rice 1998; Whitehead 2002b). Periodically some Sperm Whales make excursions into shallow shelf waters such as the North, Barents and Baltic Seas (Rice 1998). Generally areas of high Sperm Whale abundance are associated with higher primary productivity, usually resulting from upwelling (Whitehead 2002b). Sperm Whales are observed either in mid-ocean or over submarine canyons at the edges of the continental shelf, but can occur close to coasts of volcanic and oceanic islands in waters deeper than 200 m (Reid *et al.* 2003b). Major breeding areas include the Caribbean Sea and around the Azores.

There is marked geographical segregation between the sexes and age classes, which characterises this species in both hemispheres, and which may be related to competition for prey resources. In the Northeast Atlantic, females and young animals form social groups inhabiting temperate, subtropical and tropical areas, they generally inhabit water deeper than 1000m and at latitudes less than 40° and are rarely observed at latitudes higher than 55°N, corresponding roughly to a sea surface temperature greater than 15°C (Whitehead 2002b). Only males move into sub-Arctic waters to feed. Young males separate from the female groups between 4 and 21 years of age, and gradually move to higher latitudes, with larger and older males found at higher latitudes (Whitehead 2002b).

Sperm Whales regularly occur in UK waters, although are mainly recorded between July and December, and groups may be present throughout the year in some areas. Off the north and west of Scotland most sightings occur along the 1,000 m isobath, with animals either on or beyond the continental slope. The occurrence of Sperm Whales along the shelf edge may reflect increased productivity and consequent increase in prey where water currents converge along the continental slope (Pollock *et al.* 2000). All recorded Sperm Whales stranded off the North Sea during the 1990s were male (mainly 20-36 years, although the oldest was 55 years), some of which were stranded in groups of up to 16 animals. Sixty-nine of the 74 animals stranded between 1990-99 in the North Sea were between November-March, apparently during or shortly after the southward migration (Pierce *et al.* in prep). Male Sperm Whales in the north-east Atlantic occur mainly in deeper waters (greater than 200 m) around Iceland, west of Norway, beyond the shelf break north and west of Scotland, Ireland and Bay of Biscay. Observations have also been recorded in near-shore waters off Iceland, western Norway and Northern Isles of Scotland. Both males and females have been observed off the west coast of Portugal, the north coast of Spain and around the Azores (Reid *et al.* 2003b). Sperm Whales have been recorded around most of the UK Overseas Territories (Gibraltar, Cyprus, Anguilla, Bermuda, British Virgin Islands, Cayman Islands, Montserrat, Turks and Caicos, St Helena, British Antarctic Territory, South Georgia, South Sandwich Islands, and Falkland Islands).

11.1.1.2. Migration

Migrations of the Sperm Whale are not as regular or as well understood as those of most baleen whales. In some mid-latitudes there appears to be a general seasonal north-south migration with whales moving poleward in summer, but, in equatorial and some temperate areas, there is no clear seasonal migration (Whitehead 2002b). Males, generally when 25 years or older, undertake frequent large-scale latitudinal (to and from breeding grounds) and also longitudinal migrations, the extent, timing and frequency of which are not entirely understood. It has been suggested that males may show variable patterns of movement while at high latitudes, with some animals staying resident in small areas for long periods or making repeated returns to particularly favoured locations, while other having a more nomadic life style (Whitehead 2003).

The movements and distribution of Sperm Whales will be influenced by prey availability as Sperm Whales can not fast for extended periods of time, and require around 3% of their body weight in food per day (Lockyer 1981). Therefore, features that may influence prey concentration will determine to a great extent their spatio-temporal distribution.

11.1.1.3. Diet

Diet composition is known to vary between regions, months, seasons and years as well as between sexes, and with age or body length. Sperm Whales predominantly feed on medium to large sized mesopelagic cephalopods, in many areas the diet appears to consist predominantly of the genus *Gonatus*, but also contains other squid species such as histioteuthids and ommastrephids, as well as some demersal and mesopelagic fish (Kawakami 1980; Gaskin 1982; Santos *et al.* 1999; Whitehead 2002b).

Sperm Whales regularly dive to depths of 400-600 m, although may reach depths up to 2-3,000 m. Dives usually last between 25-90 minutes, but may extend to up to 138 minutes (Reid *et al.* 2003b).

11.1.1.4. Threats

Sperm Whale populations were decimated by pre-industrial whalers and have been very slow to recover, due to very low reproductive rates. There are currently estimated to be 360,000 Sperm Whales in the world’s oceans (Whitehead 2002a). Sperm Whales are also killed by entrapment in fishing gear, choking of plastic bags and marine debris and collision with ships (Whitehead 2002b). Pollution levels in Sperm Whale blubber is generally higher than most Baleen Whales, but lower than inshore odontocetes (Whitehead 2002b). As a species the Sperm Whale is not immediately threatened, but regional populations may be vulnerable.

11.1.2. Effects of Climate Change

Climate change will affect Sperm Whale distribution and migration as a result of changes in prey abundance and distribution throughout their range and in regional areas. For example, long-term interannual variation in the number of Sperm Whale strandings on the North Sea coast may be related to ocean climate, with a weak but statistically significant positive association between North Sea strandings (1563-1999) and the (three-year lagged) winter North Atlantic Oscillation (NAO) index. It appears that a link could operate through changes in the distribution of the whales’ main squid prey and consequent shift in Sperm Whale migration routes (Pierce *et al.* In prep).

Climate change could affect the reproductive success of Sperm Whales through changes in prey availability. For example, a decrease in reproductive success of female Sperm Whales near the Galápagos Islands was associated with periods of warm sea surface temperature, usually caused by El Niño Southern Oscillation events, probably linked to poor foraging success (Whitehead 1997).

Therefore any increase in temperature as a result of global warming and/or the frequency and duration of El Niño events could have serious implications for Sperm Whale populations such as those found around the Galápagos Islands (Whitehead 1997).

11.1.3. General considerations

The potential effects of climate change on Sperm Whales are similar to those faced by baleen whales (mysticetes), toothed whales, dolphins and porpoises (odontocetes) and to a certain extent, pinnipeds and sirenians. The effects of climate change, especially on prey availability, will potentially affect their distribution, abundance and migration, susceptibility to disease and contaminants, reproductive success, and ultimately, survival.

11.2. GREEN TURTLE *Chelonia mydas*

Migratory species: Yes
CMS Listing: Appendices I & II
Threat status: Vulnerable
Distribution: Circumglobal (tropical to subtropical), occurs in UKOT waters, and as a vagrant in UK waters

11.2.1 Background

11.2.1.1. Distribution

The Green Turtle has a circumglobal distribution, occurring throughout tropical and subtropical waters in the Atlantic, Indian and Pacific Oceans and Mediterranean Sea. Green Turtles are highly migratory and their complex movements and migrations take them through a wide range of marine areas and habitats, including the open ocean and coastal areas. Green Turtles are occasionally recorded around the UK but are regarded as a vagrant (Pierpoint 2000). There are nesting and foraging Green Turtles on the UK Overseas Territories of Anguilla, Ascension Island, British Indian Ocean Territory, British Virgin Islands, Cayman Islands, Cyprus, Montserrat, Pitcairn and Turks and Caicos Islands, with foraging turtles also occurring off Bermuda and St Helena (Godley *et al.* 2004).

11.2.1.2. Migration

Green Turtles are highly migratory. It is thought that, upon leaving nesting beaches, hatchlings float passively in major ocean current systems (gyres). After a number of years in oceanic waters the turtles move to neritic areas (over the continental shelf) that are rich in seagrasses and/or marine algae where they forage and grow until maturity. Upon reaching sexual maturity Green Turtles undertake migrations between foraging and nesting areas every few years. Migrations are carried out by both males and females and often cover thousands of kilometres (IUCN 2004). For example, after breeding at Ascension Island adult Green Turtles migrate to foraging grounds off Brazil, a journey of approximately 2000 km (Broderick *et al.* 2002).

11.2.1.3. Diet

Green Turtles are herbivorous, feeding predominantly seagrasses and marine algae.

11.2.1.4. Threats

The threats faced by Green Turtles are similar to most marine turtles and include (i) exploitation of eggs and adult females at nesting beaches, and of juveniles and adults in foraging areas, for example, estimates of the direct exploitation of Green Turtles in the Turks and Caicos are up to 1130 turtles per annum (Godley *et al.* 2004), (ii) predation at nesting sites, (iii) incidental mortality in fisheries, and (iv) degradation of marine and nesting habitats. Nesting habitat degradation includes coastal developments, flood protection measures, sand extraction, and light pollution. Marine habitat degradation includes increased effluent and contamination from coastal developments, increased boat traffic, harvesting of nearshore marine algae resources, and marine debris. Analysis of Green Turtle subpopulations at 32 Index Sites distributed globally indicates a 48 to 67% decline in the number of mature females nesting annually over the last three generations (IUCN 2004).

11.2.2. Effects of Climate Change

Green Turtles are directly affected by an increase temperature, with affects on temperature dependent sex determination, the timing of nesting, internesting interval, hatchling development and success, and an increase in disease. Green Turtles are also likely to be directly affected by an increase in sea levels, storm frequency and wave conditions, resulting in the loss of egg laying beaches. Any changes in ocean currents as a result of climate change will affect the migration of both hatchlings and adults. In addition the availability of food for Green Turtles is linked closely to climatic conditions that can vary substantially.

11.2.3. General considerations

The threats and impacts of climate change on Green Turtles also apply generally to other marine turtles, although the extent might vary with location and species.

11.3. ATLANTIC COD *Gadus morhua*

Migratory species: Yes
CMS Listing: Not Listed
Threat status: Vulnerable
Distribution: North Atlantic, occurs in UK waters

11.3.1. Background

11.3.1.1. Distribution

Atlantic Cod are distributed in the east and west North Atlantic (80°N - 35°N, 76°W - 61°E) from Cape Hatteras to Ungava Bay along the North American coast; east and west coast of Greenland; around Iceland; coasts of Europe from the Bay of Biscay to the Barents Sea, including the region around Bear Island. In the North Sea, Atlantic Cod occurs mainly in the northern and central areas. Atlantic Cod are found in temperate waters with temperatures ranging from 0 - 20°C. This demersal species is widely distributed in a variety of habitats, from the shoreline, including brackish waters, down to the continental shelf and depths of 600 m on the upper slope (www.fishbase.org).

11.3.1.2. Migration and Reproduction

Atlantic Cod migrate to spawning grounds, such as offshore areas in the central North Sea in January-April, then move to feeding areas. In the North Sea larval Atlantic Cod are distributed over a large part of the northern and central areas. One and two year old fish tend to overwinter in shallow coastal areas of the south-eastern North Sea, but eventually disperse into deeper waters. Larval Atlantic Cod live in the upper water layers for a period of approximately 2 months before becoming demersal. The codling remain on rough ground for 1-2 years then mature generally at 4-5 years, although small numbers may reach maturity at 2 years (FRS 2001a).

Adult Atlantic Cod are distributed throughout the west coast of Scotland, but mainly occur in offshore areas where they can occasionally be found in large shoals. Tagging experiments have shown that in late summer and early autumn there is a movement from west of the Hebrides to the north-coast areas. The return migration is in late winter and early spring. Spawning on the west coast takes place between January and April and occurs in most offshore areas. During the spawning season there is a continuous distribution of eggs and larvae around the west and north coasts of Scotland. Young are produced in spring time and live in the upper water layers until about August then become demersal. On the west coast, juveniles, during the first year of life are often found close inshore or around the entrances to sea lochs. As they grow older they move offshore and join the adult stock (FRS 2001b).

11.3.1.3. Diet

Atlantic Cod are omnivorous and feed at dawn or dusk in schools. The diet consists of fish and crustaceans, such as shrimps and crabs, and smaller quantities of molluscs and worms. As they grow they eat an increasing amount of fish including sandeels, Norway Pout, Whiting, Herring *Clupea Harengus*, Dab and young cod (FRS 2001a).

11.3.1.4. Threats

Atlantic Cod is a commercial fish species and several stocks, such as in the North Sea, are under pressure from overfishing.

11.3.2. Effects of Climate Change

Atlantic Cod stocks are vulnerable to the effects of climate change due to the pressure of overfishing. The combination of a diminished stock and a decline in the production of young that has occurred as the North Sea warmed over the past 10 years, indicate that continued warming due to climate change could endanger the long-term sustainability of Atlantic Cod in the North Sea (O'Brien *et al.* 2000). Recruitment in the North Atlantic appears to be related to sea temperature for stocks at the limits of the species range. In general, increasing temperatures are favourable for stocks at the northern limits and detrimental for those at the southern limits. Atlantic Cod in the North Sea are at the southern boundary of their range and low recruitment has been associated with increased mean sea temperatures during the first half of the year since 1988 compared to the previous three decades (O'Brien *et al.* 2000).

Fluctuations in plankton have resulted in long-term changes in Atlantic Cod recruitment in the North Sea (Beaugrand *et al.* 2003). The growth and survival of Atlantic Cod larvae depend on synchronous production with the availability of their main prey of a suitable size. Rising temperatures have modified the plankton ecosystem resulting in a mismatch between young Atlantic Cod and the abundance of suitable prey. Increased temperatures also increases Atlantic Cod metabolism and energetic cost, therefore when food is limited the optimal temperature for growth decreases (Beaugrand *et al.* 2003). Experimental work and analysis of catch statistics indicate that changes in sea temperature are a major influence on Atlantic Cod growth (Clark *et al.* 2003). The diminished growth in the species may reduce survival and lead to poor recruitment (Beaugrand *et al.* 2003). Models also suggest that increasing temperatures will lead to an increased rate of decrease in the North Sea Atlantic Cod population (Clark *et al.* 2003).

11.3.3. General considerations

The threats and impacts of climate change on Atlantic Cod also apply to other marine fish, although the extent might vary with location and species. The potential effects of climate change on marine species, either directly or indirectly, include changes in distribution, migration and abundance, phenology and synchrony with prey, spawning (timing and success), recruitment and year class strength, growth, disease and survival.

11.4. SOOTY SHEARWATER *Puffinus griseus*

Migratory Status: Trans-equatorial pelagic migrant
CMS Listing: Not listed
Threat Status: Not Threatened
UK/UKOT Occurrence: UK (passage migrant)
Primary Climate Impacts: ENSO intensification leads to less productive feeding grounds

11.4.1. Background

11.4.1.1. Range and population

The Sooty Shearwater *Puffinus griseus* is an abundant trans-equatorial seabird associated with cold offshore and pelagic waters. Breeding occurs chiefly on islands off New Zealand, Australia, Chile and the Falklands, although a few breed on mainland New Zealand and Chile (Marchant and Higgins 1990). In Australia there are colonies on 17 islands (all of less than 1,000 pairs), southern Chile (many colonies, some up to 200,000 pairs) and the Falklands (10,000-20,000 pairs) and more than 80 colonies in New Zealand, totalling c.5 million pairs (Marchant and Higgins 1990). The largest colony on the Snares Islands is estimated to support 2,750,000 breeding pairs, and the total world population is thought to be over 20 million birds **(**Heather and Robertson 1997). The majority move from breeding grounds to the North Pacific and Atlantic in the boreal summer (Briggs and Chu 1986). Adults are present or near colonies from early October to April. Breeding starts in October, when one egg is laid and incubated for 53-56 days (Carboneras 1992; Marchant and Higgins 1990). Large feeding movements of non-breeders in the southern oceans occur during this period, as birds range south to the iceberg belt. General northward movements begins in late March. Those from the Antipodes, Tierra del Fuego and Chile move to the north Pacific and those from the Falklands to the north Atlantic, with the first arrivals in the northern hemisphere in late April (Carboneras 1992). Initially birds move to the northwest of the Atlantic and Pacific. From there they move east with the prevailing winds, arriving off the west coasts of North America and Europe in August and September, before migrating back to breeding grounds (Briggs and Chu 1986).

11.4.1.2. Ecology

Breeding occurs on slopes, often densely vegetated and usually but not exclusively at coastal locations. In both the northern and southern hemisphere feeding concentrations are observed at the boundaries of cool and warm water where upwelling results in more productive waters (Briggs and Chu 1986). Birds appear quite sensitive to temperature as they spend the least possible time in tropical waters during migration and in the north Pacific, are rarely found in areas in which ocean temperatures exceed 14°C (Briggs and Chu 1986). Sooty Shearwaters feed on a variety of prey, in response to local availability. The main diet consists of small shoaling fish and cephalopods, particularly Anchovies *Engraulis*, spawning Capelin *Mallotus villosus* and squid larvae (Carboneras 1992).

11.4.1.3. Status and Threats

Although still a numerous species, there are consistent signs of current decline, and the Sooty Shearwater is now categorised as near-threatened (BirdLife International 2000). The number of burrows on the Snares Islands declined by 37% since 1970 and burrow occupancy may also have declined, indicating that an overall population decline may have occurred (BirdLife International 2000) Elsewhere the mainland New Zealand colonies are in decline and certain offshore colonies have not responded to predator control. In the California Current, Sooty Shearwater numbers have fallen by 90% in the last 20 years (Veit *et al.* 1997; Hyrenbach and Veit 2003), but it remains uncertain whether this has resulted from population declines or distributional shifts (Spear and Ainley 1999). Harvesting young birds or 'muttonbirding' currently accounts for around a quarter of a million of birds annually (Carboneras 1992; Heather and Robertson 1997), but is unlikely to account for the scale of the decline (BirdLife International 2000). Pelagic drift-netting, which formerly drowned up to 350,000 birds annually is apparently no longer problematic (Ogi *et al.* 1993).

11.4.2. Effects of climate change

11.4.2.1. Importance of ocean circulatory systems

The distribution of Sooty Shearwaters is influenced strongly by water temperatures and ocean circulatory systems (Viet *et al.* 1997; Spear and Ainley 1999). The most favoured feeding locations are areas of cooler water indicative of upwelling of nutrients to surface waters (Viet *et al.* 1997). The primary global mode of climate variability (in the 2 to 7 year time band), and that with the most effect on sea temperatures is the El Niño Southern Oscillation (ENSO), defined by sea surface temperature anomalies in the eastern tropical Pacific (Houghton *et al.* 2001). With increased greenhouse gas concentrations the frequency, and strength, of El Niño, and associated La Niña (the opposite phase of the oscillation), events is likely to increase (Timmermann *et al.* 1999). In general, seabirds have evolved to adapt to weather patterns and their ability to alter migration strategies appears to be important to survival in a changing climate (Butler *et al.* 1997). Nevertheless, the large climate variations beginning in the 1990s and associated with El Niño conditions, in combination with overfishing, have been linked to substantial changes in the ecology of marine systems (Roemich & McGowan 1995; Botsford *et al.* 1997; McCarthy *et al.* 2001). The best studied of these is the California Current system (e.g. Roemich and McGowan 1995; Viet *et al.* 1997; Sydeman *et al.* 2001; Hyrenbach and Veit 2003). Considerable changes in this marine ecosystem were described by Roemich and McGowan (1995) and were associated with a dramatic (90%) decline of Sooty Shearwaters (Viet *et al.* 1997). Prior to 1970, more than 5 million Sooty Shearwaters spent the boreal autumn months in this region (Spear and Ainley 1999)

11.4.2.2. Status and decline in the East Pacific

Numbers of Sooty Shearwaters in the California Current system fluctuated dramatically between 1987-1994, with numbers present negatively correlated with sea surface temperatures (Briggs *et al.* 1987). It is thought that that such warming is consistent with the northward shift of the subtropical water mass along the west coast of North America and the increased depth of the thermocline and warming of subsurface temperatures (Roemich and McGowan 1995). The deepening of the thermocline in coastal and pelagic upwelling systems reduces the supply of nutrients into surface waters, diminishes primary productivity and stimulates a switch from a community dominated by large-celled to a smaller-celled picoplankton assemblage (Fiedler *et al.* 1992). Widespread synchronous declines of zooplankton predators off the west coast of America (Veit *et al.* 1997) suggest that both fish and shearwaters have declined due to reduction of their food supply (Veit *et al.* 1997, Sydeman *et al.* 2001). Furthermore, concurrent declines in the Peru Current indicate that such declines occurred along much of the eastern Pacific (Spear and Ainley 1999). Because of the scale and magnitude of these declines Veit *et al.* (1997) suggest that Sooty Shearwaters have probably undergone a reduction in their population size on a global scale. However, more recent studies do not support this argument entirely (Spear and Ainley 1999).

Between 1983 and 1991, Sooty Shearwater numbers migrating across the equatorial zone of the pacific increased, and were positively correlated with sea-surface temperatures; increases were only evident more than 1,000 miles offshore, outside the zone surveyed by Veit *et al.* (1997). Spear and Ainley (1999) propose that the shearwaters have redistributed themselves in the Pacific Basin, with a shift from prevalence in eastern boundary currents to the more pelagic waters of the western and central North Pacific. This pattern would be consistent with the noted preference of Sooty Shearwaters for coldwater areas (Warham 1996; Viet *et al.* 1997), and the compensatory cooling of the western and central North Pacific as the boundary currents warmed (McGowan *et al.* 1998). Pelagic waters are considerably less productive than upwelling zones (Roemmich and McGowan 1995), and consequently feeding conditions may be significantly worse. During the period they spend in the eastern Pacific, Sooty Shearwaters gain substantial mass, which is likely to be important to sustain their trans-equatorial migration (Fiedler *et al.* 1991; Spear and Ainley 1999).

11.4.2.3. General Considerations

Changes in primary productivity drive many marine ecosystems, and the presence of highly productive upwellings associated with some ocean current systems can attract vast congregations of birds (e.g. Veit *et al.* 1997). Many seabird species are likely to be affected by changing ocean currents, for example, mass mortality of several species of shearwater has been recorded in pelagic waters as a consequence of climate-induced food shortages (Baduini *et al.* 2001). Albatrosses whose pelagic wanderings circumnavigate the globe are likely to be similarly affected, particularly if altering their routes brings them into greater conflict with fishing activities (Tuck *et al.* 2001; Croxall *et al.* 2005).

The life history of Sooty Shearwaters, and other seabirds tends towards K-selection in that adult survival is maximised at the expense of reproduction (e.g. Erikstad *et al.* 1998). The populations of such species may include a substantial non-breeding population that may buffer declines in the breeding population. Consequently changes in seabird populations may lag behind environmental change, and estimates of abundance from breeding grounds may be of less use as a real-time indicator of climatic events than estimates of demographic parameters (Sydeman *et al.* 2001). Evidence from the main breeding populations suggests that sustained impacts on migratory seabird demography have indeed occurred (BirdLife International 2000). Although direct evidence is lacking, it is likely that should extreme circulatory events alter demographic parameters unfavourably, populations will be slow to recover because such species have low reproductive rates. Seabirds that are shorter distance migrants or residents off the coasts of the Eastern Pacific may be highly threatened by longer-term changes in ocean currents and temperatures because they will be less able to track changes in the distribution of their food supplies than longer-distance migrants such as Sooty Shearwater. (Seabird populations have suffered catastrophic breeding failures, and occasionally substantial mortality of adults during El Nino events in the Pacific and elsewhere (Barber and Chavez 1983, 1986; Boersma 1997, 1998; Schreiber and Schreiber 1984; Schreiber 2002)). However, very long distance migrants, such as Sooty Shearwater, may suffer from declines in food supplies, such as in the California Current, upon which they formerly relied as part of their annual cycle. Coupled with changes in fishing intensity and patterns, also affected by climate change (Houghton *et al.* 2001), global warming is thus likely to pose a significant threat to Sooty Shearwaters and other migratory seabirds.

11.5. SIBERIAN CRANE *Grus leucogeranus*

Migratory Status: Eastern Palaearctic migrant
CMS Listing: Appendix I/II; AEWA; MoU (1993; revised 1999)
UK/UKOT Occurrence: None
Threat Status: Critical
Primary Climate Impacts: Loss of taiga/tundra vegetation changes; fluctuating hydrological regimes

11.5.1. Background

11.5.1.1. Range and status

The Siberian Crane *Grus leucogeranus* breeds in arctic Russia in Yakutia and western Siberia. Three regional populations were recognised, but one is almost certainly extinct. The eastern population breeds between the rivers Kolyma and Yana and south to the Morma mountains. Non-breeding birds summer in Dauria, on the border between Russia, Mongolia and China (BirdLife International 2000). The main wintering sites are in the middle to lower reaches of the Yangtze river, especially Poyang Hu lake, China (Kanai *et al.* 2002b). Wintering birds are also recorded in Turkmenistan and Kazakhstan (BirdLife International 2000). During migration they make several stops, notably in the Qiqihar-Baiching area and the Shaungtaize and Yellow River deltas in eastern China. The western population breeds in the Tyumen District, Russia, and winters in Fereidoonkenar and Esbaran in Iran (Kanai *et al.* 2002a). A further population of Siberian Cranes once nested in western Siberia and wintered in India. The last documented sighting of Siberian Cranes in India during the winter months was in 2002. There is a high probability this population has been recently extirpated (BirdLife International 2004a).

11.5.1.2. Ecology

Siberian Cranes breed and winter in wetlands. The favoured nesting habitats are bogs, marshes, and other wetland types of the lowland tundra and taiga, preferring wide expanses of shallow fresh water with good visibility (Archibald & Meine 1996; Meine and Archibald 1996). Wintering habitat requirements are similar. The main wintering area at Poyang Lake is a shallow artificial wetland system where numerous tubers and leaves of *Vallisneria spiralis* are present (Kanai *et al.* 2002b). In Iran, they winter in paddy-fields (Kanai *et al.* 2002a). During migration they favour large, isolated wetlands (Archibald & Meine 1996). Siberian Cranes eat a variety of food items. On the breeding grounds in spring, they eat cranberries, rodents, fish and insects (Meine and Archibald 1996). On migration and on the wintering grounds, they excavate nutrient rich roots and tubers from wetlands and are predominantly vegetarian (Kanai *et al.* 2002b).

11.5.1.3. Threats and Status

The global population is about 3,000, the majority of which belong to the eastern population which spend the winter at Poyang Hu (Delany and Scott 2002). The population in Iran has declined to somewhere between 3 (Delany and Scott 2002) and 8 (Kanai *et al.* 2002a) birds. The species is currently considered to be critically endangered (IUCN 2004; BirdLife International 2004). The main threats to the eastern population of this species are the destruction and degradation of wetlands in its passage and wintering grounds as a result of expanding human population (BirdLife International 2000). The western population is primarily threatened by hunting (Kanai *et al.* 2002a). Poyang Hu lake, which holds 95% of the global wintering population, is threatened by hydrological changes caused by the Three Gorges ((BirdLife International 2000).

11.5.2. Effects of climate change

11.5.2.1. Threats to breeding populations

Although the reproductive potential of populations of Siberian Crane decreases in cold springs and summers (Degtyarev and Labutin 1999), temperature increases in their Arctic breeding grounds of this species are likely to have a deleterious effect. The favoured breeding habitat of Siberian Cranes is open tundra/taiga wetland (Archibald & Meine 1996). Vegetation in this ecoregion is characterised by sedges, cotton grass, crowberry, small shrubs and dwarf birches (Callaghan *et al.* 2002). The lack of trees is important, as cranes favour areas with good visibility (Archibald & Meine 1996; Meine and Archibald 1996). The scarcity of trees in tundra and taiga habitats is primarily a consequence of the presence of permafrost (Harding *et al.* 2002). Under mid-range increases in greenhouse gas emissions, the extent of permafrost could be reduced by 12-22% of its current extent (Anisimov *et al.* 1997), and on longer time-scales of 100-200 years, drastic declines of up to 70% in the extent of northern tundra and southern taiga have been forecast (Cramer 1997; Piersma and Lindström 2004). Thawing of ice-rich permafrost is subject to considerable lag resulting from the large latent heat of fusion of ice. Nevertheless, simulations by Riseborough and Smith (1993) indicate that areas of 5 m thick ice-rich permafrost near the southern limit of the discontinuous zone in subarctic Canada could thaw in less than 70 years though, where permafrost currently is thick, it could persist in relict form for centuries or millennia (McCarthy *et al.* 2001). With a consequent reduction in preferred breeding habitat, it is likely that breeding populations of Siberian Cranes will be adversely affected.

In China, annual precipitation has been decreasing continuously since 1965, particularly since the 1980s (Houghton *et al.* 2001). The summer monsoon is reported to be stronger in northern China during globally warmer years, on the other hand, drier conditions have prevailed over most of the monsoon-affected area during globally colder years (McCarthy *et al. 2001*). In India, there is no discernible trend in summer monsoon rainfall, but there has been an increase in extreme rainfall events over northwest India during the summer monsoon despite a decline in the number of rainy days (Houghton *et al.* 2001). Overall, climate appears to have become more variable; in central Asia, increases in winter precipitation and a decrease in summer precipitation are projected and extreme floods and droughts are expected to become more frequent. Countries in temperate Asia are increasingly experiencing many droughts in the 20th century; for example, droughts in 1972, 1978 and 1997 in China were particularly serious and extensive, however, a large number of severe floods have also occurred in China, predominately over the middle and lower basins of the Yangtze (Changjiang), Huanghe, Huaihe, and Haihe Rivers (McCarthy *et al.* 2001).

Seasonal shifts and increased variability in rainfall are likely to have a negative impact on Siberian Cranes. Whilst wetland loss is primarily associated with extended dry periods, higher precipitation could also be detrimental. Whilst mobile organisms can respond to increases in water-levels by moving to more favourable areas, plants, such as the tuberiferous species on which the cranes feed, may be less able to shift their distribution. Thus although areas of suitable water-depth may persist regardless of hydrological regimes, the vegetation community of these areas would not necessarily remain the same. Phenotypic adaptations may dictate that cranes respond to changes in water-level by moving to areas of water of specific depth. However, because the phenology of their food sources is constrained by lack of mobility, high crane mortality due to starvation could potentially occur.

11.5.2.2. Threats to non-breeding populations

Non-breeding populations are also likely to be affected by changing climate. Many of the species' key habitats, both within and beyond existing protected areas, are subject to increasing human population pressures, and are situated in areas conducive to intensive agricultural development. Drainage, reclamation, and agricultural development have claimed major portions of the wintering grounds at Poyang and Dongting Lakes. High human density, especially in eastern China, may be leading to unsustainable levels of exploitation of the water, fish, reeds, and other resources on which cranes rely (Meine and Archibald 1996). Although loss of wetland habitat in wintering quarters of all three populations has been largely attributable to human demand for water, prolonged dry periods are exacerbating the problem. For example, at Keoladeo National Park, the former wintering grounds of the Indian population, maintenance of adequate water levels can be an acute problem, especially during dry years. Wetlands in Keoladeo are dependent on the fresh input of water each monsoon. With increased temperatures droughts are becoming more frequent and, as populations increase, demand for water resources are also increasing. This has led to serious water shortages (WWF 2005) and is probably one of the factors contributing to dispersal away from this key wintering area (Singh *et al.* 1997) and its subsequent demise.

11.5.2.3. General Considerations

Tundra and taiga habitat are likely to be amongst the most vulnerable to the impacts of climate change (e.g. Piersma & Lindström 2004). Many arctic breeding species, most of which can be considered migratory in some sense, are likely to be affected by reducing perma-frost extent and habitat encroachment (see also the Red Knot account). Similarly, Asian wetland habitats used by large populations of wintering waterfowl, are likely to be susceptible to adverse changes from additional climate stress (e.g. van Dam *et al.* 2002). These habitats are already under considerable pressure from anthropogenic activities and such pressures will be exacerbated by the impacts of likely reductions in precipitation. Although large-bodied wintering species, such as cranes, that rely on large food plants may be detrimentally affected by increased winter flooding events, other wintering waterfowl might benefit from these. Widespread flooding would increase the area available to smaller waterfowl that feed on submerged vegetation and aquatic invertebrates. By dispersing more widely, harvesting pressures might also be reduced, partly by reducing the concentration of populations of potential quarry species in small areas, but also because such populations may become more inaccessible from the shore. Thus, the impacts of climate change on migrating birds that rely on Asian wetlands, either as wintering areas or staging sites on their migratory journey could be affected either detrimentally or positively, depending on how the water regimes change with climate change.

11.6. RED KNOT *Calidris canutus*

Migratory Status: Global migrant
CMS Listing: Appendix II; AEWA
UK/UKOT Occurrence: UK (passage migrant, wintering)
Threat Status: Not threatened
Primary Climate Impacts: Loss of tundra, distribution changes

11.6.1. Background

11.6.1.1. Range and taxonomy

The Red Knot *Calidris canutus* is a long distance migrant, breeding in the high Arctic and wintering at various locations throughout the world (Delany and Scott 2002; Davidson 2002). *C. c. canutus* breeds on the Taymyr Peninsula and Central Siberia and winters in West Africa, from Morocco to the Gulf of Guinea (Taymyr population) and southwest and south Africa and Sri Lanka (central Siberian population). *C. c. rogersi* breeds on the Chuotskiy peninsula and far north-eastern Russia and winters in New Guinea, Australia and New Zealand. *C. c. roselaari* breeds on Wrangel island and Alaska and is presumed to winter on Caribbean shorelines. *C. c. islandica* breeds on high arctic islands in Canada and Greenland and western Europe. *C. c. rufa* breeds in the Canadian Arctic and winters in South America. *C. c. piersmai* was only recently described as a separate subspecies (Tomkovich *et al.* 2001) and breeds on the New Siberian archipelago and winters in Australia and New Zealand.

Intra-seasonal movements within Europe are well known, but elsewhere less so. The majority of *C. c. islandica* migrate to the Wadden Sea in autumn to moult, where they occur simultaneously with many *canutus*, which later depart for Africa (Nebel *et al.* 2000). From October to December, many join the remaining moulting population in Britain and Ireland, although populations exceeding 100,000 can remain in Wadden Sea (Maclean *et al.* unpublished data) and movements in winter are additionally affected by the availability of food (Davidson 2002). In the second half of March, many of the UK population then move back to the Wadden Sea (Davidson 2002) the remainder congregate on key sites such as the Wash and Morecombe Bay. In early May both British and Wadden Sea birds before depart for breeding grounds or to stopover sites in Iceland and Norway (Davidson 2002).

11.6.1.2. Ecology

Red Knot, as an exemplar of a large suite of shorebirds, has an ecology that is a combination of high Arctic breeding and long-distance migratory flights that require considerable, rapid accumulation of nutrients and fuel stores and dependence on a few major staging and wintering sites (Piersma & Davidson 1992; Piersma & Baker 2000; Piersma & Lindström 2004). On their breeding grounds, Red Knot favour tundra, upland glacial gravel and marshy slopes close to streams and ponds, usually near the coast (Davidson 2002b). Non-breeding birds prefer coastal mudflats but also occupy sandflats, beaches, lagoons and sheltered bays (van Gils & Wiersma 1996). In winter, their food requirements are rather narrow, predominantly soft-shelled molluscs such as *Mya* and *Macoma*, but occasionally worms and crustaceans (van de Kam *et al.* 2004). Northwards migrating Red Knot in the eastern United States rely heavily on the eggs of horseshoe crabs *Limulus polyphemus*. Breeding birds feed chiefly on adult and larval Diptera, but a diverse range of other arthropod prey is also taken on occasion.

11.6.1.3. Status and Threats

The global population of Red Knot marginally exceeds 1 million individuals. The European wintering population, which constitutes just under half the global population, is highly concentrated at a small number of key sites, particularly in the UK and the Netherlands. In the UK, significant congregations occur in Morecambe Bay, the Humber, the Forth and the Wash. Outside Europe, important sites include Banc d'Arguin in Mauritania, where over half the population of *C. c. canutus* over-winter (van Gils & Wiersma 1996) and Delaware Bay, USA, where a substantial proportion of *C. c. rufa* stages in May on their northward migration to the Arctic (Baker *et al.* 2004). Global population trends have not been estimated, but the species is probably declining. The European population has been broadly stable since 1975, following a decline since 1970 (Austin *et al.* 2004; Maclean *et al.* unpublished data), although some sources suggest a consistent decline (e.g. Delany and Scott 2002). Both *rufa* and *canutus* are also declining, the former thought to be due to later arrival at migratory stopover sites and concurrent over-harvesting of crabs (Baker *et al.* 2004).

11.6.2. Effects of climate change

11.6.2.1. Threats to breeding populations

Several links between climate and aspects of the reproductive cycle of Red Knot have been established and can be used to make some predictions with regards to the likely effects of changing climate. In some instances, climate has a direct effect on mortality or resource availability, but in others responses are in part driven by complex interactions with other species. For example, it is known that the breeding success of high Arctic breeding waders increases when spring temperatures are higher and snow melt is early (Blomqvist *et al.* 2002). Low spring temperatures affect the production of young directly by increasing rates of energy expenditure, shortening foraging periods and reducing arthropod prey availability (Schekkerman *et al.* 1998, 2003). However indirect effects are also important: the success of Arctic breeding waders is closely linked to the abundance of lemmings (*Dicrostonyx torquatus* and *Lemmus sibiricus*) (Blomqvist *et al.* 2002). When lemming numbers are low, Arctic Fox *Alopex lagopus* and Snowy Owl *Nyctea scandiaca* turn to alternative prey: the eggs and chicks of shorebirds and geese, and, occasionally, even adult birds. Peak lemming years usually occur when snowmelt is early and explain an important part of the correlation between breeding success of shorebirds and temperature (Summers and Underhill 1987; Blomqvist *et al.* 2002).

In the absence of comprehensive weather station coverage, past increases in Arctic temperatures have been inferred from proxy indicators (Smith, 1998). Glaciers and ice caps have shown retreat since about 1920 (Dowdeswell *et al.* 1997) and Greenland's ice sheet has thinned dramatically around its southern and eastern margins (Krabill *et al.* 1999, 2000). Snow-cover extent in the northern hemisphere has been reduced since 1972 by about 10%, largely as a result of spring and summer precipitation deficits since the mid-1980s (Brown 2000; Serreze *et al.* 2000) and sea-ice extent decreased by approximately 3% per decade between 1978 and 1996 (Serreze *et al.* 2000). It is predicted that over the next 30 years most of the ice in the Arctic Ocean will have melted away (MacKenzie 2002). This will have a significant effect on the temperatures of Red Knot breeding grounds (many nest near to this sea-ice) which undoubtedly has a strong cooling effect on nearby land (Piersma and Lindström 2004).

Initially, such warming might be beneficial due to an increase in arthropod prey items and a more rapid growth in the population of lemmings (which have a greater reproductive capacity) than in predator numbers. However, habitat changes with respect to vegetation, food, predators and disease are likely to result in increasingly detrimental effects (Lindström and Agrell 1999; Piersma and Lindstöm 2004). Under moderate carbon emission scenarios, the type of northern tundra used by breeding Red Knot is not expected to decline substantially over the next 80-100 years (Zöckler and Lysenko 2000), though under scenarios of high CO_2 emissions (three times that of the 20th century average), a situation that may arise in 100-200 years, the aerial extent of breeding habitat may decline by almost 70% (Cramer 1987; Piersma and Lindström 2004).

11.6.2.2. Threats to wintering populations

Changes in the quality of non-breeding habitat are also expected as a consequence of temperature increases. On the one hand, sea level rise is expected to have a negative effect by causing losses in the extent of intertidal mudflats if sea-defences maintain the current position of the shoreline (Galbraith *et al.* 2002; Austin and Rehfisch 2003), inducing higher rates of winter mortality (Atkinson *et al.* 2004). Although, to date, no published assessments have examined the responses of Arctic breeding shorebirds to these changes, some likely consequences can be predicted. Warming could also have a positive effect by reducing winter mortality and causing beneficial changes in distribution. In the UK winter temperatures increased by c. 2°C between 1975 and 2000 and are expected to rise by between 0.1°C and 0.3°C per decade over the next centaury (McCarthy *et al.* 2001). During warm winters, a higher proportion of the British population of Red Knot winter in estuaries on the east coast (Austin and Rehfisch 2005). East coast estuaries are more productive than those on the west and can thus support higher wader densities (Austin and Rehfisch 2005). For migratory birds, there may well be important cross-seasonal interactions. For example, the breeding success of red knots is affected by density-dependent effects on over-wintering populations (Boyd and Piersma 2001).

11.6.2.3. Threats on migration

Migratory flights may also be affected by changing climate, as the duration of such flights can be dependent on wind strength and direction (Butler *et al.* 1997; Gauthreaux 2005). Red Knot migrating from wintering grounds in Mauritania to breeding grounds on the Taymyr peninsula only use ‘emergency’ stopover areas along the Atlantic coast of France in years without the favourable tail-winds that allow the Wadden Sea to be reached without this additional and time-consuming stop (Piersma & Lindström 2004). Since breeding performance decreases with delays and difficulties in fuelling (Drent *et al.* 2003), changes in the prevalent wind direction or in the frequency of favourable winds could have a small but long-term impact on Red Knot by altering demographic rates. Improved recent generation of global climate models are beginning to enable consistent predictions of changes in wind regimes to be made, although not yet on a daily time-scale (McCarthy *et al.* 2001). Although different models predict slightly different results, there is general consensus that an increase in the number of deep low-pressure systems in Northern Hemisphere winter will occur, while the number of weaker storms will reduce (Carnell and Senior 1998; Sinclair and Watterson, 1999; Knippertz *et al.* 2000). Thus although the temporal resolution of predictive models are insufficient to enable accurate predictions of the effects of changes in wind regimes on migrating birds to be made, some changes are likely.

11.6.2.4. General Considerations

Pinpointing singular impacts of climate change on long-distance migratory birds is problematic. Birds that traverse the globe during the course of their annual cycle are affected not only by local conditions, but also by events in remote locations. Accurate predictions of the long-term impacts of climate change thus require a much greater understanding of how birds use a series of changing sites and of how demographic parameters interact with events throughout their life cycle (Sillett *et al.* 2000; Piersma and Lindström 2004). There may also be carry-over effects with decisions and experiences in the breeding and non-breeding parts of the cycle influencing activities in the other (e.g. Holmgren *et al.* 2001; Gunnarsson *et al.* 2004). This is an emerging area of research and its importance is only just becoming clear. Nevertheless, birds that embrace the entire globe within their flight paths serve as useful biological ‘integrators’ and potentially indicate global changes in a way that no network of observations could ever realistically achieve (Piersma and Lindström 2004).

The Red Knot, like most birds breeding at high northern latitudes will be subject to loss of habitat on its breeding grounds due to rising sea-levels, changes in the vegetative composition of tundra habitat and encroachment by northern woodland and scrub. High latitudes are likely to see the greatest magnitudes of climate change, and the greatest rate of change (McCarthy *et al.* 2001). Thus, the large and internationally important populations of migratory shorebirds that breed there are likely to be particularly vulnerable (see also Siberian Crane) and such impacts may be at least as important, in population terms, as anthropogenic factors elsewhere.

11.7. COMMON REDSHANK *Tringa totanus*

Migratory Status: Palaearctic migrant
CMS Listing: Appendix II; AEWA
UK/UKOT Occurrence: UK (breeding, passage, wintering)
Threat Status: Not threatened
Primary Climate Impacts: Wetland loss, sea-level rise and coastal mudflats

11.7.1. Background

11.7.1.1. Range and taxonomy

The Common Redshank *Tringa totanus* is a migratory wader occurring in suitable habitat throughout much of the Palaearctic. Several forms are recognised. The nominate *totanus* breeds in Europe, from Iberia west to the Urals and winters in coastal areas of the East Atlantic, Mediterranean, Asia minor and sub-Saharan Africa (Cramp & Simmons 1980). *T.t. ussuriensis* breeds in Russia east of the Urals to northern Mongolia and Manchura and migrates to southwest Asia and eastern Africa (van Gils & Wiersma 1996). *T. t. errignotae* breeds in southern Manchuria and east China, wintering in southeast Asia. *T.t. craggi* breeds in northwest Xinjiang and is thought to winter in coastal areas of China. *T. t. eurhinus* breeds in northern India and southern Tibet and migrates south to southern India and Sri Lanka (van Gils & Wiersma 1996). Both *T. t. robusta*, which breeds in Iceland and the Faeroes and *brittanica*, which breeds in the British Isles, are less migratory than other Common Redshank taxa, wintering predominantly in northwest Europe, often travelling only short distances to coastal areas (Clark 2002).

11.7.1.2. Ecology

During the breeding season, Common Redshanks are associated with a fairly wide diversity of inland and coastal grasslands, primarily in flat or gently sloping river basins (Cramp & Simmons 1980; van Gils & Wiersma 1996). Inland, they breed in flooded meadows, grassy marshes or swamp heathland, and often near saline pools in steppe grassland. In coastal areas, they favour saltmarshes (Cramp & Simmons 1980; van Gils & Wiersma 1996). Their breeding distribution and abundance is less affected by the precise nature of the vegetation, being more dependent on the presence of open areas with an ample supply of wetland food sources nearby. Breeding occurs between April and June. The diet of Common Redshanks can be varied, but most typically they feed on a relatively small range of food items. When breeding, earthworms and cranefly (Tipulidae) larvae constitute the main prey items taken (Cramp & Simmons 1980; Ausden *et al.* 2003). Outside the breeding season a small number winter inland, but most move to coastal areas, notably estuaries, but also to sheltered bays in coastal inlets (Cramp & Simmons 1980). In coastal areas birds feed predominantly on *Corophium* (Crustacea), *Hydrobia* (Mollusca) and nereid worms (van Gils & Wiersma 1996).

11.7.1.3. Status and Threats

The total global population of Common Redshank is estimated at 2.4 million, although 1 million of these are *T. t. eurhinus*, for which no formal census has been undertaken (Delany and Scott 2002). European populations of Common Redshank are fluctuating. In the UK recent declines in numbers breeding at lowland inland sites have been attributed to loss of wet grassland through agricultural intensification and significant changes in grassland management such as changes of grazing regimes (Wilson *et al.* 2004). Most birds wintering in Europe do so in the UK, and numbers here also appear to be fluctuating. A steady increase between 1970 and 1975 was followed by a temporary decline in late 1970s and early 1980s, since when the population has remained fairly stable at approximately double that in the early 1970s (Austin *et al.* 2004). Outside Europe, no systematic monitoring has occurred.

11.7.2. Effects of Climate change

There are several research programs on Common Redshank populations, primarily in the UK and near continent, which have studied the behaviour and population dynamics of Common Redshank (e.g. Brindley *et al.* 1998; Ausden *et al.*2003). These have highlighted several changes that are already occurring and provide useful pointers towards the likely responses of Common Redshank to future climates. Although acting synergistically, the effects of climate change impacts on Common Redshank can be broadly divided into three categories: (i) responses governed by sea-level rise (ii) responses to temperature changes and (iii) responses driven by changes in water regimes.

11.7.2.1. Sea-level rise

Sea level rise will affect Common Redshank breeding in coastal areas, but could also have a significant effect on all populations outside the breeding season, when the majority move to coastal areas to feed on intertidal invertebrates (Smart and Gill 2003; Watkinson *et al.* 2004).

A major potential consequence of sea level rise is the large-scale erosion of coastal habitats, particularly saltmarsh (Norris and Buisson 1994). Whilst evidence from southeast England indicates that sea level rise does not necessarily lead to loss of marsh areas if the supply of sediment is sufficient (Rehfisch and Austin 2005), the provision of sediment in many areas has decreased due to protection of areas of coast from whence it derives (McCarthy *et al.* 2001). Moreover, many saltmarshes are surrounded by hard sea defences and the landward migration of coastal habitats is thus prevented (Norris and Buisson 1994; Sharpe and Huggett 1998). As an indication of the importance of saltmarsh: Common Redshank breeding on UK saltmarshes represents about 45% of the British population (Brindley *et al.* 1998). English saltmarshes, the most valuable to Common Redshank in the UK, owing to their greater area and higher breeding densities (Brindley *et al.* 1998), are the most vulnerable to sea-level rise due to the additional effect of isostatic rebound (Sharpe and Huggett 1998). Substantial reductions in the densities of breeding Common Redshank have occurred on UK saltmarshes (Smart and Gill 2003). Although on some estuaries, these declines have been largely attributed to changes in grazing regimes (Norris *et al.* 2004), similar declines have been reported on Essex saltmarshes, where grazing does not occur, and are thought to be a consequence of erosion of breeding habitat coupled with increased frequencies of nest inundation (Cook *et al.* 1994).

Intertidal mudflats are also potentially threatened by sea level rise. Whilst declines in mudflats have been primarily due to land-reclamation and development (Norris and Buisson 1994), if sedimentation rates are too slow to compensate for sea-level rise or if sea-defences prevent realignment, significant losses would be expected to occur (Beukema 2002; Rehfisch and Austin 2005). Such losses are likely to affect overwinter survival (Atkinson *et al.* 2004) and the condition of adult birds at the beginning of the breeding season (Smart and Gill 2003).

11.7.2.2. Temperature increases

Increased temperatures could have both positive and negative effects on Common Redshank. Many (but not all) bird species have advanced the timing of egg laying in response to milder climates (Crick & Sparks 1999). Earlier laying dates may increase the length of the breeding season, resulting in some species either laying more clutches or having the option to re-lay following clutch loss, which is especially advantageous to relatively late breeding species such as Common Redshank (Kruk *et al.* 1996). Although the trend for earlier laying dates has not been quantified, hatch dates of Common Redshank vary annually and are associated with a measure of spring warming.

A further potential advantage of climate change, to wintering waders, is that severe cold winters may become less frequent (Hulme *at al.* 2002). Cold weather can adversely affect waders directly by mortality from hypothermia or indirectly by reducing net energy intake rates (Newton 1998; Clark 2002; Clark 2004). Harsh weather increases energy expenditure (Wiersma and Piersma 1994) and can also reduce energy intake depressing the activity and decreases the mass of intertidal invertebrates, although such responses are species dependent (Esselink and Zwarts 1989; Zwarts and Wanink 1993; Atkinson *et al.* 2004). Nevertheless, warmer climates could also have a negative effect on food intake as the reproductive cycle of many marine invertebrates is controlled or synchronised by environmental cues. Some, such as photoperiod are unrelated to climate and thus climatically driven changes may lead to phenotypic mistiming (Lawrence and Soame 2004). Consequently it is uncertain whether intertidal invertebrates could adapt rapidly enough, with consequences for the available prey base for foraging shorebirds, such as Common Redshank.

Recent milder winters have caused distributional changes of Common Redshank. In the UK, even though east coast estuaries are generally muddier than those on the west coast and thus support relatively higher invertebrate densities, historically west-coast estuaries have supported very high densities of over-wintering waders. The west of the UK is warmer and wetter, than elsewhere in the UK and birds are consequently less at risk of temperature induced mortality (Austin and Rehfisch 2005). Common Redshanks wintering on non-estuarine habitats have shifted their range eastward between 1984/85 and 1997/98, during a period of significant increases in mean winter temperatures (Rehfisch *et al.* 2004). Although the relative proportion of estuarine Common Redshank wintering in the west has not changed, underlying trends could be masked by the fact that birds wintering in Britain consist of both *robusta* and *britannica* and milder winters could result in both influxes and departures of birds to continental Europe (Austin and Rehfisch 2005). Indeed large increases in over-wintering Common Redshank in Europe have occurred in the colder extremities of their range such as the Baltic coast of Germany (Maclean *et al.* unpublished data). This shift in distribution appears to be due to juvenile recruitment; adult Common Redshank are highly philopatric, returning to the same wintering sites in consecutive seasons (Austin and Rehfisch 2005), thus the rate at which the populations are adapting may be slower than the rate of environmental change. A further consideration is that if, as seems likely, winter climate is becoming more variable, although the frequency with which the east experiences a cold winter is decreasing, if one does occur the potentially severe impacts (Clark 2004) may be proportionately greater due to the increased wintering population present.

Significant changes in the breeding distribution of Common Redshank may also have occurred. In Europe, there appears to be a general trend towards increases in breeding populations in the north and decreases in the south (Cramp & Simmons 1980). In the UK, despite a contraction in distributions and reductions in abundance throughout the remainder of the UK, distributions on the Outer Hebrides and Shetland have extended (Gibbons *et al.* 1993)

11.7.2.3. Changes in hydrological regimes

Changes in hydrological regimes, particularly on breeding habitats, are also likely to affect Common Redshank populations (Smart and Gill 2003). In the UK for example, climate models predict decreases in spring and summer rainfall, particularly in the east (McCarthy *et al.*2001). On both coastal and inland grazing marshes, field selection and the density of breeding Common Redshank within fields is determined principally by the length of wet features (J. Smart *et al.* unpubl. data). During the breeding season, Common Redshank feed on a range of soil, surface-active and aquatic invertebrates, but the proportion of aquatic invertebrates increasing as the season progresses and, consequently, Common Redshank benefit from the presence of water bodies through increased breeding success (Ausden *et al.* 2003) Optimisation of grazing marsh habitat in relation to water regimes, may become progressively more difficult to manage as a result of increased summer temperatures and a predominance of drier springs and summers (Briggs and Hossell 1995). Not only are such features more likely to dry out, but a greater need for irrigation in adjacent agricultural areas could lead to an increase in water extraction and a concomitant lowering the water tables (Briggs and Hossell 1995).

11.7.2.4. General Considerations

Although there are many uncertainties surrounding the magnitude of global and local climate change impacts, the effects of climate on some Common Redshank populations are already apparent. Given that the rates of climate changes are expected to accelerate (McCarthy *et al.* 2001), there is little doubt that these effects will become increasingly important and that others will emerge. However, there is a paucity of studies examining the effects of climate on Common Redshank outside Western Europe, where conservation issues and climate change impacts may be very different. There is an increasing need therefore to examine the effects of climate change at larger and more appropriate scales than in the past and to establish whether responses to climate in Western Europe are typical of that elsewhere. Furthermore, because components of climate change act synergistically with each other and with other factors, there is a need to adopt more integrative approaches to understanding their effects on migratory waders.

The issues facing Common Redshank, though are typical of many lowland meadow birds of north-western Europe, which are amongst the most threatened of European birds (Beintema *et al.* 1997). Climate change impacts on the hydrological regimes, particularly the effect of reduced precipitation, will affect all birds that forage on soil invertebrates in this habitat, many of which are migratory. Changes in coastal areas will have similar impacts on many coastal shorebirds, all of which are migratory to some extent (see also Red Knot). Changes on the wintering ground, for example through habitat loss or alteration in habitat quality, will have impacts on breeding populations, because of the density dependent nature of demographic rates. Such impacts can resonate through breeding populations that may not use the affected wintering area as the balance of distribution shifts between wintering areas (Sutherland & Dolman 1994). However, general climate warming may be beneficial by increasing over-winter survival rate, reducing high mortalities as severe winter weather events reduce in frequency and by permitting birds to winter closer to their breeding grounds, thereby reducing the risks and costs of longer distance migration. The latter are benefits that will derive from the adaptability of such migrants to reduce migration distance in response to warmer conditions. Species that are less adaptable, and cannot take advantage of warmer conditions to reduce their migration routes, may be detrimentally affected by climate change through changes in food supplies and competitive interactions with invasive species on their traditional wintering grounds.

11.8. AQUATIC WARBLER *Acrocephalus paludicola*

Migratory Status: Trans-Saharan migrant
CMS Listing: Appendix I; MoU (2003)
UK/UKOT Occurrence: UK (passage migrant)
Threat Status: Vulnerable
Primary Climate Impacts: Changes in hydrological regimes, Sahel drought

11.8.1. Background

11.8.1.1. Range and movements

The Aquatic Warbler is a globally threatened and vulnerable migratory passerine (Heredia 1996; BirdLife International 2000). Its breeding range is restricted to mid-latitude zones in the western Palaearctic, where July isotherms lie between 18-26ºC (Cramp & Brooks 1992). Formerly, Aquatic Warblers bred across much of Western Europe, but became extinct in the 20th century largely due to loss of its fen mire habitat from factors such as drainage for agriculture and peat extraction (AWCT 1999). Its current breeding range is highly fragmented with populations in western Russia, Hungary, Poland, Belarus, Ukraine, Germany and Lithuania (BirdLife International 2000). The majority of the Russian population is in Europe, but populations possibly persist in western Siberia (Heredia 1996; AWCT 1999).

Aquatic Warblers are thought to winter in sub-Saharan West Africa, but the wintering range is poorly known. They are recorded fairly regularly in the Senegal delta, with additional records consisting of three from Mali, one from northern Ghana (Urban *et al.* 1997) and two from the Gambia (C. Barlow, pers. comm.). Post-breeding, they migrate through western Europe (including the UK in unknown, but probably small numbers) across the Mediterranean to Africa, where they were formerly frequently recorded in Morocco, but have become considerably scarcer in recent years (Urban *et al.* 1997; AWCT 1999; Atienza *et al.* 2001). The migratory route of eastern populations has not been ascertained with certainty and may entail travel to as yet unknown wintering locations (Cramp & Brooks 1992). Fewer records from Western Europe in the spring suggest a more easterly return migration route (Urban *et al.* 1997). Stable isotope signatures in feathers indicate that Aquatic Warbler subpopulations across Europe do not form a single mixed wintering population. Birds breeding further north/west in Europe possibly winter further north in sub-Saharan Africa (Pain *et al.* 2004).

11.8.1.2. Ecology

Aquatic Warblers breed in marsh habitats (mostly sedge fen mires) characterised by specific vegetation types and hydrological regimes. They favour open marshes, with clumps of sedge and iris species rather than reedbeds and willows (Cramp & Brooks 1992; Kozulin *et al.* 2004). Large expanses of matted sedge are avoided as such vegetation restricts locomotion (Cramp & Brooks 1992). Breeding densities are highest when water depths lie between 5cm below and 12cm above ground level (Kozulin *et al.* 2004). Favoured nest sites are in areas of dry sedge rooted in deeper water, with an ample food supply within 30 metres (Dyrcz & Zdunek 1993). In Africa Aquatic Warblers are found in reedbeds, flooded grasslands and on shallow lake edges (Urban *et al.* 1997). During migration, a broader range of habitats are utilised, but the species is still associated strongly with nearby water (Cramp & Brooks 1992). In Europe, Aquatic Warblers feed mainly on insects, but also on spiders and small snails. In Africa, its diet is unknown (Urban *et al.* 1997).

11.8.1.3. Threats and status

Recent surveys have extended the known distribution of this species, and two-thirds of the known population has been discovered since 1995. The total population, excluding potential west Siberian breeders, is estimated at 13,500-21,000 singing males (BirdLife International 2004b). Over 90% of the world population, occurs in Belarus (58%), Ukraine (16%) and Poland (18%) (Pain *et al.* 2004). The current population is fragmented and still declining as a result of destruction of 80-90% of its habitat in the river systems of upper Pripyat, Yaselda and Biebrza/Narew. These systems hold approximately 75% of the European population and it is estimated that Aquatic Warbler has declined at a rate of 40% per decade (BirdLife International 2004b). Loss of breeding habitat has occurred primarily due to drainage for agriculture and peat extraction, damming of floodplains, unfavourable water management and the canalisation of rivers (AWCT 1999). Habitat degradation is widespread where traditional fen management has ceased allowing succession to unsuitable overgrown reedbed, scrub or woodland (Kozulin *et al.* 2004). Uncontrolled fires in spring and summer pose a direct threat to birds and nests, and can burn out the upper peat layer of fens (AWCT 1999). In wintering grounds, wetland habitats have fluctuated markedly in response to a series of devastating droughts (Peach *et al.* 1991). Wetland drainage, intensive grazing, succession to scrub, desertification and salination of irrigated soils are also potential threats (AWCT 1999).

11.8.2. Climate change

11.8.2.1. Threats to breeding populations

Potential climate change impacts on Aquatic Warbler during the breeding season are likely to be primarily caused by changes in hydrological regimes. The density of birds on the breeding grounds is closely related to water level fluctuations and it declines markedly when water depths fall outside the range of 5 to 12 cm with respect to ground level (Kozulin *et al.* 2004). Reductions in water levels cause declines due to a poorer species composition and biomass of prey insects, especially those whose development is linked to the presence of open water. High summer rainfall and prolonged spring floods have a negative impact on the state of the population because nests are inundated (Kozulin *et al.* 2004). Long-term declines are primarily driven by vegetation changes, in particularly a decline in the area of open fen. Prolonged periods of low rainfall expedite successional changes and promote the growth of non-aquatic grass and sedge (Kozulin *et al.* 2004). Marked changes in the future hydrological regime of Aquatic Warbler breeding habitats in response to changing climate are likely. Higher winter precipitation in addition to earlier snow melt as a result of warmer temperatures could increase water levels substantially in early spring. Drier, hotter summers would lower the water table, especially if drought were to increase the amount of water abstracted to irrigate adjacent agricultural land. Thus differences between water-levels at the start and end of breeding season are likely to increase and the area of habitat suitable for breeding is likely to decrease.

11.8.2.2. Threats during winter and migration

Changing hydrological regimes may also have a significant impact on Aquatic Warblers in sub-Saharan Africa. Estimates of annual survival rates and the population index of the Sedge Warbler *Acrocephalus schoenobaenus* has been shown to correlate closely with annual rainfall for the previous wet season in west African wintering quarters (Peach *et al.* 1991). Since both the habitat requirements and distribution of wintering Sedge Warblers are similar to those of Aquatic Warblers (Urban *et al.* 1997), it is plausible that a similar relationship between rainfall and Aquatic Warbler numbers might exist. However, consideration of exactly how rainfall affects the survival of warblers wintering in sub-Saharan wetlands is hampered by our scant knowledge of the distribution and habitat utilisation of this species.

The availability of freshwater habitats over the extensive floodplains of the Senegal and Niger Rivers is dependent upon abundant summer rainfall over large catchment areas. The extent of wetland habitats south of the Sahara in West Africa has fluctuated markedly since the late 1960s in response to a series of severe droughts (Brooks 2004). Peach *et al.* (1991) suggested that a shortage of habitat in dry years could increase competition for food and, hence induce higher rates of density-dependent mortality in Sedge Warblers. Aquatic Warblers are likely to persist at much lower densities than Sedge Warblers so, unless the resource requirements of Aquatic Warbler are extremely specialised, it is likely that a reduction in carrying capacity and concomitant increases in density-dependent mortality are less important. However further threats are posed by the continued expansion of the Sahara Desert due to drought and increased land drainage and grazing (Dietz *et al.* 2001; Brooks 2004). Wetlands just south of the Sahara Desert are likely to be important staging posts, used just prior to the journey across the Sahara. If such wetlands are lost, the journey of trans-Saharan migrants will be lengthened significantly and higher rates of mortality will probably occur during migration.

Under the most rapid global warming scenarios, increasing areas of Africa are expected to experience changes in summer or winter rainfall that significantly exceed natural variability. Large areas of equatorial Africa are predicted to experience increases in December to February rainfall and decreases in precipitation in July to August, although the outcome for the Sahel are poorly specified (Hulme *et al.* 2001). Although impacts on Aquatic Warblers are likely to be most detrimental during periods of prolonged drought, which may or may not increase in frequency, such climatic episodes can serve as an analogy of climate change.

11.8.2.3. General Considerations

The challenges faced by Aquatic Warblers are typical of those faced by many trans-Saharan migrants. Changing hydrological regimes are likely to affect many species that breed in wetlands and other ‘damp’ habitats (see Common Redshank). Climatic impacts on their wintering grounds and, particularly, on the northwards spring migration are likely to be particularly important. Reductions in water-levels and drying out of wetland habitats in the Sahel region are known to cause significant mortalities of Palaeartic-African migrant passerines, which can take many years, if not decades to be reversed. Persistent changes in rainfall patterns may have very serious consequences that could be explored by population modelling of the more common species, such as Sedge Warbler *Acrocephalus schoenobeanus*, for which much high quality demographic data in available. Conditions on the autumn migration are likely to be less critical in population terms as mortality at this stage is likely to be at least partly compensatory (e.g. Newton 1998), with, for example, increased mortality in autumn leading to reduced competition on the wintering grounds. However, the importance of processes in Africa are difficult to determine due to our incomplete knowledge of occurrence, movements and demography of birds in this area during the boreal winter.

11.9. PIED FLYCATCHER *Ficedula hypoleuca*

Migratory Status: Trans-Saharan migrant
CMS Listing: Appendix II
UK/UKOT Occurrence: UK, Gibraltar
Threat Status: Not Threatened
Primary Climate Impacts: Phenotypic miscuing

11.9.1. Background

11.9.1.1. Range and taxonomy

The Pied Flycatcher *Ficedula hypoleuca* is a fairly common migrant between the Western Palaearctic and Afro-tropical regions. The taxonomy of this species is complex, with clines of paler brown morphs in males, but four sub-species are currently recognised (Cramp & Perrins 1993; Hope-Jones 1997; Urban *et al.* 1997). The nominate *F. h. hypoleuca* breeds throughout much of Europe east to the Ural Mountains; *F. h. sibirica* breeds east of the Ural mountains to the river Ob; *F. h. iberiae* in parts of north and central Iberia and *F. h. speculigerus* in north Africa. All races winter in west and central Africa: *hypoleuca* and *sibirica* south of the Sahara to Gabon and northern Liberia and east to the Ituri forest in the Democratic Republic of Congo, *iberiae* mostly in West Africa and *speculigerus* from Senegal to the Ivory Coast (Urban *et al.* 1997). Small numbers of these last two subspecies also winter in northwest Africa, but probably only sporadically (Hope-Jones *et al.* 1977, Urban *et al.* 1997). All populations follow a predominantly southwesterly migratory route in autumn, passing through the Iberian Peninsula into northwest Africa (Hope-Jones *et al.* 1997). Although most pass back through the Iberian Peninsula, sometimes a more easterly route is taken in spring with birds crossing elsewhere in the Mediterranean (Hope-Jones 2002). Populations have increased in the UK, Belgium, the Netherlands, southern Germany, Switzerland and Finland, but recent decreases have occurred in Switzerland and Fenno-Scandia (BirdLife International 2004).

11.9.1.2. Ecology

The favoured breeding habitat of this species is mature deciduous woodland, dominated by Oak *Quercus*, but they also breed in Aspen *Populus*, Birch *Betula* and mixed conifer-deciduous woodlands or occasionally parks and orchards (Cramp & Perrins 1993). In Algeria and Morocco it is usually associated with forests of Cedar *Cedrus*, Oak and Aleppo Pine *Pinus halepensis.* In their wintering quarters, Pied Flycatchers inhabit secondary forest, savannah woodland, gardens and cultivated areas (Urban *et al.* 1997). The main factor restricting abundance within suitable breeding habitat is the availability of nesting holes (Lundberg and Alatalo 1992; Cramp & Perrins 1993), nevertheless Pied Flycatchers regularly utilise nest boxes and recent range expansions in parts of Britain, Finland and the Netherlands have been attributed to the provision of such boxes (Hope-Jones *et al.* 1977; Cramp & Perrins 1993). Most arrive on their breeding grounds during late April and May, but this varies with latitude. Males tend to arrive one week before females to establish territories (Lundberg and Alatalo 1992). Pied Flycatchers are largely insectivorous, feeding on flying and non-flying arthropods, particularly Hymenoptera, Diptera and Coleoptera (Lundberg and Alatalo 1992). During the breeding season larval Lepidoptera are important for nestlings, but diets of both adults and nestlings tend to vary in accordance with the availability of prey (e.g. Eeva *et al.* 2000). Fruit and seed are taken regularly in small amounts in late summer and during migration, when feeding conditions are poor. The species is also primarily insectivores at its wintering grounds, but has been known to eat *Lantana* fruits (Urban *et al.* 1997).

11.9.2. Effects of climate change

11.9.2.1. Phenological disjunctions

Pied Flycatchers are amongst the best-studied passerines in Europe and the results of these studies reveal illuminating insights into the potential consequences of climate change on migratory birds. There is now substantial evidence to suggest that most populations of Pied Flycatcher have responded to warmer temperatures by advancing their phenology, particularly of breeding (e.g. Both and Visser 2001; Sanz 2003; Both *et al.* 2004). Whilst potentially this allows birds to adapt to the effects of changing climate, one potential problem associated with advancing breeding schedules is that the rate of advancement of these events may not correspond to rates of environmental change and populations could become out of synchrony with their environment (Crick 2004). In some populations of Pied Flycatcher, the timing in food peaks has become earlier, but breeding is prevented by lack of sufficient change in spring arrival (Both and Visser 2001).

The extent of these phenological disjunctions varies between populations. In Spain and the Netherlands birds have not arrived earlier from their wintering quarters over the past 20 years (Both and Visser 2001; Sanz *et al.* 2003). Advancement in breeding appears to be constrained by their migratory schedule, possibly because the proximate cue triggering spring departure in Africa has not altered (Both and Visser 2001). Wintering tropical migrants may have difficulty forecasting weather conditions at their breeding grounds (Lundberg and Alatalo 1992) and the date of departure of many migratory bird species are controlled by endogenous rhythms and photoperiodic cues which do not relate to climate change (Coppack and Both 2003; Coppack *et al.* 2003). In southwest Finland, the migratory schedule appears not to have constrained breeding times. Arrival has advanced significantly and is correlated with temperatures in central Europe to the extent that birds have increased the time between arrival and breeding (Ahola *et al.* 2004). The contrasts with elsewhere could potentially be explained by spatiotemporal differences between the timing of breeding and temperature trends. Increases in European spring temperatures appear to be confined to late April (Ahola *et al.* 2004). Since populations breed later at higher latitudes, phenological advancements of northerly populations could occur earlier in their reproductive cycle (Sanz *et al.* 2003; Ahola *et al.* 2004). For example, it is known that Pied Flycatchers stop for short periods during migration (Cramp & Perrins 1993) and it is plausible that northern populations could benefit more than their southern counterparts from warmer temperatures during the migration period, by acquiring fat and protein reserves more rapidly and thus shortening their migration journey time. Long-term studies in southern Europe reveal that fledgling body mass, recruitment rate, male and female body mass after hatching and energy expenditure decreased during a period of significant warming (Sanz *et al.* 2003).

If northern populations are less prone to phenological disjunction, it is possible that northward range expansions could reduce the detrimental effects of mistimed reproduction. Whilst the distribution of Pied Flycatcher has extended northwards in some parts of its range, this expansion has been largely attributed to increased nest box availability and southward extensions have also occurred (in the Balkans and Morocco, Cramp & Perrins 1993). Evidence for a significant northward shift in response to climate change is lacking and highly unlikely to outweigh the negative impacts of climate change. Large-scale geographical analyses of populations throughout Europe reveal that although advancement in laying varies, the observed advancement in response to climate has not been enough to track temperature increases and future adaptation to climate change is therefore likely to be constrained (Both *et al.* 2004).

It has also been suggested that increases in clutch size in response to warming could offset the negative impacts of climate change (Bairlein & Winkel 2001). However, this thesis is not adequately supported, as Pied Flycatcher females lay smaller clutches after warmer, moister winters (Sanz 2003). Although not necessarily correlated with temperatures later in the year, mild winters are often indicative of an earlier onset of spring (Sanz *et al.* 2003). Furthermore increases in clutch size do not automatically lead to increased reproductive success, but depend on the extent to which breeding advancements track changes in the availability of food supplies (Both *et al.* 2004). Mounting evidence suggests that breeding advancement cannot keep pace with rapid advancement in food availability (Sanz 2003; Both *et al.* 2004). In oak woodlands, the favoured breeding habitat of Pied Flycatchers, spring air temperatures determine both rate of development of caterpillars and the peak date of caterpillar biomass (Visser and Holleman 2001). Since caterpillars are the main source of food for growing nestlings, Pied Flycatchers face a double jeopardy from climate change: the timing of fledging may not coincide with peaks in food abundance and accelerated caterpillar development makes the window of food availability even shorter (Buse *et al.* 1999). Consequently fitness components of pied flycatcher appeared to be suffering from climate change. Long-term studies in southern Europe reveal that fledgling body mass, recruitment rate, male and female body mass after hatching and energy expenditure decreased during a period of significant warming (Sanz *et al.* 2003).

11.9.2.2. General Considerations

Overall there is compelling evidence to suggest that selection for earlier laying is becoming stronger in migratory songbirds (Both and Visser 2001; Drent *et al.* 2003). However, further climate change may pose a serious threat to these species if they are unable to track changes on their breeding grounds sufficiently, such that the difference between the timing of breeding and the phenological schedule dictating survival and recruitment starts to change. A number of studies have shown that long-distance migrants have responded less to climate change than short-distance migrants, suggesting that long-distance migrants may be more threatened by climate change through phenological disjunction and miscuing than other groups of birds (Tryjanowski *et al.* 2002; Hubalek 2003). Long-distance migrants might be vulnerable to the impacts of climate change, if the cues they use to time their departure from their wintering grounds do not change sufficiently to allow them to take advantage of the earlier arrival of spring on their breeding grounds and there is not enough genetic variability of the complete time schedule from initiation of spring migration start of breeding. This will be the case, particularly, if they respond to endogenous rhythms or to environmental stimuli unrelated to temperature to determine the timing of departure from their wintering quarters. Selection studies suggest that there is a strong selection gradient for earlier breeding. However, the consequences depend on how such (genetic) traits as timing of start of spring migration and timing of breeding are connected. This is currently unknown.

11.10. SAIGA ANTELOPE *Saiga tatarica*

Migratory Status: Variable distance and extent depending on local climatic conditions
CMS Listing: Appendix II
UK/UKOT Occurrence: None
Threat Status: Critically Endangered
Primary Climate Impacts: Alteration in migratory behaviour, Increased mass mortality and low reproductive output during extreme climatic events

11.10.1.Background

11.10.1.1. Range

Saiga Antelope occurred formerly across much of the steppe, semi-desert and desert habitat of eastern Europe and Asia as far as Mongolia. This range declined rapidly to a low in the 1920s and 30s and became fragmented before expanding to recolonise some of its formal range in USSR and Kazakhstan. However, almost all the remaining populations of Saiga are currently small or declining once more.

11.10.1.2. Ecology

Saiga generally inhabit steppe, semi-desert and desert areas and prefer relatively open, flat terrain with access to water, and low-growing vegetation. The exact habitat and areas used varies with season depending on migratory movements, but the main factor limiting Saiga distribution is depth of snow coverage. Saiga can only obtain food if the snow depth does not exceed 20-40cm and generally will not remain in an area when the snow cover exceeds this depth. More than 80 species of plants and lichens have been recorded in the diet of Saiga, with less species being consumed in winter than summer. Group sizes vary with time of year, generally consisting of less than 50 animals during breeding in winter and reaching over 500 animals during spring migration. Its migration ecology is described below.

11.10.1.3. Status and threats

All known populations are either declining steeply (Kazakhstan and Kalmykia populations) or are relatively stable but of very small size (Mongolian populations). The main cause of the declines is thought to be increased poaching for horns resulting from economic collapse in rural areas. However, the declines may also be affected by increasing human presence, agricultural developments (including the construction of canals and fences) and other constructions in some areas.

11.10.2.Effects of Climate Change

The distribution, and the timing and extent of seasonal and local migrations of Saiga are all closely linked to local weather and climatic conditions. Migration to its winter range generally occurs in August and September and is linked to the first snow fall or a rapid drop in temperature. In milder winters and at times with less snow fall Saiga generally winter further north, while in winters of higher that average snow fall they winter further south. Similarly, animals generally reach their summer grounds by early June, but arrive as early as May in drought years and as late as July in wet years. Similarly, local migrations within seasonal ranges can be triggered by local weather conditions. In particular, in winter, heavy local snow falls may cause large proportions of the population to move to different areas within the winter range where snow cover is less and food is more readily available. Meanwhile in summer, severe droughts can result in large proportions of Saiga within the summer range moving to different areas with greater access to water and food. As a result of this strong link between local climate and movements, any changes in local climate triggered by global changes will have an affect on the distribution and movement of Saiga. In particular, if climate change results in higher snow fall in winter and increasing droughts in summer, the distribution of Saiga could be strongly affected, with animals moving to avoid these conditions, to areas where they have not traditionally occurred. While such effects themselves may not be detrimental to the well-being of Saiga populations, human development and agriculture may mean that such adaptations to changing conditions may not be possible as Saiga will generally avoid areas of agriculture or high human usage.

As well as affecting the distribution and movements of Saiga, population sizes of Saiga are strongly linked to local climatic conditions. In particular, *dzhuts* (a set of climatic conditions that results in a deep or dense snow cover, or a layer of ice covering the snow, usually combined with low temperatures and strong winds) often lead to high levels of mortality of Saiga and, if they are preceded by a spring or summer drought, populations can fall by up to 50% after a single bad year. These climatic events can also affect reproductive rates, with females in poor condition as a result of a lack of available food, re-absorbing embryos or failing to conceive. Therefore, these climatic events increase mortality and reduce reproductive rates, both of which will affect the viability of a population. If the frequency or intensity of droughts and *dzhuts* increase with changes in climate this may be sufficient to result in a decline in populations due to the effects on mortality and reproduction. This is particularly important in small populations or if they occur in conjunction with other increases in mortality or with the current substantial declines in populations resulting from increased poaching.

11.10.3.General Considerations

Saiga Antelope inhabit similar geographic areas and habitats as a small number of other migratory mammals, some of which are also listed on the CMS Appendices. These species also tend to move in relation to rains and the availability of forage and may thus be similarly affected if rainfall patterns change substantially with climate change. Wild Yak *Bos grunniens* (CMS Appendix I) is a much larger and stronger species, better adapted to snowy conditions than Saiga, and are thus less likely to be affected by increased snowfall and *dzhuts*. The main threats to this species are uncontrolled hunting, loss of habitat to pastoralists and hybridisation and disease transfer with domestic Yak (Hedges 2000). Wild Bactrian Camel *Camelus bactrianus* (CMS Appendix I) is adapted to arid plains but migrates to mountains to take advantage of springs and snow for water sources – it is likely to be able to better tolerate drought and *dzhuts* than Saiga, but serious prolonged drought would be a threat to the three remnant populations in Mongolia and China and modelling would be valuable to assess how the species' climate space might change under a range of climate change scenarios. However, the main threats to this species are currently hunting and competition with domestic animals for water and pasture (Hare 2002). Asiatic Wild Ass *Equus hemionus* (CMS Appendix II) is a nomadising species of desert, semidesert and steppe and some of its races are relatively restricted in range; it is threatened by hunting and competition with domestic livestock (Moehlman & Feh 2002) and climate change may provide added pressure and increase its interactions with pastoralists. The smaller Mongolian Gazelle *Procapra gutturosa* (CMS Appendix II) has small populations occurring in the grassy steppe and subdeserts of Mongolia, China and Russia. *Dzhuts* are known to cause mass mortalities for this species (Sokolov & Lushchekina 1997) and any climate change that increased their frequency and severity would be a concern.

For these and other such migratory ungulates, the distribution, movements and sizes of their populations are known to be strongly linked to local climatic conditions. As such, if global climate change leads to large changes in local conditions this has the potential to have large impacts on their populations. In particular, changes in the frequency and/or extent of *Dzhuts* may have large effects or impacts. While populations may be able to adapt to changes in local climatic conditions, additional population impacts from poaching, human development and agriculture may interact with the effects of climate change to reduce their ability to adapt to the changed conditions.

11.11. MIGRATORY MAMMALS OF SUB-SAHARAN GRASSLANDS

Migratory Status: Seasonal movements between grassland areas over distances of up to several hundred of kilometres.
CMS Listing: Appendices I & II
UK/UKOT Occurrence: None

11.11.1.Background

A variety of mammal species living on grasslands (savannah) in sub-Saharan Africa regularly migrate, particularly in association with seasonal changes in rainfall. These species face similar problems associated with climate change and in many cases there is a need to think of these species as a group rather than individually in terms of their conservation. Three species will be considered here as representative examples: Wildebeest *Connchaëtes taurinus*, Savannah Elephant *Loxodonta africana* and Thompson's Gazelle *Gazella thomsoni*.

11.11.1.1. Range

These species are all restricted to sub-Saharan Africa. However, within this area, some species are widespread (e.g. the Savannah Elephant), while others have more restricted distributions (e.g. Wildebeest and Thompson's Gazelle).

11.11.1.2. Ecology

These species primarily feed on short, seasonal grasses that grow rapidly in response to seasonal rains. However, outside of the rainy season, most species will consume leaves from a variety of trees and shrubs. Elephants will also consume the woody parts of trees in the dry season.

11.11.1.3. Status and threats

The species included in this group have statuses ranging from Low Risk to Endangered. The main threats include poaching, habitat loss and fragmentation, competition with human agriculture and human encroachment into protected areas.

11.11.2.Effects of Climate Change

While this group of animals represents a variety of species, the effects of climate change on them, particularly in relation to migration, are very similar. The biggest effect of climate change on these species is likely to be linked to changes in the distribution of seasonal rains on which these species rely at certain times of the year. Migratory movements are, at least in part, a response to the rapid growth of grasses associated with the rainy season, with animals moving, often in large numbers, to areas of high rainfall. Any change in the rainfall pattern will, therefore, result in a change of destination and/or migration routes as animals track these changes. While this would not be an issue in an undisturbed savannah environment, this is a problem when combined with human development and agriculture. These activities often surround game reserves, which are often strongholds for many of these species. For example the network of reserves formed by the Masai-Mara Game Reserve, the Serengeti National Park and the Maswa Game Reserve currently cover much of the annual ranges of wildebeest, Thompson's Gazelle and associated species. However, if the patterns of seasonal rain changes, these animals are likely to spend more time outside of these protected areas. This is likely to increase conflict with human agriculture and may also lead to an increase in poaching. In addition, any changes in the migratory routes required to move between new areas of peak seasonal grass growth, as rain patterns change, may be blocked by agricultural land and, in particular, cattle fences, limiting the ability of the migratory mammals to respond successfully to climate change. The loss of the ability to migrate to areas with high seasonal rains at specific times of year, is likely to have a serious impact on both the population sizes of this group of migratory mammals and on the general well-being of the local ecosystems that have co-evolved in conjunction with migratory movements of large numbers of mammals.

11.11.3.General Considerations

The migratory mammals of sub-Saharan grasslands are some of the most charismatic and familiar terrestrial mammals. As a result, there have been many programmes to protect these animals including the creation of isolated and networks of reserves. However, there have been little consideration given to the implications of climate change as part of the conservation plans for these species. In particular, habitat tracking, changes in preferred migratory routes, extents of migrations and destinations may lead to animals moving out of these reserve areas where they are protected. In addition, as agricultural and urban development increase in the areas around reserve areas, these responses to climate change may not be possible. This may lead to formally migratory populations becoming resident, with implications both for the mammal species and the grassland ecosystem as a whole. Therefore, it is important that potential changes in migratory movements resulting from climate change are taken into consideration when looking at the management of reserves and surrounding areas to allow animals to adapt to changes in local conditions.

11.12. CARIBOU/REINDEER *Rangifer taurandus*

Migratory Status: Some populations migrate long distances between winter woodland and summer tundra habitats.
CMS Listing: Not listed.
UK/UKOT Occurrence: None
Primary Climate Impacts: Reduction in suitable habitat and disruption of migration routes associated with range shifts. Increases in harassment by insect pests that are temperature dependent that may result in decreased body condition and increased mortality.

11.12.1.Background

11.12.1.1. Range

Caribou have a circumpolar distribution in sub-arctic and arctic regions including Scandinavia, Russia, Alaska, Canada and Greenland with nine recognised subspecies.

11.12.1.2. Ecology

Caribou generally occurs in woodland or at forest edges. However, some populations migrate to the Arctic tundra in summer months. The species feeds primarily on lichens, particularly in winter, but also on various plants and fungi. Some populations migrate long distances.

11.12.1.3. Status and threats

One subspecies found in Canada, *R. t. pearyi*, is listed as Endangered by ICUN. This population is restricted to the Arctic island Archipelagos of Canada and the north-west coast of Greenland and is thought to be declining due to the effects of changes in the local climate and continued hunting of a declining population. The other subspecies are classified as least concern and are currently not thought to be threatened.

11.12.2.Effects of Climate Change

Unlike migratory mammals in sub-Saharan Africa, where changes in seasonal rainfall patterns associated with climate change are likely to result in conflicts with human development and agriculture, the main issues for Caribou are associated with multiple impacts of climate change on the animal's ecology. Greater snow depths at high latitudes (associated with increased evaporation at lower latitudes caused by climate warming) will affect the ability of animals to move through their habitat as well as making it harder to access food buried under the snow. In addition, multiple freeze-thaw cycles will result in hard crusts forming on the snow that are harder for animals to dig through. These changes in the cost of movement and foraging will not only increase the likelihood of animals starving in winter, but may also increase exposure to predators such as wolves. Climate changes can also affect the reproductive success of Caribou, with warm, wet winters being associated with a decline in calving success.

Changes in temperatures at high latitudes will also affect the way that Caribou interact with a number of pest species. For example, a range of insect species including mosquitoes, warble flies and bot flies attack Caribou. As temperatures increase, the activity of these insects also increases and this can have a detrimental impact on Caribou. As insect activity increases, so does the level of harassment experienced by Caribou, disrupting feeding as well as increasing blood loss. This can result in a loss of condition at a critical time of year when animals need to be building up fat reserves for the winter and adult females require energy for reproduction. As a result, warmer temperatures can result in an increased mortality the following winter and a decreased pregnancy rates among females. These will have unknown implications for the maintenance of Caribou populations, but in general it is likely to result in a decline in population sizes.

11.12.3. General Considerations

Caribou are probably the most migratory of the ungulate species of the northern Arctic regions, but other species migrate smaller distances in response to changes in food (Berger 2004), such as Musk Ox *Ovibos moschatus* and Moose *Alces alces*, as well as more southerly Pronghorn *Antilocapra americana*, Mule Deer *Odocoileus hemionus* and Wapiti *Cervus elaphus*. While most Caribou and Musk Ox populations are not currently threatened, the tundra habitats on which they rely are amongst the most vulnerable to the impacts of climate change. The total global area of this habitat is likely to decrease as global temperatures increase and this may also lead to reductions in the quality of available habitat. The boreal forest habitats used in the winter are likely to increase, which may be beneficial for these migratory ungulates, but increased snowfall may counteract any benefits, by reducing the availability of food and increasing the length of time before snowmelt. Such changes in local climatic conditions may reduce the foraging ability of migratory ungulates, particularly in winter months, with a potential to impact on the reproductive success of populations. Such changes may be difficult to predict and may not be susceptible to adaptation measures as they are directly linked to the climate itself and are not compounded by human activities that could also be managed to reduce impacts. Proper assessments are required to explore the impact of such changes, based on appropriate data and spatio-temporal population dynamics models that incorporate scenarios of climate change.

11.13. POND BAT *Myotis dasycneme*

Migratory status: Medium-range migrant in Europe (to 300km)
CMS listing: Appendix II (European species of Vespertilionidae)
Threat status: Vulnerable
UK/UKOT Occurrence: None

11.13.1.Background

11.13.1.1. Range and population

The Pond Bat, *Myotis dasycneme*, belongs to a large genus that is almost worldwide in distribution. This species has been included in the fairly distinctive subgenus *Leuconoe* with about 40 species. It is considered one of Europe's rarer and more threatened species, ranging from north western Europe to the Yenisey River in Russia (from c.2°E to c.90°E) and from northern France through Hungary, central Siberia and Kazakhstan in the south, to southern Sweden, Baltic States and eastwards in the north (from c. 48-60°N). The population is estimated at between 100,000 and 200,000 individuals (Limpens *et al.* 2000). More recently, isolated individuals have been found in UK and Finland.

11.13.1.2. Ecology

Principal summer roost sites are in buildings and trees, where female maternity colonies range from a few tens to several hundred individuals. The food is mostly small aquatic insects taken from close to the surface of open smooth-surfaced fresh water. Some prey may be taken by trawling with the large feet from the water surface. Foraging range may be up to 15km from the day roost. Most individuals located in winter months are found hibernating in underground habitats, such as caves, mines, bunkers and other fortifications. In such places they hibernate singly or in small groups of from two to ten individuals, with up to a total of 700 found in one site. Movements of up to 300 km between summer and winter sites are recorded. Foraging routes (and probably migratory routes) generally follow sheltered linear landscape elements (such as rivers). Males may aggregate at sites along migration routes.

11.13.1.3. Status and threats

Recent studies have shown the Pond Bat to be more common than formerly realised, but it is still a poorly known species, although the subject of increasing interest. It is the subject of a Europe-wide action plan for its conservation (Limpens *et al.* 2000), is included in Annex II of the EU Habitats and Species Directive (thereby requiring special measures for its conservation), and is a Priority species of the Agreement for the Conservation of European Populations of Bats. It is also included in a series of sample summary species action plans in Hutson *et al.* (2001).

Roosts in buildings are threatened where the bats may not be welcome or where there is disturbance, changes in use, renovation or demolition. Roosts in trees may be affected by unfavourable management of the individual trees or of wider woodland habitats. Underground habitats used for hibernation may be threatened by closure, changes in use or increased disturbance. In particular, the bats are particularly sensitive in roost sites used for maternity colonies and for hibernation. Changes in water quality may affect its insect prey, and changes in landscape, including habitat fragmentation and loss of linear landscape features, may also threaten the species.

11.13.2.Effects of climate change

The Pond Bat is a bat of middle latitudes in Europe. A general increase in temperatures may encourage a shift to the north into countries where there is currently plenty of open water habitats but few suitable hibernation sites. The effects of climate change on hibernating bats have hardly been investigated. Considering the related North American *Myotis lucifugus*, Humphries *et al.* (2002) predict changes in the hibernation distribution to maintain suitable hibernation temperatures and other conditions required to meet the energetic constraints of the bat.

Climate change may affect the timing and synchrony of breeding in this species. Drier summers may reduce available water surface for foraging and may cause loss of mature trees used for roosting. Heavy summer storms may reduce foraging opportunity and could cause high mortality of young if prolonged.

Climate change may affect the distance between fixed hibernation sites and suitable summer foraging and breeding territories. Thus migration may be extended or reduced. An extension of migration may affect the species, since species of this genus are not generally long-range migrants. Also, the associated habitat requirements along the new migration route may not exist.

Drier springs and summer may result in reduced water levels and increased water extraction. Any reduction in water bodies suitable for foraging and changes in water quality that may affect the insect prey are likely to affect the distribution of this bat and may affect its ability to migrate. Although the species has been recorded foraging over brackish water, this is rare, but sea level rise may affect the water quality in a wide range of lowland areas of its distribution and could cause a loss of foraging habitat through salination.

11.13.3.General considerations

Most of the above factors would apply equally to one or two other European bat species, and in large part to many European species. Further complications may be experienced if phenological disjunctions or asynchronies appear through reduced hibernation period following warming which may also lead to changes in insect food supply and to asynchronies of parturition time.

11.14. BRAZILIAN FREE-TAILED BAT *Tadarida brasiliensis*

Migratory status: Long-range migrant in parts of range
CMS listing: Appendix I
Threat status: Near Threatened
UK/UKOT Occurrence: Cayman Is, Montserrat, and possibly Turks & Caicos Is
Primary Potential Climate Impacts: Increased storm intensity affecting feeding, temperature increase affecting habitat

11.14.1.Background

11.14.1.1. Range and population

The Brazilian (or Mexican) Free-tailed Bat is distributed from c.40°S in Argentina and Chile through Central America and much of the Caribbean to the southern states of USA (to c.40°N). It is scarcely recorded in much of Central America and Amazonia. The genus comprises about eight species found through the tropics and subtropics.

This species forms the largest aggregations of any terrestrial vertebrate, with maternity colonies of up to 20 million, rising to close to 40 million including young. These larger colonies occur in caves, with some large colonies (up to one million) under bridges and small colonies in houses(or even trees) in the more tropical parts of the range. Most of the US population is now concentrated into about 12 sites. It is scarce on Cayman Islands, the current status on Montserrat is uncertain, and it is only known from subfossil remains on Turks and Caicos Islands.

Accounts of the species can be found in Williams (1989); see also Hutson *et al.* (2001) (see also CMS report UNEP/ScC11/Doc.7 and CMS/ScC12/Doc.12).

11.14.1.2. Ecology

Generally, this species is a cave bat, but small colonies are found in buildings in some areas. It is an insectivorous species, using aerial hawking generally high in open areas over a wide range of habitats. It may range to 60km during nightly foraging flights and often forages opportunistically on large concentrations of migrating insect pests. Unlike migration in the more temperate bat species, migration in this species is to maintain foraging opportunity, rather than to seek suitable hibernation sites.

In North America, populations on the Pacific side (Oregon, Nevada, south-western Utah, western Arizona and California) and those east of eastern Texas do not undertake long migrations, but may undertake local movements of up to 150 km (LaVal, 1973). The populations in between undertake longer migrations of up to 1840 km from natal sites in USA (Glass, 1982; Williams, 1989), some stopping in USA, but many moving into north and central Mexico and possibly further south. Population numbers in central Mexico are much reduced from February to September, building up during October and decrease again by late January (Villa & Cockrum, 1962). It is mainly females that migrate north in spring to summer maternity colony sites, although males are first to arrive at these roosts. Recent DNA studies suggest that the separation of migratory and non-migratory populations into separate subspecies is unjustified (e.g. McCracken *et al.* 1994; McCracken & Gassell, 1997). Russell & McCracken (2001) were, however, able to show differences between the populations of North and South America.

Stopping-off points are important on this migration. Davis *et al.* (1962) estimated that these bats might travel nearly 500 km per night, but Villa-R. & Cockrum (1962) suggested maximum documented daily travel at about 35 km, and data in Glass (1982) suggest up to 50 km/day (but compare that with estimated daily travel from maternity colony sites of up to 60 km). Cockrum (1969) suggests that the bats travel nearly 70 km between stopping-off points, which may only be used for a few days or even one day. From Oklahoma, bats moved to the Mexican coast east to Sierra Madre Oriental and into the eastern half of the Mexican plateau (Glass, 1982). Migration is often in large flocks.

Migration at the southern end of the range is unknown, although similar migrations probably occur here and the potential has been discussed (e.g. Villa-R & Villa Cornejo, 1969; Wullich, 1994).

11.14.1.3. Status and threats

The concentration of huge numbers of individuals into a single site makes these bats particularly vulnerable. Although such large numbers still exist, population declines of over 99% have been recorded from North American roost sites, including one site that was estimated to contain 35 million bats and now contains almost none. The major colonies rely on caves (or other underground habitats) at both ends of their migration route and, for the most part, at the frequent stop-over points in between. These underground sites are subject to a wide range of possible perturbations, from accidental disturbance to intended bat extermination or exclusion. The presence of a specific strain of rabies virus in this bat is also a conservation problem. As a wide-ranging forager, specific habitat threats are difficult to define, but large scale changes to land use and changes in agricultural practices, as well as the use of pesticides, have been identified as of particular concern.

Apart from its inclusion in CMS Appendix I, the species is protected in Mexico and USA. Elsewhere it is not protected, or protected under such general legislation as to not be effective, or its protected status is unknown. For North America and Mexico there is also the Program for the Conservation of Migratory Bats of Mexico and the United States (PCMM), a non-governmental accord with strong government support for the conservation of this and other migratory bat species.

11.14.2. Effects of climate change

At the higher latitude ends of the range, this species forms very large maternity colonies, which require vast numbers of insects as prey (it is estimated that the 20 million bats that form a colony in Bracken Cave, Texas, consume over 100 tons of insects per night). Changes in the availability of prey due to climate change would have a significant impact on the bats.

Of the northern migratory populations, males and non-breeding females mostly remain in Mexico (and possibly further south), where increased intensity of storms and increased desertification may affect the availability of prey for this species. Such conditions may also affect the prey availability for the adult females during their wintering in Mexico.

No threats to migration are predicted, but there may be additional problems of continuity of food supply and stop-over points if migration is extended by a northward expansion.

A significant sea level rise on some of the Caribbean islands may affect foraging areas and may limit already limited populations on these islands. The islands carry isolated populations of the species, but from a global population conservation perspective, they do not contribute much to the world populations.

A general warming may provide conditions suitable for this species to range into higher latitudes, where large populations moving into important sites may create competition with those species already using such sites.

This is still an extremely abundant and widespread bat species, but in view of the major well-recorded regional declines observed in North America, coupled with the exceptional aggregations formed, the species should be subject to special consideration. Whilst apparently an adaptable forager with the capability to cover large areas of terrain in a night, the large colonies still rely on the availability of a truly enormous supply of insect food. The loss of any one of the major North American colonies would have severe impact on the total population there. The knowledge of the populations and conservation issues in South America, especially at the southern ends of the range, are largely unknown.

11.14.2.1. Habitat loss

Since the species does not have very specific foraging habitat requirements, habitat loss is more likely to affect the underground habitats used as roosts where changes in ambient climate may affect the internal climate of the roost site. Even this is unlikely to be a problem for the larger colonies, which can almost create their own environmental conditions of temperature, humidity and other atmosphere.

11.14.2.2. Phenology disjunctions, miscues or asynchrony

As with most bats, what is considered long-range migration does not match for distance many of the migrations undertaken by birds. In addition bats tend to migrate in short hops and so may be able to track the availability of food supplies and other environmental conditions as they migrate. A species like this is also not especially reliant on the availability of particular landscape elements to provide protection and foraging during migration. It is thus less likely to be affected by changes in prey availability and habitat changes during migration, but the synchrony of births and the availability of suitable prey during the parturition and lactation period for the adults, and the post-weaning period particularly for the young, are crucial.

11.14.3.General considerations

The concentration of bats into caves or cave-like sites results in a wide range of threats (Hutson et al. 2001). Many such sites may be used by large numbers of bats and/or a wide range of species. In particular, free-tailed bats (family Molossidae) may form very large colonies that need a large area of suitable foraging terrain. In the case of free-tailed bats, foraging bats can range over considerable areas, other species are much more reliant on a local foraging source. In either case, the bats often exhibit a very high level of roost fidelity. Thus, the loss of a single colony, or even a single roost site, used seasonally or on passage or permanently, can have a huge impact on the population. Changes in habitat around such long-term traditional roost sites can have similar impact.

11.15. STRAW-COLOURED FRUIT BAT *Eidolon helvum*

Migratory status: Long-range migrant within continental Africa
CMS listing: Proposed for Appendix II
Threat status: Least Concern
UK/UKOT Occurrence: None
Primary Potential Climate Impacts: Variable effects of ENSO and La Nina events affecting food availability, increased temperature reducing rain forest area and increasing desertification.

11.15.1.Background

11.15.1.1. Range and population

The Straw-coloured Fruit Bat, *Eidolon helvum*, is a widespread resident in much of central Africa and on to neighbouring islands, including those in the Gulf of Guinea and those, such as Zanzibar, off Tanzania. Seasonally, populations undertake migrations to north and south, to 18^{o}N in Niger and to 32^{o}S in South Africa. The occurrence at the northern and southern extremes of the range is patchy and erratic. A separate subspecies, *E. h. sabaeum* occurs in the south-west of the Arabian Peninsula and a separate species, *E. dupreanum*, in Madagascar.

The species forms large colonies of 10s to 100s of thousands, occasional colonies have been estimated to about one million, with one temporary colony in Zambia estimated at about five million. Many of the large colonies occur in major cities and this, coupled with its wide distribution and seasonal and erratic occurrence, may give a misleading impression of the total population. Many colonies have recorded major declines, such as in Kampala where early reports were of one million which declined to estimates of 250,000 in the late 1960s to as few a 20,000 now. Large colonies in Lome, Togo and Abidjan, Cote d'Ivoire, are also believed to be in decline.

Accounts of the species can be found in DeFrees & Wilson (1988), Bergmans (1990), Mickleburgh *et al.* (1992), Nowak (1994). See also CMS report UNEP/ScC11/Doc.7 and CMS/ScC12/Doc.12.

11.15.1.2. Ecology

The species is one of the largest bat species in Africa. It feeds on a wide range of fruit and flowers and is important for pollination and seed dispersal. It occupies a wide range of forest, savannah and urban habitats to an altitude of 2000m. Urban colonies include Accra, Freetown, Abidjan, Lagos, Douala, Kampala and Dar Es Salaam. The bats show extreme roost-site fidelity in a number of these urban colonies. The large, and often noisy, colonies are usually in trees, with smaller groups sometimes roosting in rock crevices or the entrance zone of caves. Bats may range up to 30km from the roost during evening dispersal for foraging.

Most of the major colonies are absent for part of the year, some for a relatively short period of about two months, while others may only be present for that sort of period. Migrations may take the bats more than 1500km. Migration may not always be associated with a lack of local food resources, but rather to take advantage of temporarily abundant food resources elsewhere. In some circumstances the bat might be better classed as 'nomadic' rather than 'migratory', since its movements may be somewhat erratic depending on available food resources and ambient weather conditions. The extent to which bats move into the northern and particularly southern extremes of the range varies markedly from year to year.

There is usually one young per year, which is born following a conventional four-month foetal development in some populations, or following a period of delayed implantation. This variation may be related to migratory patterns.

11.15.1.3. Status and threats

While still an abundant and widespread species in Africa, there is growing evidence of major declines and increasing threats to urban populations. The colonies in towns and cities are often unwelcome due to fruit feeding, defoliation of roost trees, defecation on buildings (especially commercial buildings). There is a growing intolerance of such colonies. In some cases exploitation for meat may be a problem. The species is widely persecuted as a pest by fruit growers, although there are few places where serious damage has been demonstrated, and damage is likely to be outweighed by the benefits from pollination and seed dispersal. Increasingly, agriculture and development are encroaching on natural habitats, including important tropical forest habitats.

Thus there is a need for the protection of key roosts, and there may be a need for the management of hunting and other persecution. There is also a need for further study of the migration of the species to understand better how this affects its conservation.

It is probable that the species is not protected anywhere in the main part of its range (except for a few colonies protected by tradition), but it has been proposed for consideration for listing in Appendix II of CMS

11.15.2.Effects of climate change

Large climate variations are predicted as a result of increased frequency and strength of El Nino events and those of its associated La Nina. These variations are expected to affect large areas of mainland Africa, but the actual impacts, their strength and effect in relation to this bat species are very uncertain at present.

Climate change may bring about loss of synchrony within breeding colonies. At present most colonies have a fairly strictly limited parturition period, but there are colonies, such as the very temporary colony at Kasanka National Park in Zambia, that include animals in a wide range of breeding conditions. Bumrungsri (2002), studying the Short-nosed Fruit Bat, *Cynopterus brachyotis*, in Thailand, found that in the year following an ENSO incidence a greater percentage of females reproduced, there was greater synchrony of lactation and higher body mass of lactating females. Juveniles were more abundant and larger and heavier than in the ENSO year. This coincided with higher fruit availability in the year after the ENSO year.

Climate change is likely to affect the distribution of this and other fruit bats. It has already been noted in the Australian Grey-headed Flying Fox (*Pteropus poliocephalus*) and Black Flying Fox (*Pteropus alecto*) that the northern limits of distribution have moved south (Hughes, 2003). The southern limits of *P. poliocephalus* also appear to have moved south with resident colonies now based at the latitude of Melbourne. While the overall distribution of *Eidolon* might not change, its breeding distribution might expand and its occurrence at the extremes of its northerly and southerly distribution may be more regular. It is a species that shows some flexibility and has relatively recently established a colony in an area of Sudan following the establishment of suitable food plants at a human settlement.

As with other large fruit bats, the species can take advantage of the fruiting or flowering of a wide range of plants and may also be flexible enough that it may not be particularly adversely affected by shifts in phenology of food plants. Again, the Grey-headed Flying Fox of Australia has shown considerable flexibility in shifting its seasonal movements to take advantage of whichever of its favoured food plants is doing best in a particular year. This somewhat nomadic tendency may have a number of advantages in a changing climate.

Loss of wet tropical forest would be a threat, since this is probably an important reserve habitat. Further drought affecting Savannah woodland and related open woodland would be a more immediate problem.

11.15.3.General considerations

In the absence of clearer predictions of climate change affecting mainland Africa, it is difficult to suggest likely effects on bats. In the case of the Straw-coloured Fruit Bat, the species may be sufficiently flexible in its foraging habits to cope with changes in available fruit and flowers and their seasonality. Increased drought may exclude it from large areas and may bring other side effects of further human damage to habitat. Other factors may exacerbate existing threats to the species, in particular in relation to the concentration of large numbers of individuals into colonies in urban situations.

While climate change effects may be limited for these larger Old World fruit bats, it may not be so for some of the smaller species, especially some of the nectar specialists. In that respect, of particular concern might be where there is a very strong mutualism between nectarivores and their food plants, such as in species of the New World phyllostomid genera *Choeronycteris* and *Leptonycteris* (Fleming & Valiente-Banuet, 2002), where phenological disjunctions could easily occur and could have very serious impacts.

Although there have been suggestions that climate change may affect the status of certain diseases carried by bats, there seems limited support for the strong association suggested by Epstein *et al.* (2003) that ‘in 1998, bats bearing Nipah virus swept onto Malaysian pig farms after fleeing forest fires fuelled by intense drought associated with the largest El Nino event of the century… As a result of this event, Nipah virus killed more than 100 people and crippled the swine industry’. The bats in question were large fruit bats (flying foxes). There is already a widespread perception that fruit bats in Africa, and especially *E. helvum*, can transmit a wide range of diseases and cause other health problems to human populations. Some of these perceptions are without foundation and others are based on isolated instances, such that education about health risks is an important element of the conservation of such bats.

11.16. MONARCH BUTTERFLY *Danaus plexippus*

Migratory status: Partial long-range migrant
CMS listing: Appendix II
Threat status: Least Concern
UK/UKOT Occurrence: None

The only invertebrate listed in the Appendices of the Bonn Convention is the Monarch Butterfly. This emblematic species is very distinct at both caterpillar and adult stage and has achieved celebrity status in the USA. Most of what we know about its migration comes from the USA (Brower, 1996) where several schemes exist to record and map its temporal distribution and track its progress using tagged individuals. Monitoring also includes a July 4 (Independence Day) Monarch count. As a consequence of these studies it is known that the eastern population over-winters in a small area in Mexico, which then migrates to the southern USA to breed and produce a second generation. This second generation then migrates to the northeastern USA where other generations may be produced before the return migration to Mexico in the autumn.

Thus, unlike vertebrates, the annual migration cycle involves several generations rather than individual animals. West of the Rockies, the population winters on the Californian coast and there may be other populations wintering in Florida. Like many other migrant animals, the species has a long migration and experiences the climate of each zone that it passes through. It has been suggested that increased winter rainfall may adversely affect its over-wintering population in Mexico (Anderson & Brower, 1996).

The Monarch exists elsewhere in the world, for example in Hawaii, the Caribbean, Australia and the Canaries/southern Spain. However, nowhere is the species as well studied as in the USA. The species has recently been regularly recorded in Gibraltar but doesn't undergo the same long distance migration as in the USA. The migratory behaviour may only have developed to keep pace with milkweeds (the larval foodplants) in suitable condition. If milkweeds in favourable condition exist locally, for example at higher altitude, then long distance migration may not be necessary, as would appear to be the case in Europe.

Acknowledgements

We are very grateful to the project's Steering Group for all the help and advice they have given throughout: Andy Williams (Defra), Eric Blencowe (Defra), Jeff Kirby (Defra) and David Webb (Defra); Mike Harley (English Nature) and Wyn Jones (JNCC). Jean Smyth and Tom Adams of Defra provided help with Steering group meetings.

At the BTO, we are grateful to the help provided by Ilya Maclean and Rachel Coombes for research with respect to the Case Studies and Appendices, to John McWilliams for providing information on breeding birds in the U.K.O.T.s, to Angela Rickard for help arranging the workshop and to Jane Waters for help with the report. We are particularly grateful to Mandy T. Andrews for all her efforts in undertaking the considerable secretarial task of putting together the report.

The team at Aberdeen University are grateful to the help and advice provided by Begona Santos and Paul Racey; and CEH is grateful to David Roy.

Finally, we are very grateful to all the experts who attended the International Workshop and gave freely of their time to contribute ideas and comments as well as guidance on references that we might have missed otherwise.

References

Ackerly, D.D. (2003) Community assembly, niche conservatism, and adaptive evolution in changing environments. *International Journal of Plant Science*, **164,** (3 Supplement) S165-S184.

Aebischer, N.J., Coulson, J.C. & Colebrook, J.M. (1990) Parallel long-term trends across four marine trophic levels and weather. *Nature,* **347**, 753-755.

Aguilar, A. & Borrell, A. (1994) Abnormally high polychlorinated biphenyl levels in striped dolphins (Stenella coeruleoalba) affected by the 1990-1992 Mediterranean epizootic. *The Science of the Total Environment,* **154**, 237-247.

Aguilar, A. & Raga, J.A. (1993) The striped dolphin epizootic in the Mediterranean Sea. *Ambio* **22,** 524-528.

Aguilar, A., Borrell, A. & Pastor, T. (1999) Biological factors affecting variability of persistent pollutant levels in cetaceans. In: *Chemical Pollutants and Cetaceans*. (eds P. J. H. Reijnders, A. Aguilar and G. P. Donovan). Cambridge, International Whaling Commission. Special Issue, **1**, 83-116.

Ahola, M., Laaksonen, T., Sippola, K., Eeva, T., Rainio, K. & Lehikoinen, E. (2004) Variation in climate warming along the migration route uncouples arrival and breeding dates. *Global Change Biology,* **10,** 1610-1617.

Alerstam, T. (1990) *Bird Migration*. Cambridge University Press, Cambridge

Alerstam, T., Hedenström, A. & Åkesson, S. (2003) Long-distance migration: evolution and determinants. *Oikos,* **103**, 247-260.

Anderson, J.B. & Brower, L.P. (1996). Freeze-protection of overwintering monarch butterflies in Mexico: critical role of the forest as a blanket and an umbrella. *Ecological Entomology*, **21**, 107-116.

Anderson, L.W., Ruzzante, D.E., Walton, M., Berggren, P., Bjørge, A. & Lockyer, C.H. (2001) Conservation genetics of harbour porpoises, Phocoena phocoena, in eastern and central North Atlantic. *Conservation Genetics,* **2,** 309-324.

Andrewartha, H.G. & Birch, L.C. (1954) *The distribution and abundance of animals.* University of Chicago Press, Chicago.

Anisimov, O.A., Shiklomanov, N.I. & Nelson, F.E. (1997) Effects of global warming on permafrost and active layer thickness: results from transient general circulation models. *Global and Planetary Change*, **61,** 61-77.

Archaux, F. (2004) Breeding upwards when climate is becoming warmer: no bird response in the French Alps, *Ibis* **146**,136-144.

Archibald, G.W. & Meine, C.D. (1996) Family Gruidae (Cranes). In: *Handbook of the birds of the world: vol. 3* (eds del Hoyo, J., Elliott A. and Sargatal, J). Pp 60-89. Barcelona: Lynx Edicions.

Arita, H.T. & Ortega, J. (1998) The Middle American Bat Fauna - conservation in the Neotropical-Nearctic border. In *Bat Biology and Conservation* (eds Kunz, T.H. & Racey, P.A.) Pp 295-308. Smithsonian Institution Press, Washington/London. 365pp.

Arkhipkin, A.I., Grzebielec, R., Sirota, A.M., Remeslo, A.V., Polishchuk, I.A. & Middleton, D.A.J. (2004) The influence of seasonal environmental changes on the ontogenetic migrations of the squid Loligo gahi on the Falkland shelf. *Fisheries Oceanography,* **13,** 1-9.

Arlettaz, R., Criste, P., Lugon, A., Perrin, N. & Vogel, P. (2001) Food availability dictates the timing of parturition in insectivorous mouse-eared bats. *Oikos,* **95**, 105-111.

Asher, J., Warren, M., Fox, R., Harding, P., Jeffcoate, G. & Jeffcoate, S. (2001). *The Millennium Atlas of butterflies in Britain and Ireland*. Oxford University Press, Oxford.

Askins, R.A. & Ewert, D.N. (1991) Impact of hurricane Hugo ion bird populations on St. John, United States Virgin Islands. *Biotropica,* **23**, 481-487.

Atienza, J.C., Pinilla, J. & Justribó, J.H. (2001) Migration and conservation of the Aquatic Warbler Acrocephalus palicola in Spain. *Ardeola,* **48**, 197-208.

Atkinson, P.W., Clark, N.A., Bell, M.C., Dare, P.J., Clark, J.A. & Ireland, P.L. (2003) Changes in commercially fished shellfish stocks and shorebird populations in the Wash, England. *Biological Conservation* **114**, 127-141.

Atkinson, P., Frederiksen, M., Pradel, R. & Rehfisch, M.M. (2004). *Towards developing thresholds for waterbirds that take into account turnover. Wetland Bird Survey Project 2003-2005/2.* BTO, Thetford.

Atkinson, P.W., Crooks, S., Drewitt, A., Grant, A., Rehfisch, M.M., Sharpe, J. & Tyas, C. (2004) Managed realignment in the UK - the first five years of colonization by birds. *Ibis*, **(Suppl. 1),** 101-110.

Ausden, M., Rowlands, A., Sutherland, W.J. & James, R. (2003) Diet of breeding Lapwing Vanellus vanellus and Redshank Tringa totanus on coastal grazing marsh and implications for habitat management. *Bird Study*, **50**, 285-293.

Austin, G. & Rehfisch, M.M. (2003) The likely impact of sea level rise on waders (Charadrii) wintering on estuaries. *Journal of Nature Conservation*, **11**, 43-58.

Austin, G. & Rehfisch, M.M. (2005) Shifting non-breeding distributions of migratory fauna in relation to climate change. *Global Change Biology*, **11**, 31-38.

Austin, G., Jackson, S.F. & Mellan, H.J. (2004) WeBS Alerts 2001/2001: *Changes in numbers of wintering waterbirds in the United Kingdom, its Constituent Countries, Species Protected Areas (SPAs) and Sites of Special Scientific Interest (SSSIs)*. BTO Research Report No. 349. BTO, Thetford.

Austin, G.E., Peachel, I. & Rehfisch, M.M. (2000) Regional trends in coastal wintering waders in Britain. *Bird Study,* **47**, 352-371.

Avery, M.I. & Krebs, J.R. (1984) Temperature and foraging success of Great Tits, Parus major, hunting for spiders. *Ibis,* **126**, 33-38.

AWCT - Aquatic Warbler Conservation Team (1999) World population, trends and conservation status of the Aquatic Warbler Acrocephalus paludicola. *Vogelwelt,* **120**, 65-85.

Baillie, S.R., Clark, N.A. & Ogilvie, M.A. (1986) *Cold weather movements of waterfowl and waders: An analysis of ringing recoveries.* BTO Research Report 19. BTO, Thetford.

Baillie, S.R. & Peach, W.J. (1992) Population limitation in Palearctic-African migrant passerines. *Ibis,* **134, Suppl. 1**,120-132.

Baillie, S.R., Marchant, J.H., Crick, H.Q.P., Noble, D.G., Balmer, D.E., Beaven, L.P., Coombes, R.H., Downie, I.S., Freeman, S.N., Joys, A.C., Leech, D.I., Raven, M.J., Robinson, R.A. & Thewlis, R.M. (2005) *Breeding Birds in the Wider Countryside: their conservation status 2004*. BTO Research Report No. 385. BTO, Thetford.

Bairlein, F. & Hüppop (2004) Migratory fuelling and global climate change. *Advances in Ecological Research,* **35,** 33-47.

Bairlein, F. (1991) Seasonal occurrence, body mass and fattening of migratory birds in N. Algeria during autumn migration. *Vogelwarte,* **34,** 237-248.

Bairlein, F. & Winkel, W. (2001) Birds and climate change. In: *Climate of the 21st century: changes and risks* (eds Lozan, J.L., Grassl, H. and Hupfer, P.), pp. 278-282. Hamburg, Germany: Wissenschaftliche Auswertungen.

Baker, A.J., González, P.M., Piersma, T., Niles, L.J., de Lima Serrano do Nascimento, I., Atkinson, P.W., Clark, N.A., Minton, C.D.T., Peck, M.K. & Aarts, G. (2004) Rapid population decline in red knots: fitness consequences of decreased refuelling rates and late arrival in Delaware Bay. *Proceedings of the Royal Society of London B*, **27,** 875-882.

Balmford, A., Moore, J.L., Brooks, T., Burgess, N., Hansen, L.A., Williams, P. & Rahbek, C. (2001) Conservation conflicts across Africa. *Science,* **291,** 2616-2619.

Bannister, J.L. (2002) Baleen whales. In: *Encyclopedia of marine Mammals*. (eds W. F. Perrin, B. Würsig & J. G. M. Thewissen). Pp 62-72, San Diego: Academic Press.

Barber, R.T. & Chavez, F.P. (1983) Biological consequences of El Nino. *Science,* **222**, 1203-1210.

Barber, R.T. & Chavez, F.P. (1986) Ocean variability in relation to living resources during the 1982-1983 El Nino. *Nature,* **319,** 279-285.

Barbour, R.W. & Davis, W.H. (1969) *Bats of America*. University Press of Kentucky, Lexington. 286pp.

Barbraud, C. & Weimerskirch, H. (2001) Emperor penguins and climate change. *Nature,* **411,** 183-186.

Barclay, R.M.R. (1984) Observations on the migration, ecology and behaviour of bats at Delta Marsh, Manitoba. *Canadian Field-Naturalist,* **98,** 331-336.

Barrett, R.T. (2002) The phenology of spring migration to north Norway. *Bird Study,* **49**, 270-277.

Battersby, J. (ed.) Tracking Mammals Partnership (2005) *UK Mammals: Species Status and Population Trends. First report by the Tracking Mammals Partnership*. JNCC/Tracking Mammals Partnership, Peterborough. 116+xxxii pp.

Baudini, C.L., Hyrenbach, K.D., Coyle, K.O., Pinchuk, A., Mendenhall, V. & Hunt Jr., J.R. (2001) Mass mortality of short-tailed shearwaters in the south-eastern Bearing Sea during summer 1997. *Fisheries Oceanography*, **10**, 117-130.

Beare, D.J., Batten, S., Edwards, M., & Reid, D.G. (2002) Prevalence of boreal Atlantic, temperate Atlantic and neritic zooplankton in the North Sea between 1958 and 1998 in relation to temperature, salinity, stratification intensity and Atlantic inflow. *Journal of Sea Research,* **48,** 29-49.

Beare, D., Burns, F., Jones, E., Peach, K., Portilla, E., Greig, T., McKenzie, E. & Reid, D.G. (2004a) An increase in the abundance of anchovies and sardines in the north-western North Sea since 1995. *Global Change Biology,* **10,** 1209-1213.

Beare, D.J., Burns, F., Greig, T., Jones, E.G., Peach, K., Kienzle, M., McKenzie, E. & Reid, D.G. (2004b) Long-term increases in prevalence of North Sea fishes having southern biogeographic affinities. *Marine Ecology Progress* Series, **284,** 269-278.

Beaugrand, G. (2003) Long-term changes in copepod abundance and diversity in the north-east Atlantic in relation to fluctuations in the hydroclimatic environment. *Fisheries Oceanography,* **12,** 270-283.

Beaugrand, G. & Ibanez, F. (2004) Monitoring marine plankton ecosystems. II: long-term changes in North Sea calanoid copepods in relation to hydro-climatic variability. *Marine Ecology Progress, Series,* **284,** 35-47.

Beaugrand, G. & Reid, P.C. (2003) Long-term changes in phytoplankton, zooplankton and salmon related to climate. *Global Change Biology,* **9,** 801-817.

Beaugrand, G., Brander, K.M., Lindley, J.A, Souissi, S. & Reid, P.C. (2003) Plankton effect on cod recruitment in the North Sea. *Nature,* **426,** 661-664.

Beintema, A.J., Dunn, E. & Stroud, D.A. (1997) Birds and wet grasslands. In *Farming and birds in Europe: the Common Agriculture Policy and its implications for bird conservation* (eds Pain, D.J. & Pienkowski, M.W.). Pp 269-296. London: Academic Press.

Bensusan, K.J., Perez, C.E. & Acolina, J.P. (2005). Observations on the dragonflies and damselflies (Insecta: Odonata) of Gibraltar. *Iberis*, **1**, 48-53.

Bennun, L.A. and Njoroge, P. (1999) *Important Bird Areas in Kenya.* Nairobi, Kenya: The East African Natural History Society.

Berger, J. (2004) The last mile: How to sustain long-distance migration in mammals. *Conservation Biology*, **18,** 320-331.

Bergmans, W. (1990) Taxonomy and biogeography of African fruit bats (Mammalia, Megachiroptera). 3. The genera *Scotonycteris* Matschie, 1894, *Casinycteris* Thomas, 1910, *Pteropus* Brisson, 1762, and *Eidolon* Rafinesque, 1815. *Beaufortia,* **40,** 111-177.

Berrow, S.D. & Rogan, E. (1997) Review of Cetaceans Stranded on the Irish Coast, 1901-95. *Mammal Review* **27,** 51-76.

Berrow, S.D., Holmes, B. & Kiely O.R. (1996) Distribution and abundance of Bottle-nose dolphins Tursiops truncatus (montagu) in the Shannon estuary. *Biology and Environment: Proceedings of the Royal Irish Academy*, **96B,** 1-9.

Berry, P.M., Vanhinsberg, D., Viles, H.A., Harrison, P.A., Pearson, R.G., Fuller, R.J., Butt, N. & Miller, F. 2001. Impacts on terrestrial environments. Pp 43-150 in Harrison, P.A., Berry, P.M. & Dawson, T.P. (eds) *Climate change and Nature Conservation in Britain and Ireland: Modelling natural resource responses to climate change (the MONARCH project).* UKCIP Technical report, Oxford.

Berthold, P. & Helbig, A.J. (1992) The genetics of bird migration: stimulus, timing and direction. *Ibis,* **134,** 35-40.

Berthold, P. (1998) *Bird migration: a general survey*. Oxford: Oxford University Press.

Berthold, P. (1990) Patterns of avian migration in light of current global 'greenhouse' effects: a central European perspective. *Acta XX Congressus Internationalis Ornithologici*, Pp 780-786.

Besbeas, P., Freeman, S.N., Morgan, B.J.T. & Catchpole, E.A. (2002) Integrating mark-recapture-recovery and census data to estimate animal abundance and demographic parameters. *Biometrics,* **58,** 540-547.

Beukema, J.J. (2002) Expected changes in the benthic fauna of Wadden Sea tidal flats as a result of sea-level rise or bottom subsidence. *Netherlands Journal of Sea Research*, **47,** 25-39.

BirdLife International (2000) *Threatened birds of the world. Barcelona and Cambridge*, Madrid: Lynx Edicions.

BirdLife International (2004a) *Siberian Crane* Grus leucogeranus *fact sheet*. Available: http://www.birdlife.net/datazone/species/index.html

BirdLife International (2004b) *Birds in Europe: population estimates, trends and conservation status. Cambridge:* BirdLife International.

Bjørge, A. (2002) How persistent are marine mammal habitats in an ocean of variability? In: *Marine mammals: biology and conservation.* (eds P. G. H. Evans and J. A. Raga) Pp 63-91, New York: Kluwer Academic/Plenum Publishers.

Bjørge, A. & Tolley K.A. (2002) Harbour Porpoise. In *Encyclopedia of Marine Mammal*s. (eds Perrin, W.F. Wursig, B. & Thewissen, J.G.M.), Pp 549-551. San Diego: Academic Press.

Bjorndal, K.A., Ed. (1981) *Biology and conservation of sea turtles*. Washington DC: Smithsonian Institution Press.

Blomqvist, S., Holmgren, N., Åkesson, S., Hedenström, A. & Petterson, J. (2002) Indirect effects of lemming cycles on sandpiper dynamics: 50 years of counts from southern Sweden. *Oecologia*, **133,** 146-158.

Boere. G.C. & Taylor, D. (2004) Global and regional governmental policy and treaties as tools towards the mitigation of the effect of climate change on waterbirds. *Ibis,* **146 Suppl. 1,** 111-119.

Boersma, P.D. (1977) Breeding patterns of Galapagos Penguins as an indicator of oceanographic conditions. *Science,* **200,** 1481-1483.

Boersma, P.D. (1998) Population trends of the Galapagos Penguin: impacts of El Nino and La Nina. *The Condor.* **100,** 245-253.

Bogdanowicz, W. (2004) Pipistrellus kuhlii (Kuhl, 1817) - Weissrandfledermaus. in *Handbuch der Säugetiere Europas. Band 4: Fledertiere. Teil II: Chiroptera* II. (ed Krapp F). Pp. 875-908 Aula-Verlag, Wiebelsheim, x + 605-1186.

Borrell, A., Aguilar, A., Corsolini, S. & Focardi, S. (1996) Evaluation of toxicity and sex-related variation of PCB levels in Mediterranean striped dolphins affected by an epizootic. *Chemosphere,* **32,** 2359-2369.

Both, C. & Visser, M.E. (2001) Adjustment to climate change is constrained by arrival date in a long-distance migrant bird. *Nature*, **411,** 296-298.

Both, C., Visser, M.E. & Verboven, N. (1999) Density-dependent recruitment rates in great tits: the importance of being heavier. *Proc. R. Soc. Lond.*, B **266,** 465-469.

Both, C., Artemyev, A.V., Blaauw, B., Cowie, R.J., Dekhijzen, A., Eeva, T., Enemar, A., Gustafsson, L., Ivankina, E.V., Järvinen, A., Metcalfe, N.B., Nyholm, N.E.I., Potti, J., Ravussen, P.A., Sanz, J.J., Silverin, B., Slater, F.M., Sokolov, L.V., Török, J., Winkel, W., Wright, J., Zang, H. & Visser, M.E. (2004) Large-scale geographical variation confirms that climate change causes birds to lay earlier. *Proceedings of the Royal Society of London B*, **271,** 1657-1662.

Botsford, L., Catilla, J.C. & Peterson, C.H. (1997) The management of fisheries and marine ecosystems. *Science,* **277,** 509-515.

Boyd, H. & Piersma, T. (2001) Changing balance between survival and recruitment explains population trends in Red Knots *Calidris canutus islandica* wintering in Britain, 1969-1995. *Ardea*, **89,** 301-317.

Boyd, I.L. (1996) Individual variation in the duration of pregnancy and birth date in Antarctic fur seals: the role of environment, age, and sex of fetus. *Journal of Mammalogy,* **77,** 124-133.

Boyd, I.L. (2002) Antarctic marine mammals. In *Encyclopedia of Marine Mammals*. (eds W. F. Perrin, W.F.,Würsig, B. &. Thewissen, J.G.M. Pp *30-36,* San Diego, Academic Press.

Boyd, I.L., Lockyer, C. & Marsh, H.D (1999) Reproduction in marine mammals. In *Biology of Marine Mammals*. J. E. Reynolds III and S. A. Rommel. Washington, USA, Smithsonian Institute Press: 218-286.

Boyle, P. R., Ed. (1983) *Cephalopod Life Cycles*. London, Academic Press.

Bradbury, R.B., Wilson, J.D., Moorcroft, D., Morris, A.J. & Perkins, A.J. (2003) Habitat and weather are weak correlates of nestling condition and growth rates of four UK farmland passerines. *Ibis,* **145,** 295-306.

Bradley, N.L., Leopold, A.C., Ross, J. & Huffaker, W. (1999) Phenological changes reflect climate changes in Wisconsin. *Proeedings of the National Academy of Sciences USA,* **96,** 9701-9704.

Bradshaw, W.E. & Holzapfel, C.M. (2001) Genetic shifts in photoperiod response correlated with global warming. *Proceedings of the National Academy of Sciences, USA,* **98,** 14509-14511

Briggs, B. & Hossell, J. (1995) The Implications of Global Climate for Biodiversity. *RSPB Conservation Review* No. 9.

Briggs, K.T. & Chu, E.W. (1986) Sooty Shearwaters off California: Distribution, abundance and habitat use. *Condor*, **88,** 355-364.

Briggs, K.T., Tyler, W.G., Lewis, D.B. & Carlson, D.R. (1987) Bird communities at sea of California, 1975-1983. *Studies in Avian Biology*, **11,** 1-74.

Brindley, E., Norris, K., Cook, T., Babbs, S., Brown, C.F., Massey, P., Thompson, R. & Yaxley, R. (1998) The abundance and conservation status of redshank Tringa tetanus nesting on saltmarshes in Great Britain. *Biological Conservation*, **86,** 89-297.

Brink, F.H. van den (1967) *A Field Guide to the Mammals of Britain and Europe*. Collins, London. 221pp.

Britton, P.L. (1978) Seasonality, density and diversity of birds of a papyrus swamp in western Kenya. *Ibis*, **120,** 450-466.

Broderick, A.C., Godley, B.J. & Hay, S.J. (2001) Metabolic heating and the prediction of sex ratios for green turtles (*Chelonia mydas*). *Physiological and Biochemical Zoology,* **74,** (2): 161-170.

Broderick, A.C., Glen, F., Godley, B.J. & Hays, G.C. (2002) *A management plan for the marine turtles of the Ascension Island.* Marine Turtle Research Group.

Brooks, N. (2004) *Drought in the African Sahel: long-term perspectives and future prospects*. Norwich: Tyndall Centre for Climate Change.

Brouwer, A. (1999) *Induction of biotransformation enzymes by polyhalogenated aromatic hydrocarbons (PHAHs): potential impact on animal physiology and health. Chemical Pollutants and Cetaceans.* P. J. H. Reijnders, A. Aguilar and G. P. Donovan. Cambridge, International Whaling Commission. Special Issue 1: 209-221.

Brower, L.P. (1996). Monarch butterfly orientation: missing pieces of a magnificent puzzle. *Journal of Experimental Biology*, **199,** 93-103.

Brown, E.G. & Pierce, G.J. (1998) Monthly variation in the diet of harbour seals in inshore waters along the southeast Shetland (UK) coastline. *Marine Ecology Progress,* Series **167,** 275-289.

Brown, R.D. (2000) Northern Hemisphere snow cover variability and change, 1915-1997. *Journal of Climate*, **13,** 2339-2355.

Buden, D.W. (1985) Additional records of bats from the Bahama Islands. *Caribbean Journal of Science,* **21,** 19-25.

Bumrungsri, S. (2002) *The foraging ecology of the short-nosed fruit bat,* Cynopterus brachyotis *(Muller, 1838), in lowland dry evergreen rain forest, Southeast Thailand.* Unpublished thesis, University of Aberdeen.

Burd, F. 1994. *Sites of Historical Sea Defence Failure. Phase II Study.* Hull: Institute of Estuarine and Coastal Studies.

Burns, J.J. (2002) Arctic marine mammals. In: *Encyclopedia of Marine Mammals*. (eds W. F. Perrin, B. Würsig & J. G. M. Thewissen). Pp 39-45. San Diego: Academic Press.

Burton, J. (1995) *Birds and Climate Change*. Christopher Helm, London.

Buse, A., Drury, S.J., Woodburn, R.J.W. *et al.* (1999) Effects of elevated temperature on multi-species interactions: the case of Pedunculate Oak, Winter Moths and Tits. *Functional Ecology*, **13,** 74-82.

Butler, R., Williams, W.T.D., Warnock, N. & Bishop, M.A. (1997) Wind assistance: a requirement for migration of shorebirds? *Auk*, **114,** 456-466.

Callaghan, T.V., Werkman, B.R. & Crawford, R.M.M. (2002) The tundra-taiga interface and its dynamics: Concepts and applications. *Ambio, Suppl*. Is.: 6-14.

Cameron, G.N. & Scheel, D. (2001) Getting warmer: Effects of global climate change on distribution of rodents in Texas. *Journal of Mammalogy*, **82,** 652-680.

Cannell M.G.R., Palutikof J.P. & Sparks T.H. (1999) *Indicators of Climate Change in the UK.* The Stationery Office, London.

Cannon, R.J.C. (1998). The implications of predicted climate change for insect pests in the UK, with emphasis on non-indigenous species. *Global Change Biology*, **4**, 785-796.

Carboneras, C. (1992) Family Procellaridae (petrels and shearwaters). In *Handbook of the birds of the world: vol. 1 Ostrich to ducks.* (eds del Hoyo, J., Elliott A. and Sargatal, J.) Pp 216-257. Barcelona: Lynx Edicions.

Carnell, R.E. & Senior, C.A. (1998) Changes in mid-latitude variability due to increasing greenhouse gases and sulphate aerosols. *Climate Dynamics*, **14,** 369-383.

Cebrian, D. (1995) The striped dolphin *Stenella coeruleoalba* epizootic in Greece, 1991-1992. *Biological Conservation* **74,** 143-145.

Chamberlain, D.E., Vickery, J.A., Glue, D.E., Robinson, R.A., Conway, G.J., Woodburn, R.J.W. & Cannon, A.R. (2005) Annual and seasonal trends in the use of garden feeders by birds in winter. *Ibis*, **147,** 563-575.

Charif, R.A. & Clark, C.W. (2000) *Acoustic monitoring of large whales off north and west Britain and Ireland: a two-year study, October 1996-September 1998.* JNCC Report No. 313. Joint Nature Conservation Committee.

Clark, J.A. (2002) Common Redshank. In: *The Migration Atlas: Movements of the Birds of Britain and Ireland.* (eds Wernham, C., Toms, M., Marchant, J., Clark, J., Siriwardena, G. & Baillie, S.) Pp 336-339. T & AD Poyser, London.

Clark, J.A. (2004) Ringing recoveries confirm higher wader mortality in severe winters. *Ringing & Migration*, **22,** 43-50.

Clark, J.A., Robinson, R.A., Balmer, D.E., Adams, S.Y., Collier, M.P., Grantham, M.J., Blackburn, J.R. & Griffin, B.M. (2004) Bird ringing in Britain & Ireland 2003. *Ringing & Migration,* **22,** 85-127.

Clark, R.A., Fox, C.J., Viner, D. & Livermore, M. (2003) North Sea cod and climate change - modelling the effects of temperature on population dynamics. *Global Change Biology,* **9,** 1669-1680.

CMS/ScC12/Doc.12. (2004) *Draft proposals for the inclusion of bat species on CMS Appendices*. 37pp.

Cockeron, P.J. & Connor, R.C. (1999) Why do baleen whales migrate? *Marine Mammal Science,* **15(4),** 1228-1245.

Cockrum, E.L. (1969) *Migration in the guano bat,* Tadarida brasiliensis. Miscellaneous Publications 51, University of Kansas Museum of Natural History **51,** 303-336.

Cole, S., Codling, I.D., Parr, W. & Zabel, T. (1999) *Guidelines for managing water quality impacts within UK European marine sites*. UK Marine SAC Project.

Collinson, N. & Sparks, T. (2005) Nature's calendar – 2004 results for the UK phenology network. *British Wildlife,* **16,** 251-256.

Cook, A.S., O'Dowd, B. & Durdin, C.J. (1994) *Breeding redshanks on Essex saltmarshes in 1993*. Royal Society for the Protection of Birds, unpublished report.

Coppack, T. & Both, C. (2003) Predicting life-cycle adaptation of migratory birds to global climate change. *Ardea*, **90,** 369-378.

Coppack, T., Pulido, F. & Berthold, P. (2001) Photoperiodic response to early hatching in a migratory bird species. *Oecologia*, **128,** 181-186.

Coppack, T., Pulido, F., Czisch, M., Auer, D.P. & Berthold, P. (2003) Photoperiodic response may facilitate adaptation to climatic change in long-distance migratory birds. *Proceedings of the Royal Society of London Series B Biological Sciences,* **270 (Suppl.1),** 43-46.

Corbet, G.B. (1978) *The Mammals of the Palaearctic Region - a taxonomic review*. British Museum (Natural History), London.

Cramer, W. (1997) Modelling the possible impact of climate change on broad-scale vegetation structure**,** examples from northern Europe. In: *Global Change and Arctic Terrestrial Ecosystems* (eds Oechel, W.C., Callaghan, T., Gilmanoc, T., Holten, J.I., Maxwell, B., Molau, U. & Sveinbjörnsson, B.), pp312-329. New York: Springer.

Cramp, S & Brooks, D.J. eds. (1992) *The Birds of the Western Palearctic: Handbook of the Birds of Europe, the Middle East, and North Africa*, Vol. 6. Oxford: Oxford University Press.

Cramp, S & Perrins, C.M. eds. (1993) *The Birds of the Western Palearctic: Handbook of the Birds of Europe, the Middle East, and North Africa,* Vol. 7. Oxford: Oxford University Press.

Cramp, S & Simmons, K.E.L. eds. (1980) *The Birds of the Western Palearctic: Handbook of the Birds of Europe, the Middle East, and North Africa*, Vol. 3. Oxford: Oxford University Press.

Crick, H.Q.P. & Sparks, T.H. (1999) Climate change related to egg-laying trends. *Nature,* **399,** 423-424.

Crick, H.Q.P. (2004) The impact of climate change on birds. *Ibis*, **146,** 48-56.

Crick, H.Q.P., Dudley, C., Glue, D.E. & Thomson, D.L. (1997) UK birds are laying eggs earlier. *Nature,* **388,** 526.

Crick, H.Q.P., Robinson, R.A., Appleton, G.F. Clark, N.A. & Rickard, A.D. (eds) (2002) *Investigation into the causes of the decline of starlings and house sparrows in Great Britain*. BTO, Thetford.

Crisman, T.L., Chapman, L.A. & Chapman, C.A. (1996*) Conserving Tropical Wetlands Through Sustainable Use*. *Geotimes*, **July 1996**, 23-25.

Croxall, J.P., Silk, J.R.D., Phillips, R.A., Afanasyev, V., Briggs, D.R. (2005) Global circumnavigations: tracking year-round ranges of nonbreeding albatrosses. *Science,* **307,** 249-250.

Cryan, P. (2004) Chemistry and migration mysteries. *Bats,* **22**(3)**,** 12-13.

da Fonseca, G.A.B., Balmford, A., Bibby, C., Boitani, L., Corsi, F., Brooks, T., Gascon, C., Olivieri, S., Mittermeier, R,A. Burgess, N., Dinerstein, E., Olson, D., Hannah, L., Lovett, J., Moyer, M., Rahbek, C., Stuart, S. & Williams, P. (2000) Following Africa's lead in setting priorities. *Nature*, **405,** 393-394.

Davidson, N. (2002) Red Knot. In: *The Migration Atlas: Movements of the Birds of Britain and Ireland.* (eds Wernham, C., Toms, M., Marchant, J., Clark, J., Siriwardena, G. & Baillie, S.) Pp 293-296. T & AD Poyser, London.

Davies, N.B. & Green, R. (1976) The development and ecological significance of feeding techniques in the Reed warbler (*Acrocaphalus scirpaceus*). *Animal Behaviour*, **24,** 213-229.

Davis, A.J., Lawton, J.H., Shorrocks, B. & Jenkinson, L.S. (1998a) Individualistic species responses invalidate simple physiological models of community dynamics under global environmental change. *Journal of Animal Ecology,* **67,** 600-612.

Davis, A.J., Jenkinson, L.S., Lawton, J.H., Shorrocks, B. & Wood, S. (1998b) Making mistakes when predicting shifts in species range in response to global warming. *Nature* **391,** 783-786.

Davis, R.B., Herred II, C.F. & Short, H.L. (1962) Mexican free-tailed bats in Texas. *Ecological Monographs* **32,** 311-346.

DeFrees, S.L. & Wilson, D.E. (1988) Eidolon helvum. *Mammalian Species* **312,** 1-5.

de Swart, R.L., Ross, P.S., Vedder, L.J., Timmerman, H.H., Heisterkamp, S., Van Loveren, H., Vos, J.G., Reijnders, P.J.H. & Osterhaus, A.D.M.E. (1994) Impairment of immune function in harbour seals (Phoca vitulina) feeding on fish from polluted water. *Ambio* **23,** 155-159.

Degtyarev, A.G. & Labutin, Y.V. (1999) On reproduction of the Siberian crane, Grus leucogeranus (Gruiformes, Gruidae) in Yakutia. *Zoologichesky Zhurnal*, **78,** 1210-1217.

Delany, S. & Scott, D. (2002) *Waterbird Population Estimates*. Third Edition, Wageningen, The Netherlands: Wetlands International Global Series No. 12.

Dennis, M.K. (1993) Wintering Blackcaps and Chiffchaffs in the London Area, *London Bird Report,* ***57*****,** 145-152.

Dennis, M. (2000) Wintering Blackcaps and Chiffchaffs in Essex, *Essex Bird Report, 2001***,** 154-158.

Dietz, A.J., Verhagen, A. & Ruben, R. (2001) *Impact of climate change on drylands with a focus on West Africa*. Wageningen: ICCD.

Domingo, M., Kennedy, S. & Van Bressem, M. (2002) Marine mammal mass mortalities. *Marine mammals: biology and conservation.* (eds P. G. H. Evans & J. A. Raga) Pp 425-456, Kluwer Academic/Plenum Publishers.

Dowdeswell, J., Hagen, J.O., Bjornsson, H., Glazovsky, A., Holmlund, P., Jania, J., Josberger, E., Koerner, R., Ommanney, S. & Thomas, B. (1997) The mass balance of circum Arctic glaciers and recent climate change. *Quaternary Research*, **48,** 1-14.

Drake, V.A. (1994). The influence of weather and climate on agriculturally important insects - an Australian perspective. *Australian Journal of Agricultural Research*, **45**, 487-509.

Drent, R., Both, C., Green, M., Madsen, J. & Piersma, T. (2003) Pay-offs and penalties of competing migratory schedules. *Oikos*, **103,** 274-292.

Drouot, V., Gannier, A. & Goold, J. C. (2004) Summer social distribution of sperm whales (*Physeter macrocephalus*) in the Mediterranean Sea. *Journal of the Marine Biological Association of the United Kingdom,* **84,** 675-680.

Ducrotoy, J. P. (1999) Indications of change in the marine flora of the North Sea in the 1990s. *Marine Pollution Bulletin,* **38,** 646-654.

Dunn, P. (2004) Breeding dates and reproductive performance. *Advances in Ecological Research,* **35,** 69-87.

Durant, J.M., Anker-Nilssen, T. & Stenseth, N.C. (2003) Trophic interactions under climate fluctuations: the Atlantic puffin as an example. *Proc. R. Soc. Lond. B.,* **270,** 1461-1466.

Dyrcz, A. & Zdunek, W. (1993) Breeding ecology of Aquatic Warbler *Acrocephalus paludicola* on the Biebrza marshes, northeast Poland. *Ibis,* **135,** 181-189.

E.E.A. (2004) *Impacts of Europe's changing climate*. European Environment Agency, Copenhagen.

Edwards, M. & Richardson, A. J. (2004) Impact of climate change on marine pelagic phenology and trophic mismatch. *Nature,* **430,** 881-884.

Edwards, M., Beugrand, G., Reid, P.C., Rowden, A.A. & Jones, M.B. (2002) Ocean climate anomalies and the ecology of the North Sea. *Marine Ecology Progress* Series **239,** 1-10.

Edwards, M., Reid, P. & Planque, B. (2001) Long-term and regional variability of phytoplankton biomass in the Northeast Atlantic (1960-1995). *ICES Journal of Marine Science,* **58,** 39-49.

Eeva, T., Veistola, S. & Lehikoinen, E. (2000) Timing of breeding in subarctic passerines in relation to food availability. *Canadian Journal of Zoology*, **78,** 67-78

Eeva, T., Lehikoinen, E., Ronka, M., Lummaa, V. & Currie, D. (2002) Different responses to cold weather in two pied flycatcher populations. *Ecography,* **25,** 705-713.

Elkins, N. (2004) Weather and bird behaviour. Poyser, London.

Epstein, P.R. (2001) West Nile virus and the climate. *Journal of Urban Health,* **78,** 367-371.

Epstein, P.R., Chivian, E. & Frith, K. (2003) Emerging diseases threaten conservation. *Environmental Health Perspectives,* **111A,** 506-507.

Ericsson, G., Ball, J.P. & Danell, K. (2002) Body mass of moose calves along an altitudinal gradient. *Journal of Wildlife Management*, **66,** 91-97.

Erikstad, K.E., Fauchald, P., Tverra, T. & Steen, H. (1998) On the cost of reproduction in long-lived birds: the influence of environmental variability. *Ecology,* **79,** 1781-1788.

Esselink, P. & Zwartz, L. (1989) Seasonal variations in burrow depth and tidal variation in feeding activity of *Nereis diversicolor. Marine Ecoogy. Progress Series,* **56,** 243-254.

Evans, A.D., Smith, K.W., Buckingham, D.L. & Evans, J. (1997) Seasonal variation in breeding performance and nestling diet of Cirl Buntings Emberiza cirlus in England. *Bird Study,* **44,** 66-79.

Evans, P.G.H. (1980) Cetaceans in British Waters. *Mammal Review,* **10,** 1-56.

Evans, P.G.H. (1992) *Status review of Cetaceans in British and Irish waters*. Oxford: Sea Watch Foundation.

Evans, P.G.H. & Hammond, P.S (2004) Monitoring cetaceans in European waters. *Mammal Review,* **34,** 131-156.

Faustino, C., Jennelle, C.S., Connolly, V., Davis, A.K., Swarthout, E.C., Cooch, E.G. & Dhondt, A.A. (2004) *Mycoplasmal gallisepticum* infection dynamics in a House Finch population: empirical analysis of seasonal variation in survival, encounter and transmission rate. *Journal of Animal Ecology,* **73,** 651-669.

Feng, H.Q., Wu, K.M., Cheng, D.F. & Guo, Y.Y. (2004). Northward migration of Helicoverpa armigera (Lepidoptera : Noctuidae) and other moths in early summer observed with radar in northern China. *Journal of Economic Entomology*, **97**, 1874-1883.

Ferguson, S.H., Stirling, I. & McLoughlin, P. (2005) Climate change and ringed seals (Phoca hispida) recruitment in western Hudson Bay. *Marine Mammal Science,* **21,** 121-135.

Ferguson, S.H. & Elkie, P.C. (2004). Seasonal movement patterns of woodland caribou (*Rangifer tarandus caribou*). *Journal of Zoology, London*, **262,** 125-134.

Ferrero, R.C., Hobb, R.C. & Van Blaricom, G.R. (2002) Indications of habitat use patterns among small cetaceans in the central North Pacific based on fisheries observer data. *Journal of Cetacean Research and Management,* **4,** 311-321.

Fiedler, P.C. (2002) Ocean Environment. In: *Encyclopedia of Marine Mammals*. (eds W. F. Perrin, B. Würsig and J. G. M. Thewissen). Pp824-830, San Diego, Academic Press.

Fiedler, P.C., Philbrick, V. & Chavez, F.P. (1991) Oceanic upwelling and productivity in the eastern tropical Pacific. *Limonol. Oceanogr*, **36,** 1834-1850.

Fiedler, W., Bairlein, F. & Köppen, U. (2004) Using large-scale data from ringed birds for the investigation of effects of climate change on migrating birds: pitfalls and prospects. *Advances in Ecological Research,* **35,** 49-68.

Findley, J.S. & Jones, C. (1964) Seasonal distribution of the hoary bat. *Journal of Mammalogy*, **45,** 461-470.

Fleming, T.H. & Eby, P. (2003) Ecology of Bat Migration. in *Bat Ecology*. (Eds Kunz, T.H. & Fenton, M.B.) Pp 156-208. The University of Chicago Press, Chicago & London. 779pp.

Fleming, T.H. & Eby, P. (in press). Ecology of bat migration. (in Kunz, T.H. & Fenton, M.B., *Bat Ecology*, Plenum Press, New York).

Fleming, T.H. & Valiente-Banuet, A. (2002) *Columnar Cacti and Their Mutualists*. University of Arizona Press, Tucson. 371pp.

Forcada, J. (2002) Distribution. *Encyclopedia of Marine Mammals*. W.F. Perrin, B. Würsig and J.G. M. Thewissen. San Diego, Academic Press: 327-333.

Forchhammer, M.C., Clutton-Brock, T.H., Lindstrom, J. & Albon, S.D. (2001) Climate and population density induce long-term cohort variation in a northern ungulate. *Journal of Animal Ecology*, **70,** 721-729.

Forchhammer, M.C., Post, E. & Stenseth, N.C. (2002) North Atlantic Oscillation timing of long- and short-distance migration. *J. Anim. Ecol.*, **71,** 1002-1014.

Forchhammer, M.C., Stenseth, N.C., Post, E. & Langvatn, R. (1998) Population dynamics of Norwegian red deer: Density-dependence and climatic variation. *Proceedings of he Royal Society of London,* Series B, **265,** 341-350.

Forister, M.L. & Shapiro, A.M. (2003). Climatic trends and advancing spring flight of butterflies in lowland California. *Global Change Biology*, **9**, 1130-1135.

Foster, M.S. (1974) Rain, feeding behaviour and clutch size in tropical birds. *Auk,* **91,** 722-726

Franken, R.J. & Hik, D.S. (2004) Interannual variation in timing of parturition and growth of collard pikas (Ochotona collaris) in the southwest Yukon. *Integrative and Comparative Biology*, **44,** 186-193.

Fraser, W. R. & Hofmann, E. E. (2003) A predator's perspective on causal links between climate change, physical forcing and ecosystem response. *Marine Ecology Progress Series,* **265,** 1-15.

Frederiksen, M., Wanless, S., Harris, M.P., Rothery, P. & Wilson, L.J. (2004) The role of industrial fisheries and oceanographic change in the decline of North Sea black-legged kittiwakes. *Journal of Applied Ecology,* **41,** 1129-1139

Frederiksen, M. 2002 *The use of data from bird ringing schemes as indicators of environmental change: a feasibility study.* Report to the European Topic Centre.

FRS (1998) Scottish Ocean Climate Status Report. Fisheries Research Services. Aberdeen.

FRS (2001a) *Cod stocks in the North Sea. Fish stock information leaflet No. 7.* Fisheries Research Services. Aberdeen.

FRS (2001b) *West of Scotland cod stocks. Fish stock information leaflet No. 8*. Fisheries Research Services. Aberdeen.

FRS (2003) *Scottish Ocean Climate Status Report. Fisheries Research Services*. Aberdeen. Report 05/03.

Fryxell, J.M. & Sinclair, A.R.E. (1988) Causes and consequences of migration by large herbivores. *Trends in Ecology and Evolution*, **3,** 237-241.

Fuller, G.B. & Hobson, W.C. (1986) Effects of PCBs on reproduction in mammals. *PCBs and the Environment*. J. S. Waid. Boca Raton, Florida, CRC Press. II: 101-125.

Furness, R.W., Greenwood, J.J.D. & Jarvis, P.J. (1993) Can birds be used to monitor the environment? In: *Birds as monitors of environmental change* (eds Furness, R.W. & Greenwood, J.J.D.) Pp 1-41. London: Chapman & Hall.

Galbraith, H., Jones, R., Park, P., Clough, J., Herrod-Julius, S., Harrington, B. & Page, G. (2002) Global climate change and sea level rise: potential losses of intertidal habitat for shorebirds. *Waterbirds,* **25,** 173-183.

Gannier, A. (2004) The large-scale distribution of humpback whales (Megaptera novaeangliae) wintering in French Polynesia during 1997-2002. *Aquatic Mammals,* **30**(2)**,** 227-236.

Gannon, M.R. & Willig, M.R. (1994) The effects of Hurricane Hugo on bats of the Luquillo Experimental Forest of Puerto Rico. *Biotropica,* **26(3),** 320-331.

Garcia, E.F., Bunsusan, K. & Cortes, J. (in prep.) Phenology and numbers of migrant raptors during the pre-nuptial passage at the Strait of Gibraltar over a 35 year period: a comparison

Gardarsson, A. & Einarsson, A. (1997) XX. *Journal of Animal Ecology,* **66,** 439-451.

Gauthreaux, S.A. Jr. & Belser, C.G. (1999) Bird Migration in the region of the Gulf of Mexico. The Ostrich. Proceedings of the International Ornithological Congress XXII, Durban, South Africa, 16–22 August 1998 In: Adams, N.J. & Slotow, R.H. (eds) Proc. 22 Int. Ornithol. Congr., Durban: 1931-1947. Johannesburg: BirdLife South Africa.

Gaskin, D. E. (1982) *The Ecology of Whales and Dolphins*. London, Heinemann Press.

Gates, S., Gibbons, D.W., Lack, P.C. & Fuller, R.J. (1993) Declining farmland bird species: modelling geographical patterns of abundance in Britain. In: *Large Scale Ecology and Conservation Biology*: (eds Edwards, P.J., May, R.M. & Webb, N.R.) 153-177. Oxford: Blackwell.

Gaudet, J.J (1977) Natural drawdown on Lake Naivasha, Kenya and the formation of papyrus swamps. *Aquatic Botany*, **3,** 1-47.

Gauthreaux, S.A. (2005) Atmospheric trajectories and spring bird migration across the Gulf of Mexico. Presentation to ESF-BIRD Final Conference Migration in the life-history of birds. Institute of Avian Research, Vogelwarte Helgoland, Wilhelmshaven, Germany.

Gazaryan, S.V. (2002) Observations on noctule bats hibernating in tree hollows in Precausasus. *Plecotus et al*., **5,** 28-34.

George, T.L., Fowler, A.C., Knight, R.L. & McEwen, L.C. (1992) XX. *Ecological Applications,* **2,** 274-284.

Geraci, J. R. & Lounsbury, V. (2002) Marine mammal health: holding the balance in an ever changing sea. Marine mammals: biology and conservation. P. G. H. Evans and J. A. Raga. New York, Kluwer Academic/Plenum Publishers: 365-384.

Geraci, J.R. *et al.* (1989) Humpback whales fatally poisoned by dinoflagellate toxin. *Canadian Journal of Fisheries and Aquatic Sciences*, **46** (11)**,** 1895-1898.

Geraci, J.R., Harwood, J. & Lounsbury, V.J. (1999) Marine mammal die-offs. In: *Conservation and Management of Marine Mammals*. (eds J. R. Twiss Jr. and R. R. Reeves) pp 367-395. Smithsonian Institution Press, Washington.

Gibbons, D.W., Reid, J.B. & Chapman, R.A. (1993) *The New Atlas of Breeding Birds in Britain and Ireland: 1988-1991*. T & AD Poyser, London.

Gill, J., Warkinson, A. & Côté, I. (2004) Linking sea level rise, coastal biodiversity and economic activity in Caribbean island states: towards the development of a coastal island simulator. *Tyndall Centre for Climate Change Research. Technical Report 9*.

Gilmartin, W.G. & Forcada, J. (2002) Monk seals. *Encyclopedia of Marine Mammals.* W. F. Perrin, B. Würsig and J. G. M. Thewissen. Academic Press, San Diego 756-759.

Glas, B.P. (1982) Seasonal movements of Mexican free-tailed bats Tadarida brasiliensis mexicana banded in the Great Plains. *The Southwestern Naturalist,* **27**(2)**,** 127-133.

Glen, F. & Mrosovsky, N. (2004) Antigua revisited: the impact of climate change on sand and nest temperature at a hawksbill turtle (*Eretmochelys imbricata*) nesting site. *Global Change Biology* **10,** 2036-2045.

Glen, F., Broderick, A.C., Godley, B.J. & Hays, G.C. (2003) Incubation environment affects phenotype of naturally incubated green turtle hatchlings. *Journal of the Marine Biological Association of the United Kingdom,* **83,** 1183-1186.

Godley, B.J., Broderick, A.C., Glen, F. & Hay, S.J. (2002) Temperature-dependent sex determination of Ascension Island green turtles. *Marine Ecology Progress Series,* **226,** 115-124.

Godley, B.J., Broderick, A.C., Downie, J.R., Glen, F., Houghton, J.D., Kirkwood, I., Reece, S. & Hays, G.C. (2001) Thermal conditions in nests of loggerhead turtles: further evidence suggesting female skewed sex ratios of hatchling production in the Mediterranean. *Journal of Experimental Marine Biology and Ecology,* **263,** 45-63.

Godley, B.J., Broderick, A.C., Campbell, L.M., Ranger, S. & Richardson, P.B. (2004) *An Assessment of the Status and Exploitation of Marine Turtles in the UK Overseas Territories and Wider Caribbean*. Final project report for the Department of Environment, Food and Rural Affairs and the Foreign and Commonwealth Office.

Godley, B.J., Broderick, A.C., Frauenstein, R., Glen, F. & Hays, G.C. (2002a) Reproductive seasonality and sexual dimorphism in green turtles. *Marine Ecology Progress Series,* **226,** 125-133.

Gosler, A., Greenwood, J.J.D. & Perrins, C. (1995) Predation risk and the cost of being fat. *Nature,* **377,** 621-623.

Goss-Custard, J.D., Caldow, R.W.G., Clarke, R.T., Durrell, S.E.A. & Sutherland, W.J. (1995a) Deriving population parameters from individual variations in foraging behaviour. I. Empirical game theory distribution model of oystercatchers *Haematopus ostralegus* feeding on mussels *Mytilus edulis. Journal of Animal Ecology*, **64**, 265-276.

Goss-Custard, J.D., Caldow, R.W.G., Clarke, R.T., & West, A.D. (1995b) Deriving population parameters from individual variations in foraging behaviour. II. Model tests and population parameters. *Journal of Animal Ecology*, **64**, 277-289.

Goss-Custard, J.D. (1970) Dispersion in some overwintering wading birds. In *Social Behaviour in Birds and Mammals* (ed. J.H. Crook). Academic Press, London. pp. 3-35.

Grant, P.R. & Grant, B.R. (2002) Unpredictable Evolution in a 30-Year Study of Darwin's Finches. *Science,* **296,** 707-711

Green, R.E. (1999) Applications of large-scale studies of demographic rates to bird conservation. *Bird Study,* **46,** S279-S288.

Greene, C.H. & Pershing, A.J. (2004) Climate and the conservation biology of North Atlantic right whales: the right whale at the wrong time? *Frontiers in Ecology and Environmental Science,* **2**(1)**,** 29-34.

Gunnarsson, T.G., Gill, J.A., Sigurbjornsson, T. & Sutherland, W.J. (2004) Pair bonds: arrival synchrony in migratory birds. *Nature,* **431,** 646.

Hammond, P.S., Berggren, P., Benke, H., Borchers, D.L., Collet, A., Heide-Jørgensen, M.P., Heimlich, S., Hiby, S., Leopold, M.F. & Oien, N. (2002) Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. *Journal of Applied Ecology,* **39,** 361-376.

Hansen, B., Turrell, W.R. & Østerhus S. (2001) Decreasing overflow from the Nordic seas into the Atlantic Ocean through the Faroe Bank channel since 1950. *Nature,* **411,** 927-930.

Harding, R., Kuhry, P., Christensen, T., Sykes, M.T., Dankers, R. & van der Linden, S. (2002) Climate feedbacks at the tundra-taiga interface. *Ambio,* **12,** 47-55.

Hare, J. (2002) *Camelus bactrianus*. In: IUCN 2004. *2004 IUCN Red List of Threatened Species.* <www.redlist.org>.

Harrison, P.A., Berry, P.M. & Dawson, T,P. (2001) *Modelling natural resource responses to climate change.* Environmental Change Institute, Oxford.

Harrington, R. Woiwod, I.P., & Sparks, T.H. (1999) Climate change and trophic interactions. *Trends Ecol. Evol.,* **14,** 146-150.

Harvell, C.D. *et al.* (1999) Emerging marine diseases - climate links and anthropogenic factors. *Science,* **285**, 1503-1510.

Harvell, C. D., Mitchell, C. E., Ward, J. R., Altizer, S., Dobson, A. P., Ostfeld, R. S. & Samuel, M. D. (2002) Climate warming and disease risks for terrestrial and marine biota. *Science* **296**, 2158-2162.

Harwood, J. (2001) Marine mammals and their environment in the twenty-first century. *Journal of Mammalogy,* **82,** 630-640.

Hays, G.C., Broderick, A.C., Glen, F. & Godley, B.J. (2003) Climate change and sea turtles; a 150-year reconstruction of incubation temperature at a major turtle rookery. *Global Change Biology,* **9,** 642-646.

Hays, G.C., Broderick, A.C., Glen, F. & Godley, B.J., Houghton, J.D.R. & Metcalfe, J.D. (2002) Water temperature and internesting intervals for loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) sea turtles. *Journal of Thermal Biology,* **27,** 429-432.

Heath, M.R., Adams, R.D., Brown, F., Dunn, J., Fraser, S., Hay, S.J., Kelly, M.C., Macdonald, E.M., Robertson, M.R., Robertson, S. & Wilson, C. (1999a) *Plankton monitoring off the east coast of Scotland in 1997 and 1998*. Fisheries Research Services, Aberdeen.

Heath, M.R., Beare, D.J., Dunn, J., Fraser, J.G., Hay, S.J. & Turrell, W.R. (1999b) *Monitoring the effects of climate change - overwintering abundance of* Calanus finmarchicus *in the Faroe-Shetland Channel. Fisheries Research Services Report 14/99*. . Fisheries Research Services, Aberdeen.

Heather, B.D. & Robertson, H.A. (1997) *The field guide to the birds of New Zealand*. Oxford, UK: Oxford University Press.

Hedges, S. (2000) *Bos grunniens*. In: IUCN 2004. *2004 IUCN Red List of Threatened Species.* <www.redlist.org>.

Heide-Jørgensen, M.P. & Laidre, K.L. (2004) Declining extent of open-water refugia for top predators in Baffin Bay and adjacent waters. *Ambio,* **33**(8)**,** 487-494.

Heihsohn, G & Heinsohn, R. (1999) Long-term dynamics of a rodent community in an Australian tropical rainforest. *Wildlife Research*, **26,** 187-198.

Helle, E., Olsson, M. & Jensen, S. (1976) PCB levels correlated with pathological changes in seal uteri. *Ambio,* **5**(4)**,** 261-263.

Heredia, B. (1996) Aquatic Warbler. In: *Globally threatened birds in Europe: action plans*. (eds Heredia, B., Rose, L. & Painter, M. Strasbourg: Council of Europe.

Hernández, M., Robinson, I., Aguilar, A., González, L.M., López-Jurado, L.F., Reyero, M.I., Cacho, E., Franco, J., López-Rodas, V. & Costas, E. (1998) Did algal toxins cause monk seal mortality? *Nature,* **393,** 28.

Hickling, R., Roy, D.B., Hill, J.K & Thomas, C.D. (2005). A northward shift of range margins in British Odonata. *Global Change Biology*, **11**, 502-506.

Hill, J.K., Thomas, C.D. & Huntley, B. (1999). Climate and habitat availability determine 20th century changes in a butterfly's range margin. *Proceedings of the Royal Society of London B*, **266**, 1197-1206.

Hilton-Taylor, C. (Compiler) (2000) *2000 IUCN Red List of Threatened Species*. IUCN, Gland, Switzerland and Cambridge, UK. Xviii+61pp.

Hochachka, W.M. & Dhondt, A.A. (2000) Density-dependent decline of host abundance resulting from a new infectious disease. *Proceedings of the National Academy of Sciences*, **97**, 5503-5506.

Hoffman, D., Rattner, B.A., Scheunert, I. & Korte, F. (2001) Environmental Contaminants. In: *Ecotoxicology of Wild Mammals*. (Eds R. F. Shore and B. A. Rattner) pp 1-48. John Wiley & Sons Ltd, Chichester.

Holmgren, N., Jönsson, P. & Wennerberg, L. (2001) Geographical variation in the timing of breeding and moult in dunlin Calidris alpina on the Palearctic tundra. *Polar Biology,* **24,** 369-377.

Hope-Jones, P. (2002) Pied Flycatcher. In: *The Migration Atlas: Movements of the Birds of Britain and Ireland*. (Eds Wernham, C., Toms, M., Marchant, J., Clark, J., Siriwardena, G. & Baillie, S.) Pp 584-586. T & AD Poyser, London.

Hope-Jones, P., Mead, C.J. & Durman, R.F. (1977) The migration of the Pied Flycatcher from and through Britain. *Bird Study*, **24,** 2-14.

Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, M. & Johnson, C.A., eds. (2001) *Climate Change 2001: The Scientific Basis*.: Cambridge University Press, Cambridge, UK.

Hubalek, Z. (2003) Spring migration of birds in relation to North Atlantic Oscillation. *Folia Zool*, **52,** 287-298.

Hucke-Gaete, R. ed. (2000) Review of the conservation status of small cetaceans in southern South America. UNEP/CMS Secretariat. Bonn, Germany. Hughes, L. 2003. Climate change and Australia: Trends, projections and impacts. *Austral Ecology,* **28,** 423-443.

Hulme, M., Doherty, R.M., Ngara, T., New, M.G. & Lister, D. (2001) African climate change: 1900-2100. *Climate Research*, **17,**145-168.

Hulme, M., Jenkins, G.J., Lu, X., Turnpenny, J.R., Mitchell, T.D., Jones, R.G., Lowe, J., Murphy, J.M., Hassell, D., Boorman, P., McDonald, R. & Hill, S. (2002) *Climate change scenarios fro the United Kingdom: the UKCIP02 scientific report*. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia. Norwich, UK.

Huntley, B. (1991) How plants respond to climate change: migration rates, individualism and the consequences for plant communities. *Annals of Botany*, **67** (Suppl. 1), 15–22.

Huppop, O. & Huppop, K. (2003) North Atlantic Oscillation and timing of spring migration in birds. *Proc R. Soc Zool. Lond*., B **270** (1512)**,** 233-240.

Hutson, A.M. (1999) *Transboundary movements and the conservation of bats in Europe*. Pp. 51-58, *in* UNEP/CMS (ed) *Proceedings of the CMS Symposium on Animal Migration (Gland , Switzerland, 13 April 1997)*. CMS Technical Series Publication No. 2, Bonn/The Hague. 106pp.

Hutson, A.M., Mickleburgh, S.P. & Racey, P.A. (2001) Microchiropteran Bats - global status survey and conservation action plan. IUCN, Gland.

Hyrenbach, K.D. & Veit, R.R. (2003) Ocean warming and seabird communities of the southern California Current System (1987-98): response at multiple temporal scales. *Deep-Sea Research II*, **50,** 2537-2565.

ICES (1998) *Report of the working group on biological effects of contaminants*. International Council for the Exploration of the Sea. Quebec, Canada. ICES CM 1998/E:3.

ICES (2004) *The Annual ICES Ocean Climate Status Summary 2003/2004.* ICES Cooperative Research Report, No. 269. 32.

Ilyin, V.Y. (2000) Dynamics of the ranges of three bat species in south-easternmost Europe. *Plecotus et al.*, **3,** 43-49.

Inouye, D.W., Barr, B., Armitage, K.B. & Inouye, B.D. (2000) Climate change is affecting altitudinal migrants and hibernating species. *Proc. Natl Acad. Sci. USA,* **97,** 1630-1633.

Insley, H., Peach, W., Swann, B. & Etheridge, B. (1997) Survival rates of redshank Tringa totanus wintering on the Moray Firth. *Bird Study,* **44,** 277-289.

IPCC (2001a) *Climate Change 2001: impacts, adaptation and vulnerability*. Cambridge University Press, Cambridge.

IPCC (2001b) *Climate Change 2001: the scientific basis*. Cambridge University Press, Cambridge.

IUCN (2001) *IUCN Red List Categories and Criteria: Version 3.1*. IUCN Species Survival Commission, IUCN, Gland, Switzerland, and Cambridge, UK. 30pp.

IUCN (2004) *IUCN Red List of Threatened Species*. < http://www.iucnredlist.org>. Downloaded on 10th March 2004.

IUCN (2004) Red list of threatened species. www.redlist.org.

IWC (1997) *Report of the IWC workshop on climate change and cetaceans*. Report of the International Whaling Commission. Cambridge. **47,** 293-313.

Jackson, S.T. & Overpeck, J.T. (2000) Responses of plant populations and communities to environmental changes of the late Quaternary. *Paleobiology*, **26** (4 Supplement)**,** 194-220.

Jarvinen, A. & Vaisanen, R.A. (1983) Egg size and reproductive traits in a southern passerine Ficedula hypoleuca breeding in an extreme northern environment. *Ornis Scand.,* **14,** 253-262.

Jarvinen, A. (1989a) Patterns and causes of long-term variation in reproductive traits of the Pied Flycatcher Ficedula hypoleuca in Finnish Lapland. *Orn. Fenn*., **66,** 24-31.

Jarvinen, A. (1989b) Clutch size variation in the Pied Flycatcher Ficedula hypoleuca. *Ibis,* **131,** 572-577.

Jarvinen A (1996) Correlation between egg size and clutch size in the Pied Flycatcher *Ficedula hypoleuca* in cold and warm summers. Ibis, **138**, 620-623.

Jenni, L. & Kery, M. (2003) Timing of autumn bird migration under climate change: advances in long-distance migrants and delays in short-distance migrants. *Proc R. Soc. Lond. B*., **270,** 1467-1471.

Jenouvrier, S. Barbraud, C. & Weimerskirch, H. (2003) Effects of climate variability on the temporal population dynamics of southern fulmars. *J. Anim. Ecol*., **72,** 576-587.

Jepson, P.D., Bennett, P.M., Allchin, C.R., Law, R.J., Kuiken, T., Baker, J.R., Rogan, E. & Kirkwood, J.K. (1999) Investigating potential associations between chronic exposure to polychlorinated biphenyls and infectious disease mortality in harbour porpoises from England and Wales. *The Science of the Total Environment,* **243/244,** 339-348.

Johns, T.C., Ingram, W.J., Johnson, C.E., Jones, A., Mitchell, J.F.B., Roberst, D.L., Sexton, D.M.H., Stevenson, D.S., Tett, S.F.B. & Woodage, M.J. (2001) *Anthropogenic climate change for 1860 to 2100 simulated with the HadCM3 model under updated emissions scenarios*. Hadley Centre, Exeter.

Jones, G. (1987) Selection against large size in the Sand Martin Riparia riparia during a dramatic population crash. *Ibis,* **129,** 274-280.

Jones, K.E., Barlow, K.E., Vaughan, N., Rodrigues-Duran, A. & Gannon, M. (2001) Short-term impacts of extreme environmental disturbance on the bats of Puerto Rico. *Animal Conservation,* **4,** 59-66.

Jones, M.L. & Swartz, S.L. (2002) Gray whale. In: *Encyclopedia of Marine Mammals*. (Eds W. F. Perrin, W.F., Würsig, B. & Thewissen, J.G.M.) pp 524-536. Academic Press, San Diego,

Kanai, Y., Nagendran, M., Ueta, M., Markin, Y., Rinne, J., Sorokin, A.G., Higuchi, H. & Archibald, G.W. (2002a) Discovery of breeding grounds of a Siberian Crane Grus leucogeranus flock that winters in Iran, via satellite telemetry. *Bird Conservation International,* **12,** 327-333.

Kanai, Y., Ueta, M., Germogenov, N., Nagendran, M., Mita, N. & Higuchi, H. (2002b) Migration routes and important resting areas of Siberian cranes (*Grus leucogeranus*) between northeastern Siberia and China as revealed by satellite tracking. *Biological Conservation*, **106,** 339-346.

Karl, T. R., Diaz, H.F., and Kukla, G., (1988) Urbanization: Its detection and effect in the United States climate record. *J. Climate*, **1**, 1099-1123.

Kasamatsu, F. & Joyce, G.G. (1995) Current status of odontocetes in the Antarctic. *Antarctic Science,* **7**(4)**,** 365-379.

Kaschner, K. (2004) *Modelling and mapping resource overlap between marine mammals and fisheries on a global scale*. Alber-Lubwigs-Universitat. Freiburg, Germany. PhD.

Kawakami, T. (1980) *A review of sperm whale food. Scientific Report of the Whales* Research Institute of Tokyo **32,** 155-197.

Kennedy, S. (1996) Infectious diseases of cetacean populations. The Conservation of Whales and Dolphins. (Eds M. P. Simmonds and J. D. Hutchinson). 333-353. John Wiley & Sons, Chichester,

Kennedy, S. (1999) Morbilliviral infections in marine mammals. Chemical Pollutants and Cetaceans. Reijnders, P.J.H. Aguilar, A. & Donovan, G.P. Cambridge, International Whaling Commission. Special Issue 1: 267-273.

Kennedy, S., Kuiken, T., Ross, H.M., McAliskey, M., Moffett, D., McNiven, C.M. & Carole, M. (1992) Morbillivirus infection in two common porpoises (*Phocoena phocoena*) from the coasts of England and Scotland. *Vet. Record,* **131,** 286-290.

Kimerle, A.A., & Anderson, N.H. (1971) Production and bioenergetic role of the midge *Qlyptotendipes barbipes* (Staeger) in a waste stabilization lagoon. *Limnol. Oceanogr.*, **16**, 646-659.

Kinnison, M.T. & Hendry, A.P. (2001) The pace of modern life II: from rates of contemporary microevolution to pattern and process *Genetica,* 112-113**,** 145-164.

Kinzelbach, R., Nicolai, B. & Schlenker, R. (1997) Der Bienenfresser Merops apiaster als Klimazeiger: Zum Einflug in Bayern, der Schweiz und Baden im Jahr 1644. *J. Ornithol.*, **138,** 297-308.

Kitaysky, A.S. & Golubova, E.G. (2000) Climate change causes contrasting trends in reproductive performance of planktivorous and piscivorous alcids. *J. Anim. Ecol.,* **69,** 248-262.

Klinowska, M. (1991) *Dolphins, porpoises and whales of the world.* The IUCN Red Data Book. Gland, Switzerland, IUCN.

Knippertz, P., Ulbrich, U. & Speth, P. (2000) Changing cyclones and surface wind speeds over the North Atlantic and Europe in a transient GHG experiment. *Climate Research*, **15,** 109-122.

Kokko, H. (1999) Competition for early arrival in migratory birds. *Journal of Animal Ecology,* **68,** 940–950.

Konvicka, M., Maradova, M., Benes, J., Fric, Z. & Kepka, P. (2003). Uphill shifts in the distribution of butterflies in the Czech Republic: effects of changing climate detected on a regional scale. *Global Ecology and Biogeography*, **12**, 403-410.

Kozulin, A., Vergeichik, L. & Stepanovich, Y. (2004) Factors affecting fluctuations of the Aquatic Warbler Acrocephalus paludicola population of Byelarussian mires. *Acta Ornithologica*, **39,** 35-44.

Krabill, W., Abdalati, W., Frederick, E., Manizade, S., Martin, C., Sonntag, J., Swift, R., Thomas, R., Wright, W. & Jungel, J. (2000) Greenland ice sheet: high elevation-balance and peripheral thinning. *Science*, **289,** 428-430.

Krabill, W., Frederick, E., Manizade, S., Martin, C., Sonntag, J., Swift, R., Thomas, R., Wright, W. & Jungel, J. (1999) Rapid thinning of parts of the southern Greenland ice sheet. *Science*, **283,** 1522-1524.

Krapp, F. (ed.) (2001) *Handbuch der Saugetiere Europas*, Band 4: Fledertiere, Tiel I: Chiroptera 1: Rhinolophidae, Vespertilionidae I. AULA-Verlag, Wiebelsheim. Pp. 1-603.

Krapp, F. (ed.) (2004) *Handbuch der Saugetiere Europas*, Band 4: Fledertiere, Tiel II: Chiroptera II: Vespertilionidae 2, Molossidae, Nycteridae. AULA-Verlag, Wiebelsheim. Pp. 605-1186.

Kruk, M., Noordervliet, M.A.W., & ter Keurs, W.J. (1996) Hatching dates of waders and mowing dates in intensively exploited grassland areas in different years. *Biological Conservation*, **77,** 213:218.

Kuehl, D.W., Haebler, R. & Potter, C. (1991) Chemical Residues in Dolphins From the United-States Atlantic Coast Including Atlantic Bottle-Nosed Obtained During the 1987/88 Mass Mortality. *Chemosphere,* **22,** (11)**,** 1071-1084.

Kuehl, D.W., Haebler, R. & Potter, C. (1994) Coplananr PCB and metal residues in dolphins from the United States Atlantic coast including Atlantic bottlenose obtained during the 1987/88 mass mortality. *Chemosphere,* **28,** 1245-1253.

Kuiken, T., Bennett, M.E., Allchin, C.R., Kirkwood, J.K., Baker, J., Lockyer, C., Walton, M. & Sheldrick, M.C. (1994) PCBs, cause of death and body condition in harbour porpoises (Phocoena phocoena) from British waters. *Aquatic Toxicology,* **28,** 13-28.

Lack, D. (1954) *The Natural Regulation of Animal Numbers*. Oxford University Press, Oxford.

Lafferty, K.D., Porter, J.W. & Ford, S.E. (2004) Are diseases increasing in the ocean? *Annu. Rev. Ecol. Syst.,* **35,** 31-54.

Laidre, K.L. & Heide-Jørgensen, M.P. (2005) Arctic sea ice trends and narwhal vulnerability. *Biological Conservation,* **121,** 509-517.

Laidre, K.L., Heide-Jørgensen, M.P., Logdson, M.L., Hobbs, R.C., Heagerty, P., Dietz, R., Jørgensen, O.A. & Treble, M.A. (2004). Seasonal narwhal habitat associations in the high Arctic. *Marine Biology,* **145,** 821-831.

LaVal, R.K. & LaVal, M.L. (1979) Notes on reproduction, behaviour, and abundance of the red bat, *Lasiurus borealis*. J*ournal of Mammalogy,* **60,** 209-212

LaVal, R.K. (1973) Observations on the biology of Tadarida brasiliensis cyanocephala of southeastern Louisiana. *American Midland Naturalist,* **89,** 112-120.

LaVal, R.K. (2004) Impact of global warming and locally changing climate on tropical cloud forest bats. *Journal of Mammalogy,* **85,** 237-244

Lawrence, A.J. & Soame, J.M. (2004) Effects of climate change on the reproduction of coastal invertebrates. *Ibis,* **146,** *S29-S39.*

Learmonth, J.A. (2001) *Environmental contaminants in the Moray Firth cSAC: A summary of information on the impacts/potential impacts on bottlenose dolphins and proxy species*. Moray Firth Partnership.

LeDuc, R. (2002) Biogeography. *Encyclopedia of Marine Mammals*. (Eds Perrin, W.F.B., Würsig, W.F. & Thewissen, J.G.M). pp 99-103. Academic Press, San Diego.

Leech, D.I., & Crick, H.Q.P. (in prep.*) Influence of weather variables on the productivity of single-brooded bird species in Britain.* BTO, Thetford.

Leech, D.I., Crick, H.Q.P. & Rehfisch, M.M. (2004) *The effect of climate change on bird species in the UK.* BTO Research Report No. 369. BTO, Thetford.

Lehikoinen, E., Sparks, R.H. & Zalakevicius, M. (2004) Arrival and departure dates. *Advances in Biolgical Research,* **35,** 1-32.

Lens, L. & Dhondt, A.A. (1992) The effect of a severe storm on a population of Crested Tits *Parus cristatus* in Belgium. *Bird Study,* **39,** 31-33.

Levey, D.J., Bolker, B.M., Tewksbury, J.M., Sargent, S. & Haddad, N.M. (2005) Effects of landscape corridors on seed dispersal by birds. *Science*, **209**, 146-148.

Levitus, S., Antonov, J.I., Boyer, T.P. & Stephens, C. (2000) Warming of the world ocean. *Science,* **287,** 2225-2229.

Limpens, H.J.G.A., Lina, P.H.C. & Hutson, A.M. (2000) *Action Plan for the Conservation of the Pond Bat in Europe (*Myotis dasycneme*)*. Council of Europe Publishing, Nature and Environment, No. 108. 50pp.

Lindblade, K., Carswell., G. & Tumahairwe, J. (1998) Mitigating the relationship between population growth and land degradation. Land-use change and farm management in Southwestern Uganda. *Ambio*, **27,** 565-571

Lindström, Å. and Agrell, J. (1999) Global change and the possible effects on the migration and reproduction of arctic-breeding waders. *Ecological Bulletin*, **47,** 145-159.

Lockyer, C.H. (1981) Estimates of growth and energy budget for the sperm whale, *Physeter catodon*. *FAO Fisheries Series,* **5** III**,** 489-504.

Loxton, R.G. & Sparks, T.H. (1997) *Spring arrival dates of migrant birds at Portland, Dungeness, Bardsey and Calf of Man observatories.* Report prepared for meeting between BTO and BOC at Thetford, 15/12/97.

Lundberg, A. & Alatalo, R.V. (1992) *The pied flycatcher*. T & AD Poyser, London.

MacKenzie, D. (2002) Arctic Meltdown. There will be anarchy as northern seas open up to shipping. *New Scientist*, **2** March**,** 5.

Maclean, I.M.D. (2004) *An ecological and socio-economic analyses of biodiversity conservation of East African wetlands.* PhD Thesis, Norwich, UK: University of East Anglia.

MacLeod, C. D., Bannon, S. M., Pierce, G. J., Schweder, C. S., Learmonth, J. A., Herman, J. S. & Reid, R. J. (2005) Climate change and the cetacean community of north-west Scotland. *Biological Conservation* **124**, 477-483.

MacLeod, K., Simmonds, M.P. & Murray, E. (2003) Summer distribution and relative abundance of cetacean populations off north-west Scotland. *Journal of the Marine Biological Association of the United Kingdom,* **83,** 1187-1192.

Macleod, K., Fairbairns, R.S., Gill, A., Fairbairns, B., Gordon, J., Blair-Myers, C. & Parsons, E.C.M. (2004) Seasonal distribution of minke whales Balaenoptera acutorostrata in relation to physiography and prey off the Isle of Mull, Scotland. *Marine Ecology Progress Series,* **277,** 263-274.

Magris, L. (2003) *The Jersey Bat Survey*. Environment and Public Services Committee, Jersey. 37pp.

Mann, J., Connor, R.C., Tyack, P.L. & Whitehead, H. Eds. (2000) *Cetacean societies: field studies of dolphins and whales*. The University of Chicago Press, Chicago.

Manzanilla, S.R. (1989) The 1982-1983 El Nino event recorded in dentinal growth layers in teeth of Peruvian dusky dolphins (Lagenorhynchus obscurus). *Canadian Journal of Zoology,* **67,** 2120-2125.

Marchant, J.H. & Wernham, C.V. (2003) *Phenology of autumn passage of Willow Warblers at Dungeness, 1960-2000*. BTO Research Report No. 323. BTO, Thetford.

Marchant, J.H. (1992) Recent trends in breeding populations of some common trans-Saharan migrant birds in northern Europe. *Ibis,* **134,** Suppl. 1**,** S113-S119.

Marchant, S. & Higgins, P.J., eds (1990) *Handbook of Australian, New Zealand and Antarctic birds, vol. 1.* Oxford University Press, Melbourne.

Marchant, S. & Higgins, P.J., eds (1993) *Handbook of Australian, New Zealand and Antarctic birds, vol. 2.* Oxford University Press, Melbourne.

Marsh, A.C.W., Poulton, S. & Harris, S. (2001) The yellow-necked mouse *Apodemus flavicollis* in Britain: Status and analysis of factors affecting distribution. *Mammal Review*, **31,** 203-227.

Masson, D. (1998) Atlas des Chiropteres de France Metropolitaine. Societe Francaise pour l'Etude et la Protection des Mammiferes, *Bulletin de Liaison,* **36,** 23-26.

McCarthy, J., Canziani, O.F., Leary, N.A., Dokken, D.J. & White, K.S. (2001) *Climate Change 2001: Impacts, Adaptation, and Vulnerability.* Cambridge University Press, Cambridge, UK.

McCleery, R.H., & Perrins C.M. (1998) Temperature and egg laying trends. *Nature,* **391,** 30 31.

McCracken, G.F. & Gassell, M.F. (1997) Genetic structure of migratory and non-migratory populations of Brazilian free-tailed bats. *J.Mamm.*, **78,** 349-

McCracken, G.F., McCracken, M.K. & Vawter, A.T. (1994) Genetic structure in migratory populations of the bat Tadarida brasiliensis mexicana. *J. Mamm.*, **75,** 500-514.

McGowan, J.A., Cayan, D.R. & Dorman, L.M. (1998) Climate-ocean variability and ecosystem response in the northeastern Pacific. *Science*, **281,** 210-217.

McWilliams, J.P. (2003) *Implications of climate change for biodiversity in the United Kingdom Overseas Territories*. Joint Nature Conservation Committee, Peterborough.

Meadows, M.E. & Hoffman, T.M. (2003) Land degradation and climate change in South Africa. *Geographical Journal,* **169,** 168-177.

Meine, C.D. & Archibald, G.W. (1996) *The Cranes*. Gland, Switzerland: IUCN.

Mickleburgh, S.P., Hutson, A.M. & Racey, P.A. (1992) *Old World Fruit Bats - An Action Plan for their Conservation*. IUCN, Gland. 252pp.

Mitchell, J.F.B., Johns, T.C., Gregory, J.M. & Tett, S.F.B. (1995) Climate response to increasing levels of greenhouse gases and sulphate aerosols. *Nature*, **376,** 501-504.

Mitchell, T.D., Carter, T.R., Jones, P.D., Hulme, M. & New, M. 2004. *A comprehensive set of high resolution grids of monthly climate for Europe and the Globe.* Tyndall Centre for Climate Change Research, Norwich.

Moehlman, P. & Feh, C. (2002) *Equus hemionus*. In: IUCN 2004. *2004 IUCN Red List of Threatened Species.* <www.redlist.org>.

Moline, M.A., Claustre, H., Frazer, T.K., Schofields, O. & Vernet, M. (2004) Alterations of the food web along the Antarctic Peninsula in response to a regional warming trend. *Global Change Biology,* **10,** 1973-1980.

Møller, A.P. & Merilä, J. (2004) Analysis and interpretation of long-term studies investigating responses to climate change. *Advances in Ecological Research,* **35,**111-129.

Møller, A.P. (2004) Ecological conditions during winter affect sexual selection and breeding in a migratory bird. *Proceedings of the Royal Society, Series B,* **271,** 681-686.

Moore, M.J., Berrow, S.D., Jensen, J., Carr, P., Sears, R., Rowntree, V.J., Payne, R. & Hamilton, P.K. (1999) Relative abundance of large whales around South Georgia (1979-1998) *Marine Mammal Science,* **15**(4) **,** 1287-1302.

Morgan, G.S. (1989) Fossil Chiroptera and Rodentia from the Bahamas, and the historical biogeography of the Bahamian mammal fauna. In: *Biogeography of the West Indies; past, present, and future.* (Ed C.A.Wood). Pp. 685-740, Sandhill Crane Press Inc., Gainesville.

Mormann, B., Milam, M. & Robbins, L. (2004) Hibernation: red bats do it in the dirt. *Bats* **22**(2)**,** 6-9

Morse, D.H. (1989) *American Warblers*. Harvard University Press, Cambridge, Massachusetts.

Moss, R., Oswald, J. & Baines, D. (2001) Climate change and breeding success: decline of the capercaillie in Scotland. *J. Anim. Ecol.,* **70,** 47-61.

Moss, S. (1995) *Birds and Weather*: A Birdwatcher's Guide. Hamlyn, London.

Muriuki, J.N., de Klerk, H.M., Williams, P.H., Bennun, L.A., Crowe, T.M. & vanden Berge, E. (1997) Using patterns of distribution and diversity of Kenyan birds to select and prioritize areas for conservation. *Biodiversity and Conservation*, **5,** 191-210.

Murray, M.G. (1995) Specific nutrient requirements and migration in wildebeest. In Serengeti II. Sinclair, A.R.E. and Arcese, P. (eds). Chicago University Press, Chicago, USA. Pages 231-256.

Musgrove, A.J. (2002) The non-breeding status of the Little Egret in Britain. *Brit. Birds,* **95,** 62-80.

Nager, R.S. & Zandt, H.S. (1994) Variation in egg size in Great Tits. *Ardea,* **82,** 315-328.

Nakicenovic, N. *et al.* (2000) *Special Report on Emissions Scenarios.* Cambridge University Press, Cambridge.

Nebel, S., Piersma, T., van Gils, J., Dekinga, A. & Spaans, B. (2000) Length of stopover, fuel storage and a sex-bias in the occurrence of Red Knots *Calidris c. canutus* and *C. c. islandica* in the Wadden Sea during southward migration. *Ardea*, **88,** 165-176.

Newton, I. (1998) *Population limitation in birds*. Academic Press, London.

Nicholson, M.C., Bowter, R.T. & Kie, J.G. (1997) Habitat selection and survival of mule deer: Tradeoffs associated with migration. *Journal of Mammalogy*, **78,** 483-504.

Nieminen, M., Leskinen, M. & Helenius, J. (2000). Doppler radar detection of exceptional mass-migration of aphids into Finland. *International Journal of Biometeorology*, **44**, 172-181.

Norris, K. & Atkinson, P.W. 2000. Declining coastal bird populations in Great Britain: victims of climate change and sea-level rise? *Environmental Reviews,* **8**, 303–323.

Norris, K. & Buisson, R. (1994) *Sea-level rise and its impact upon coastal birds in the UK*. RSPB Conservation Review 8**,** 63-71.

Norris, K. & Pain, D., eds. (2002*) Conserving Bird Biodiversity, general Principles and their Application*. Cambridge, UK: Cambridge University Press.

Norris, K., Atkinson, P.W. & Gill, J.A. (2004) Climate change and coastal waterbird populations. *Ibis*, (**146**, suppl. 1)**,** 82-89.

Norriss, D.W. (1995) The 1991 survey and weather impacts on the Peregrine (Falco peregrinus) breeding population in the Republic of Ireland. *Bird Study,* **42,** 20-30.

Northridge, S.P., Tasker, M.L., Webb, A. & Williams, J.M. (1995) Distribution and relative abundance of harbour porpoises (Phocoena phocoene L.), white-beaked dolphins (Lagenorhynchus albirostris Gray) and minke whales (Balaenoptera acutorostrata Lacepede) around the British Isles. *ICES Journal of Marine Science,* **52,** 55-66.

Nott, M.P. DeSante, D.F., Siegel, R.B. & Pyle, P. (2002) Influences of the El Niño/Southern Oscillation and the North Atlantic Oscillation on avian productivity in forests of the Pacific Northwest of North America. *Global Ecology and Biogeography,* **11,** 333-342.

Nowak, R.M. (1994) *Walker's Bats of the World.* John Hopkins University Press, Baltimore and London. 287pp.

Oberhauser, K. & Peterson, A.T. (2003) Modeling current and future potential wintering distributions of eastern North American monarch butterflies. *Proc. Natl. Acad. Sci.*, **100**, 14063-14068.

O'Brien, C.M., Fox, C.J., Planque, B. & Casey, J. (2000) Climate variability and North Sea cod. *Nature,* **404,** (142).

O'Connor, R.J. & Morgan, R.A. (1982) Some effects of weather conditions on the breeding of the Spotted Flycatcher Muscicapa striata in Britain. *Bird Study,* **29,** 41-48.

Ogi, H., Yatsu, A., Hatanaka, H. & Nitta, A. (1993) The mortality of seabirds by driftnet fisheries in the North Pacific. *International North Pacific Fisheries Commission Bulletin*, **53,** 499-518.

O'Shea, T.J., Reeves, R.R. & Long, A.K.E. (1998) *Marine Mammals and Persistent Ocean Contaminants*. Marine Mammal Commission Workshop, Keystone, Colorado, Marine Mammal Commission.

Osterkamp, T.E. & Romanovsky, V.E. (1999) Evidence for warming and thawing of discontinuous permafrost in Alaska. *Permafrost and Periglacial Processes*, **10,** 17-37.

Pain, D.J., Green, R.E., Gießing, B., Kozulin, A., Poluda, A., Ottosson, U., Flade, M. & Hilton, G.M. (2004) Using stable isotopes to investigate migratory connectivity of the globally threatened Aquatic Warbler Acrocephalus paludicola. *Oecologia*, **138,** 168-174.

Panek, M. (1992) The effect of environmental-factors on survival of Gray Partridge (Perdix perdix) chicks in Poland during 1987-89. *J. Appl. Ecol.*, **29,** 745-750.

Parmesan (1996) Climate and species range. *Nature,* **382,** 765-766

Parmesan, C. & Galbraith, H. (2004) Observed impacts of global climate change in the U.S. Pew Center on Global Climate Change, Arlington, VA.

Parmesan, C. & Yohe, G. (2003) A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, **421,** 37-42.

Parmesan, C., Ryrholm, N., Stefanescu, C., Hill, J.K., Thomas, C.D., Descimon, H., Huntley, B., Kaila, L., Kullberg, J., Tammaru, T., Tennent, W.J., Thomas, J.A. & Warren, M. (1999) Poleward shifts in geographical ranges of butterfly species associated with regional warming. *Nature,* **399,** 579-583.

Parry, M.L. (ed) (2001) *Assessment of Potential Effects and Adaptations for Climate Change in Europe: The Europe ACACIA Project* Jackson Environment Institute, Norwich.

Peach, W., Baillie, S. & Underhill, L. (1991) Survival of British Sedge Warblers Acrocephalus schoenobaenus in relation to west African rainfall. *Ibis*, **133,** 300-305.

Peach, W.J., du Feu, C. & McMeeking, J. (1995) Site tenacity and survival rates of wrens Troglodytes troglodytes and treecreepers Certhia familiaris in a Nottinghamshire wood. *Ibis,* **137,** 497-507.

Peach, W.J., Siriwardena, G.M. & Gregory, R.D. (1999) Long-term changes in over-winter survival rates explain the decline of reed buntings Emberiza schoeniclus in Britain. *J. Appl. Ecol.,* **36,** 798-811.

Peach, W.J., Thompson, P.S. & Coulson, J.C. (1994) Annual and long-term variation in the survival rates of British lapwings Vanellus vanellus. *J. Anim. Ecol.,* **63,** 60-70.

Pedersen, S.C., Genoways, H.H. & Freeman, P.W. (1996) Notes on bats from Montserrat (Lesser Antilles) with comments concerning the effects of Hurricane Hugo. *Caribbean Journal of Science,* **32**(2)**,** 206-213.

Perrin, W.F., Würsig, B. & Thewissen, J.G.M. Eds. (2002) *Encyclopedia of Marine Mammals*. Academic Press, San Diego.

Pienkowski, M.W. (1983) The effects of environmental conditions on feeding rates and prey-selection of shore plovers. *Ornis Scand*., **14,** 227-238.

Pierce, G.J. & Boyle, P.R. (2003) Empirical modelling if interannual trends in abundance of squid (Loligo forbesi) in Scottish waters. *Fisheries Research,* **59,** 305-326.

Pierce, G.J., Santos, M.B., Smeek, C. & Zuur, A.F. (in prep.) *Sperm whale strandings in the North Sea: a link with climate change?*

Pierce, G.J., Santos, M.B., Reid, R.J., Patterson, I.A.P. & Ross, H.M. (2004) Diet of minke whales Balaenoptera acutorostrata in Scottish (UK) waters with notes on strandings of this species in Scotland 1992-2002. *Journal of Marine Biological Association of the United Kingdom* **84,** 1241-1244.

Pierce, G.J., Miller, P.J., Thompson, P.M. & Hislop, J.R.G. (1991) Prey remains in grey seal (*Halichoerus grypus*) faeces from the Moray Firth, north-east Scotland. *Journal of Zoology, London*, **224,** 337-341.

Pierpoint, C. (2000) *Bycatch of marine turtles in UK and Irish waters*. Joint Nature Conservation Committee. Aberdeen. JNCC Report No. 310.

Piersma, T. & Baker, A.J. (2000) Life history characteristics and the conservation of migratory shorebirds. In *Behaviour and conservation* (eds Gosling, L.M. and Sutherland, W.J.), pp105-124. Cambridge University Press, Cambridge, UK.

Piersma, T. & Davidson, N.C., eds. (1992) *The Migration of Knots*. Wader Study Group Bulletin 64 (suppl).

Piersma, T. & Jukema, J. (1990) Budgeting the flight of a long-distance migrant: changes in nutrient reserve levels of bar-tailed godwits at successive spring staging sites. *Ardea*, **78**, 315-337.

Piersma, T. & Lindström, Å. (2004) Migrating shorebirds as integrative sentinels of global environmental change. *Ibis,* **146** (Suppl. 1)**,** 61-69.

Piersma, T., van Gils, J. & Wiersma, P. (1996) Family Scolopacidae (Sandpipers, Snipes and Phalaropes). In: *Handbook of the birds of the world: vol. 3 Hoatzin to auks.* (Eds del Hoyo, J., Elliott A. and Sargatal, J.). Pp 444-533. Lynx Edicions, Barcelona.

Planque, B. & Taylor, A.H. (1998) Long-term changes in zooplankton and the climate of the North Atlantic. *ICES Journal of Marine Science,* **55** (644-654).

Pollock, C.M., Mavor, R., Weir, C.A., Reid, A., White, R.W., Tasker, M.L., Webb A. & Reid, J.B. (2000) *The distribution of seabirds and marine mammals in the Atlantic Frontier, north and west of Scotland.* Joint Nature Conservation Committee. Aberdeen. 92.

Polovina, J.J., Balazs, G.H., Howell, E.A., Parker, D.M., Seki, M.P. & Dutton, P.H. (2004) Forage and migration habitat of loggerhead (*Caretta caretta*) and olive ridley *(Lepidochelys olivacea*) sea turtles in the central North Pacific Ocean. *Fisheries Oceanography,* **13** (1)**,** 36-51.

Porter, J.H., Parry, M.L. & Carter, T.R. (1991) The potential effects of climatic-change on agricultural insect pests. *Agricultural and Forest Meteorology*, **57**, 221-240.

Pörtner, H.O., Langenburgh, M. & Reipschläger, A. (2004) Biological impact of elevated ocean CO2 concentrations: lessons from animal physiology and earth history. *Journal of Oceanography,* **60,** 705-718.

Potts, G.R. (1986) *The Grey Partridge: Pesticides, Predation and Conservation*. Collins, London, UK.

Pounds, J.A., Fogden, M.P.L. & Campbell, J.H. (1999) Biological response to climate change on a tropical mountain. *Nature,* **398,** 611-615.

Procter, D. & Fleming, L.V. Eds. (1999) *Biodiversity: the UK Overseas Territories.* Peterborough, Joint Nature Conservation Committee.

Przybylo, R., Sheldon, B.C. & Merila, J. (2000) Climatic effects on breeding and morphology: evidence for phenotic plasticity. *J. Animal Ecology,* **69,** 395-403.

Pulido, F. & Berthold, P. (2004) Microevolutionary response to climate change. *Advances in Ecological Research,* **35,** 151-184.

Racey, P.A. & Entwistle, A.C. (2000) Life-history and reproductive strategies of bats. In: *Reproductive Biology of Bats*. (Eds Crighton, E.G. & Krutzsch, P.H.) Pp363-414 Academic Press, London/San Diego. 510pp.

Ratcliffe, D. (1980) The Peregrine Falcon. Buteo Books, Vermillion, SD.

Read, A. & Gaskin, D.E. (1990) Changes in growth and reproduction of Harbour porpoises, Phocoena phocoena, from the Bay of Fundy. *Can. J. Fish. Aquat. Sci.,* **47,** 2158-2163.

Reale, D., McAdam, A.G., Boutin, S. & Berteaux, D. (2003) Genetic and plastic responses of a northern mammal to climate change. *Proceedings of the Royal Society of London, Series, B.,* **270,** 591-596.

Reddy, M., Reif, J.S., Bachand, A. & Ridgway, S.H. (2001) Opportunities for using Navy marine mammals to explore associations between organochlorine contaminants and unfavourable effects on reproduction. *The Science of the Total Environment,* **274,** 171-182.

Rehfisch, M.M. & Austin, G.E. (2005) *Climate change and coastal waterbirds - the United Kingdom experience reviewed.* Paper A32, Edinburgh, UK: Proceedings of the Waterbird Around the World Conference.

Rehfisch, M.M. & Crick, H.Q.P. (2003) Predicting the impact of climate change on Arctic Breeding waders. *Wader Study Group Bulletin,* **100,** 86-95.

Reid, D.G., Edwards, M., Beaugrand, G., Skogen, M. & Stevens, D. (2003a) Periodic changes in the zooplankton of the North Sea during the twentieth century linked to oceanic inflow. *Fisheries Oceanography,* **12**(4/5)**,** 260-269.

Reid, J.B., Evans, P.G.H. & Northridge, S.P. Eds. (2003b) *Atlas of cetacean distribution in north-west European waters.* Joint Nature Conservation Committee, Peterborough.

Reijnders, P.J.H. (1986) Reproductive failure in common seals feeding on fish from polluted coastal waters. *Nature,* **324,** 456-467.

Reijinders, P.J.H. & Aguilar, A. (2002) Pollution and marine mammals. In: Encyclopedia of marine mammals. (Eds Perrin, W.F., Wursig, B. & Thewissen, J.G.M.) Pp 948-957. Academic Press, San Diego.

Reynolds III, J.E. & Powell, J.A. (2002) Manatees. In: Encyclopedia of marine mammals. (Eds Perrin, W.F., Wursig, B. & Thewissen, J.G.M.) Pp 709-720. Academic Press, San Diego.

Rice, D.W. (1998) *Marine Mammals of the World: systematics and distribution.* The Society of Marine Mammalogy, Special Publication No. 4.

Ridgeway, S.H. & Harrison, R. Eds. (1985) *Handbook of Marine Mammals. Volume 3: The Sirenians and Baleen Whales*. Academic Press, London.

Ridgeway, S.H. & Harrison, R. Eds. (1989) *Handbook of Marine Mammals. Volume 4: River dolphins and the larger toothed whales.* Academic Press, London.

Riley, J.R., Cheng, X.N., Zhang, X.X., Reynolds, D.R., Xu, G.M., Smith, A.D., Cheng, J.Y., Bao, A.D. & Zhai, B.P. (1991). The long-distance migration of *Nilaparvata lugens* (Stal) (Delphacidae) in China - radar observations of mass return flight in the autumn. *Ecological Entomology*, **16**, 471-489.

Ringrose, S., Vanderpost, C. & Matheson, W. (1997) Use of image processing and GIS techniques to determine the extent and possible causes of land/management/fence line induced degradation problems in the Okavango area, *Northern Botswana. International Journal of Remote Sensing* **18**: 2337-2364.

Riseborough, D.W. & Smith, M.W. (1993) Modelling permafrost response to climate change and climate variability. In: Proceedings, Fourth International Symposium on Thermal Engineering & Science for Cold Regions (eds Lunardinai, V.J. and Bowen, S.L.). Pp. 179-187, *U.S. Army Cold Regions Research and Engineering Laboratory, Special Report* 93-22, Hanover, NH, USA,

Robinson, R.A., Baillie, S.R. & Crick, H.Q.P. (in prep.) Weather-dependent survival: implications of climate change for passerine population processes. Submitted MS.

Robinson, R.A., Green, R.E., Baillie, S.R., Peach, W.J. & Thomson, D.L. (2004) Demographic mechanisms of the population decline of the Song Thrush Turdus philomelos in Britain. *J. Anim. Ecol.,* **73,** 670-682.

Roemich, D. & McGowan, J.A. (1995) Climate warming and the decline of zooplankton in the California Current. *Science,* **267,** 1324-1326.

Rogan, E. & Berrow, S.D. (1996) A Review of Harbour Porpoises, *Phocoena phocoena*, in Irish Waters. *Report of the International Whaling Commission,* **46,** 595-605.

Root, T.L. (1988a) Environmental factors associated with avian distributional boundaries. *J. Biogeogr.,* **15,** 489-505.

Root, T.L. (1988b) Energy constraints on avian distributions and abundances. *Ecology,* **69,** 330-339.

Root, T.L. & Schneider, S.H. (1993) Can large-scale climatic models be linked with multiscale ecological studies? *Conservation Biology,* **7,** 256-270.

Root, T.L., Price, J.T., Hall, K.R., *et al.* (2003) Fingerprints of global warming on plants and animals. *Nature,* **421,** 57-60.

Ross, P.S., Vos, J.G. Birnbaum, L.S. & Osterhaus, A.D.M.E. (2000) PCBs are a health risk for humans and wildlife. *Science,* **289,** 1878-1879.

Roy, D.B. & Sparks, T.H. (2000). Phenology of British butterflies and climate change. *Global Change Biology*, **6**, 407-416.

Russell, A. & McCracken, G.F. (2001) *Population genetic structure of very large populations: the Mexican free-tailed bat,* Tadarida brasiliensis. Abstracts for 12th International Bat Research Conference, Universiti Kebangsaan Malaysia, Bangi, Malaysia: 11.

Sæther, B.E., Sutherland, W.J. & Engen, S. (2004) Climate Influences on Avian Population Dynamics. In Birds and Climate Change. *Elsevier* , ***35*,** 185-210.

Santos, M.B. (1998) *Feeding Ecology of Harbour Porpoises, Common and Bottlenose Dolphins and Sperm Whales in the Northeast Atlantic*. University of Aberdeen. Aberdeen. 213

Santos, M.B., Pierce, G.J., Boyle, P.R., Reid, R.J., Ross, H.M., Patterson, I.A.P., Kinze, C., Tougaard, S., Lick, R., Piatkowski, U. & Hernandez-Garcia, V. (1999) Stomach contents of sperm whales Physeter macrocephalus stranded in the North Sea 1990-1996. *Marine Ecology Progress Series,* **183,** 281-294.

Santos, M.B., Pierce, G.J., Learmonth, J.A., Reid, R.J., Ross, H.M., Patterson, I.A.P., Reid, D.G. & Beare, D. (2004) Variability in the diet of harbour porpoises (*Phocoena phocoena*) in Scottish waters 1992-2003. *Marine Mammal Science,* **20**(1)**,** 1-27.

Sanz, J.J. (2002) Climate change and breeding parameters of great and blue tits throughout the western Palearctic. *Global ChangeBiol*., **8,** 409-422.

Sanz, J.J. (2003) Large-scale effect of climate change on breeding parameters of pied flycatchers in Western Europe. *Ecography*, **26,** 45-50.

Sanz, J.J., Potti, J., Moreno, J., Merino, S. & Frias, O. (2003) Climate change and fitness components of a migratory bird breeding in the Mediterranean region. *Global Change Biology*, **9,** 461-472.

Scheel, D., Vincent, T.L.S. & Cameron, G.N. (1996) Global warming and the species richness of bats in Texas. *Conservation Biology,* **10,** 452-464.

Schekkerman, H., Tulp, I., Piersma, T. & Visser, G.H. (2003) mechanisms promoting higher growth rates in arctic than in temperate shorebirds. *Oecologia,* **134,** 332-342.

Schekkerman, H., van Roomen, M.W.J. & Underhill, L.G. (1998) Growth, behaviour of broods and weather-related variation in breeding productivity of Curlew Sandpipers *Calidris ferruginea*. *Ardea,* **86,** 153-168.

Schiegg, S., Pasinelli, G., Walters, J.R. & Daniels, S.J. (2002) Inbreeding and experience affect response to climate change by endangered woodpeckers.. *Proceedings of the Royal Society of London, Series B,* **269,** 1153-1159.

Schmidt, K.H., Marz, M. & Matthysen, E. (1992) Breeding success and laying date of Nuthatches Sitta europaea in relation to habitat, weather and breeding density. *Bird Study,* **39,** 23-30.

Scholin, C.A., Gulland, F., Doucette, G.J., Benson, S., Busman, M., Chavez, F.P., Cordaro, J., DeLong, R., De Vogelaere, A., Harvey, J., Haulena, M., Lefebvre, K., Lipscomb, T., Loscutoff, S., Lowenstine, L.J., Marin, R. III, Miller, P.E., McLellan, W.A., Moeller, P.D.R., Powell, C.L., Rowles, T., Silvagni, P., Silver, M., Spraker, T., Trainer, V., & Van Dolah, F.M. (2000) Mortality of sea lions along the central California coast linked to a toxic diatom bloom. *Nature,* **403,** 80-84.

Schreiber, E.A. (2002) Climate and weather effects on seabirds. In: Schreiber, E.A. and J. Burger ed. Biology of Marine Birds. Boca Raton, Louisiana: CRC Press, 179-215.

Schreiber, R.W. & Schreiber, D. (1984) Central pacific seabirds and the El Nino-Southern Oscillation: 1982-1983 perspectives. *Science* **225,** 713-716.

Sear, C., Hulme, M., Adger, N. & Brown, K. (2001) The impacts of climate change on the UK Overseas Territories. Natural Resources Institute, Chatham Maritime, Kent/Tyndall Centre for Climate Change Research, Norwich.

Seppa, H., Nyman, M., Korhola, A. & Weckström, J. (2002) Changes of treelines and alpine vegetation in relation to post-glacial climate dynamics in northern Fennoscandia based on pollen and chironomid records. Journal of Quaternary *Science,* **17,** 287-301.

Serreze, M.C., Walsh, J.E., Chapin III, F.S., Osterkamp, T., Dyurgerov, M., Romanovsky, V., Oechel, W.C., Morison, J., Zhang, T. & Barry, R.G. (2000) Observational evidence of recent change in the northern high latitude environment. *Climatic Change,* **46,** 159-207.

Shane, S.H. (1994) Occurrence and habitat use of marine mammals at Santa Catalina Island, California from 1983-91. *Bulletin Southern California Academy of Science,* **93,** 13-29

Shane, S.H. (1995) Relationship between pilot whales and Risso's dolphins at Santa Catalina Island, California, USA. *Marine Ecology Progress Series,* **123,** 5-11

Sharpe, J. & Huggett, D. (1998) Coast in crisis: shoreline planning and biodiversity in East Anglia. *RSPB Conservation Review,* **12,** 55-66.

Shaughnessy, P.D. & Green, K. (1998) Continued increase in the population of Antarctic fur seals, Arctocephalus gazella, at Heard Island, Southern Ocean. *Marine Mammal Science,* **14**(2)**,** 384-389.

Sheldon, B.C., Kruuk, L.E.B. & Merilä, J. (2003) Natural selection and inheritance of breeding time and clutch size in the collared flycatcher. *Evolution,* **57,** 406-420.

Shump, K.A. & Shump, A.V. (1982a) *Lasiurus borealis*. *Mammalian Species,* **183,** 1-6.

Shump, K.A. & Shump, A.V. (1982b) *Lasiurus cinereus*. *Mammalian Species,* **185,** 1-5.

Siikmaki, P. (1996) Nestling growth and mortality of Pied Flycatchers in relation to weather and breeding effort. *Ibis,* **138,** 471-478.

Sillett, T.S., Holmes, R.T. & Sherry, T.W. (2000) Impacts of a global climate cycle on population dynamics of a migratory songbird. *Science*, **288,** 2040-2042.

Simberloff, D., Farr, J. A., Cox, J. & Mehlman, D.W. (1992) *Conservation Biology* **6**, 493.

Simmons, N. (in press) *Order Chiroptera. In Mammal Species of the World - Third edition*. Smithsonian Institution Press, Washington & London.

Sims, D.W., Genner, M.J., Southward, A.J. & Hawkins, S.J. (2001) Timing of squid migration reflects North Atlantic climate variability. *Proceedings of the Royal Society of London, B,* **268,** 2607-2611.

Sinclair, A.R.E. (1995) Serengeti past and present. In *Serengeti II.* (Eds Sinclair, A.R.E. and Arcese, P.) Pages 3-30. Chicago University Press, Chicago, USA.

Sinclair, A.R.E. & Fryxell, J.M. (1985) The Sahel of Africa: ecology of a disaster. *Canadian Journal of Zoology,* **63,** 987-994.

Sinclair, M.R. & Watterson, I.G. (1999) Objective assessment of extratropical weather systems in simulated climates. *Journal of Climatology*, **12,** 3467-3485.

Singh, R., Khan, B.A., & Vardhan, H. (1987) *Alternate wintering grounds for Siberian Cranes*. Proceedings of the 1983 International Crane Workshop:147-150.

Siriwardena, G.M., Wernham, D.V., & Baillie, S.R. (2004) Quantifying variation in migratory strategies using ring-recoveries. *Animal Biodiversity and Conservation,* 27**,** 299-317.

Siriwardena, G.M., Baillie, S.R., Crick, H.Q.P. & Wilson, J.D. (2000) The importance of variation in the breeding performance of seed-eating birds in determining their population trends on farmland. *J. Appl. Ecol.,* **37,** 128-148.

Sissener, E.H. & Bjørndal, T. (2005) Climate change and the migratory pattern for Norwegian spring-spawning herring - implications for management. *Marine Policy,* **29,** 299-309.

Sitters, H., Minton, C., Collins, P., Etheridge, B., Hassell, C. & O'Connor, F. (2004) Extraordinary numbers of oriental pratincoles in NW Australia. *Wader Study Group Bulletin,* **103,** 26-31.

Skelton, M. (1999). Successful overwintering by Clouded Yellow *Colias croceus* in southern England. *Atropos*, **8**, 3-6.

Slater, F.M. (1999) First-egg date fluctuations for the Pied Flycatcher Ficedula hypoleuca in the woodlands of mid-Wales in the twentieth century. *Ibis,* **141,** 497-499.

Smart, J. & Gill, J.A. (2003) Climate change and the potential impact on waders*. Wader Study Group Bulletin,* **100,** 80-85.

Smith, D.M. (1998) Recent increase in the length of the melt season of perennial Arctic sea ice. *Geophysical Research Letters,* **25,** 655-658.

Smith, F.A., Brown, H. & Shepherd, U.L. (1998) The influence of climate change on body mass of woodrats Neotoma in an arid region of New Mexico, USA. *Ecography*, **21,** 140-148.

Smithers, B.V., Peck, D.R., Krockenberger, A.K., *et al.* (2003) Elevated sea-surface temperature, reduced provisioning and reproductive failure of wedge-tailed shearwaters (*Puffinus pacificus*) in the southern Great Barrier Reef, Australia Mar. *Freshwater Res*., **54,** 973-977.

Sokolov, V.E. & Lushchenika, A.A. (1997) *Procapra gutturosa*. *Mammalian Species* **571**: 1-5.

Sokolov, L.V. (1999) Population dynamics of passerine birds. *Zool. Z. H.,* **78,** 311-324.

Soloviev, M. & Tomkovich, P. (2003) *Arctic Birds: Newsletter of International Breeding Conditions Survey No. 5.* International Wader Study Group.

Sotka, E.E. & Thacker, R.W. (2005) Do some corals like it hot? *TRENDS in Ecology and Evolution*, **20**(2)**,** 59-62.

Southward, A.J., Hawkins, S.J. & Burrows, M.T. (1995) Seventy years' observations of changes in distribution and abundance of zooplankton and intertidal organisms in the western English Channel in relation to rising sea temperature. *J. therm. Biol,* **20**(1/2)**,** 127-155.

Soutullo, A., Gill, J.A., Clark, J.A., Robinson, R.A. & Reynolds, J.D. (in prep.) Climate change and shifts in winter distribution of European breeding birds. *Animal Conservation.*

Sparks, T.H. (1999) Phenology and the changing pattern of bird migration in Britain. *International Journal of Biometerology,* **42,** 134-138.

Sparks, T.H. & Braslavská, O. (2001) The effects of temperature, altitude and latitude on the arrival and departure dates of the swallow *Hirundo rustica* in the Slovak Republic. *International Journal of Biometeorology,* **45,** 212-216.

Sparks, T. & Mason, C. (2001) Dates of arrivals and departures of spring migrants taken from Essex Bird Reports 1950-1998. *Essex Bird Report, 1999***,** 154-164.

Sparks, T. & Mason, C. (2004) Can we detect change in the phenology of winter migrant birds in the UK? In: *Climate Change and Coastal Birds*. (eds Rehfisch, M.M., Feare, C.F., Jones N.V. & Spray C.) Ibis.

Sparks, T.H. & Menzel, (2002) Observed changes in seasons: an overview. *International Journal of Climatology* **22**, 1715-1725.

Sparks, T.H., Roy, D.B. & Dennis R.L.H. (2005). The influence of temperature on migration of Lepidoptera into Britain. *Global Change Biology*, **11**, 507-514.

Spear, L.B. & Ainley, D.G. (1999) Migration routes of Sooty Shearwater in the Pacific Ocean. *Condor*, **101,** 205-218.

Spitzenberger, F. (2001) *Die Saugetierfauna Osterreichs*. Bundersministerium fur Land-und Forstwirtschaft, Umwelt and Wasserwirtschaft, Graz. 895pp.

Stainforth, D.A., Aina, T., Christensen, C., Collins, M., Faull, N., Frame, D.J., Kettleborough, J.A., Knight, S., Martin, A., Murphy, J.M., Piani, C., Sexton, D., Smith, L.A., Spicer, R.A., Thorpe, A.J. & Allen, M.R. (2005) Uncertainty in predictions of the climate response to rising levels of greenhouse gases. *Nature,* **433,** 403-406.

Stattersfield, A.J., Crosby, M.J., Long, A.J. & Wege, D.C. (1998) *Endemic Bird Areas of the world: priorities for biodiversity conservation*. BirdLife Conservation Series no. 7. BirdLife International, Cambridge.

Stebbing, A.R.D., Turk, S.M.T., Wheeler, A. & Clarke, K.R. (2002) Immigration of southern fish species to south-west England linked to warming of the North Atlantic (1960-2001). *Journal of the Marine Biological Association of the United Kingdom,* **82**(2)**,** 177-180.

Stefanescu, C., Peñuelas, J., Filella, I. (2003). Effects of climatic change on the phenology of butterflies in the northwest Mediterranean Basin**.** *Global Change Biology*, **9**, 1494-1506.

Stenseth, N., Mysterud, A., Ottersen, G., Hurrell, J.W., Chan, K.S. & Lima, M. (2002) Ecological effects of climate fluctuations. *Science,* **297,** 1292-1296.

Stern, S.J. (2002) Migration and movement patterns. In: *Encyclopedia of Marine Mammals*. (eds Perrin, W.F., Würsig B. and Thewissen J.G.) 742-750. Academic Press, San Diego.

Stevenson, I.R. & Bryant, D.M. (2000) Climate change and constraints on breeding. *Nature,* **406,** 366-367.

Still, C.J., Foster, P.N. & Schneider, S.H. (1999) Simulating the effects of climate change on tropical montane cloud forests. *Nature* **398**, 608-610.

Stirling, I., Lunn, N.J. & Iacozza, J. (1999) Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climate change. *Arctic,* **52,** (3)**,** 294-306.

Stoate, C. & Moreby, S.J. (1995) Pre-migratory diet of trans-Saharan migrant passerines in the western Sahel. *Bird Study,* **42,** 101-106.

Strelkov, P.P. (1969) Migratory and stationary bats (Chiroptera) of the European part of the Soviet Union. *Acta Zoologica Cracoviensia,* **14,** 393-439.

Strelkov, P.P. (1997a) Nursing area and its position within the range in migratory bats (Chiroptera: Vespertilionidae) from Eastern Europe and neighbouring regions: Part 1. Russian Journal of Zoology **1**(3)**,** 330-339.

Strelkov, P.P. (1997b) Nursing area and its position within the range in migratory bats (Chiroptera: Vespertilionidae) from Eastern Europe and neighbouring regions: Part II. *Russian Journal of Zoology,* **1**(4)**,** 545-553.

Summers, R.W., Butterfeild, D.P., Swann, R.L. & Insley, H. (2005) The decline of purple sandpipers *Calidris* maritima in the Moray Firth, Scotland – an effect of recruitment. *Wader Study Group Bulletin,* **106,** 34-38

Summers R.W. & Underhill L.G. (1987) Factors related to breeding production of Brent Geese *Branta b. bernicla* and waders (Charadrii) on the Taimyr Peninsula. *Bird Study,* **34,** 161-171.

Summers, R.W., Green, R.E., Proctor, R. *et al.* (2004) An experimental study of the effects of predation on the breeding productivity of Capercaillie and Black Grouse. *J. Appl. Ecol*., **41,** 513-525.

Sydeman, W.J., Hester, M.M., Thayer, J.A., Gress, F., Martin, P. & Buffa, J. (2001) Climate change, reproductive performance and diet composition of marine birds in the southern California Current system, 1969-1997. *Progress in Oceanography*, **49,** 309-329.

Szep, T. (1995) Survival rates of Hungarian sand martins and their relationship with Sahel rainfall. *Journal of Applied Statistics,* **22,** 891-904

Thain, M. & Hickman, M. (2000) *The Penguin Dictionary of Biology*. Penguin Books, London.

Thirgood, S., Mosser, A., Tham, S., Hopcraft, G., Mwangomo, E., Mlengeya, T., Kilewo, M., Fryxell, J., Sinclair, A.R.E., & Borner, M. (2004) Can parks protect migratory ungulates? The case of the Serengeti wildebeest. *Animal Conservation*, **7,** 113-120.

Thomas, C.D. & Lennon, J.J. (1999) Birds extend their ranges northwards. *Nature,* **399,** 213.

Thompson, P.M., Tollit, D.J., Corpe, H.M., Reid, R.J. & Ross, H.M. (1997) Changes in haematological parameters in relation to prey switching in a wild population of harbour seals. *Functional Ecology,* **11,** 743-750.

Thompson, P.M. & Ollason, J.C. (2001) Lagged effect of ocean climate change on fulmar population dynamics. *Nature,* **413,** 417-420.

Thomson, D.L., Baillie, S.R. & Peach, W.J. (1997) The demography and age-specific annual survival of song thrushes during periods of population stability and decline. *J. Anim. Ecol*., **66,** 414-424.

Thulin, C.G. (2003) The distribution of mountain hares *Lepus timidus* in Europe: A challenge from brown hares *L.europaeus*? *Mammal Review*, **33,** 29-42.

Timmermann, A., Oberhuber, J., Bacher, A., Esch, M., Latif, M. & Roeckner, E. (1999) Increased El Niño frequency in a climate model forced by future greenhouse warming. *Nature,* **398,** 694-697.

Tomkovich, P.S. (2001) A new subspecies of Red Knot Calidris canatus from the New Siberian Islands. *British Ornothologists' Club Bulletin,* **121,** 257-263.

Tompkins, D.M., Greenman, J.V., Robertson, P.A. & Hudson, P.J. (2000) The role of shared parasites in the exclusion of wildlife hosts: Heterakis gallinarum in the ringnecked pheasant and the grey partridge. *Journal of Animal Ecology* 69**,** 829–840.

Travis, J. & Futuyma, D.J. (1993) Global change: lessons from and for evolutionary biology In: *Biotic interactions and global change.* (Eds Karieva, P.M., Kingsolver, J.G. & Huey, R.B.) pp 251-263. Sinauer Associates, Sunderland, MA.

Tryjanowski, P., Kuzniak, S. & Sparks, T. (2002) Earlier arrival of some farmland migrants in western Poland. *Ibis,* **144,** 62-68.

Tuck, G.N., Polacheck, T., Croxall, J.P. & Weimerskirch, H. (2001) Modelling the impact of fishery by-catches on albatross populations. *Journal of Applied Ecology,* **38,** 1182-1196.

Tyler, G.A. & Green, R.E. (2004) Effects of weather on the survival and growth of Corncrake Crex crex chicks. *Ibis,* **146,** 69-76.

Tynan, C.T. & DeMaster, D.P. (1997) Observations and predictions of Arctic climatic change: potential effects on marine mammals. *Arctic,* **50**(4)**,** 308-322.

UNEP. (2001) UNEP/IGM/1/Information document for the Open-ended Intergovernmental Group of Ministers on International Environmental Governance

UNEP/CMS. (2002) Biodiversity in motion. Migratory specie and their value to sustainable development. http://www.cms.int/cop7/list_of_docs/WSSDmotion.html.

UNEP (2002) *Feasibility study on additional bats Agreements under CMS/ScC11/Doc.7.*

Urban, E., Fry, C.H. & Keith, S. (1997) *The Birds of Africa, Volume V: Thrushes to Puffback Flycathers.* Princeton University Press, Princeton, NJ.

Usher, M.B., Crawford, T.J. & Banwell, J.L. (1992) An American invasion of Great Britain: The case of the native and alien squirrel (Sciurus) species. *Conservation Biology*, **6,** 108-115.

Vahatalo, A.V., Rainio, K., Lehikoinen, A. & Lehikoinen, E. (2004) Spring arrival of birds depends on the North Atlantic Oscillation. *J. Avian Biol.,* **35,** 210-216.

Van Bressem, M.F. *et al* (2001). An insight into the epidemiology of dolphin morbillivirus worldwide. *Veterinary Microbiology,* **81,** 287-304.

van de Kam, J., Ens, B.J. & Piersma, T. (2004) *Shorebirds: an illustrated behavioural ecology.* Utrecht: KNNV Uitgerverij.

Van Gelder, R.G. & Wingate, D.B. (1961) The taxonomy and status of bats in Bermuda. *American Museum Novitates,* **2029,** 1-9.

Van Gils, J. & P. Wiersma (1996) Family Scolopacidae. *In*: del Hoyo, J., Elliot, A. & J. Sargartal (Eds) (1996) *Handbook of the birds of the World Vol.3: Hoatzins to Auks*. Lynx Ediciones, Barcelona. p488-533.

Vande-weghe, J.P. (1981) L'avifauna des papyraies au Rwanda et au Burundi. *Gerfaut*, **71,** 489-536.

Veit, R.R., McGowan, J.A., Ainley, D.G., Wahl, T.R. & Pyle, P. (1997) Apex marine predator declines ninety percent in association with changing oceanic climate. *Global Change Biology,* **3,** 23-28.

Villa, R.B. & Villa Cornejo, M. (1969) Algunos murcielagos del norte de Argentina. *Miscellaneous Publications 51, University of Kansas Museum of Natural History,* **51,** 407-428.

Villa, R.B. & Cockrum, E.L. (1962) Migration in the guano bat Tadarida brasiensis mexicana (Saussure). *J.Mamm*., **43**(1)**,** 43-64.

Virtanen, T., Neuvonen, S. & Nikula, A. (1998). Modelling topoclimatic patterns of egg mortality of *Epirrita autumnata* (Lepidoptera: Geometridae) with a Geographical Information System: predictions for current climate and warmer climate scenarios. *Journal of Applied Ecology*, **35**, 211-322.

Visser, M.E. & Lambrechts, M.M. (1999) Information constraints in the timing of reproduction in temperate zone birds: great and blue tits.. *Proceedings of the 22nd IOC*, pp249-264, Birdlife South Africa, Johannesburg.

Visser, M.E. & Holleman, J.M. (2001) Warmer springs disrupt the synchrony of oak and winter moth phenology. *Proceedings of the Royal Society of London B,* **265,** 1867-1870.

Visser, M.E., Adriaensen, F., van Balen, J.H., Blondel, J., Dhondt, A.A., van Drongen, S., du Feu, C. Ivankina, E.V., Kerimov, A.B., de Laet, J., Matthysen, E., McCleery, R., Orell, M & Thomson, D.L. (2003) Variable responses to large-scale climate change in European Parus populations. *Proc. R. Soc. Lond. B,* **270,** 367-372.

Visser, M.E., Both, C. & Lambrechts, M.M. (2004) Global climate change leads to mistimed avian reproduction. *Advances in Ecological Research,* **35,** 89-110.

Visser, M.E., Silverin, B., Lambrechts, M.M. & Tinbergen, J.M. (2002) No evidence for tree phenology as a cue for the timing of reproduction in tits Parus spp. *Avian Science,* **2,**77-86.

Visser, M.E., van Noordwijk, A.J., Tinbergen, J.M. & Lessells, C.M. (1998) Warmer springs lead to mis-timed reproduction in Great Tits (Parus major). *Proceedings of the Royal Society of London, Series B,* **265** 1867-1870.

Vogel, P., Jutzeler, S., Rulence, B. & Reutter, B.A. (2002) Range expansion of the greater white-toothed shrew Crocidura russula in Switzerland results in local extinction of the bicoloured white-toothed shrew C. leucodon. *Acta Theriologica*, **47,** 15-24.

Walker, S, (1995) Mexico-U.S. partnership makes gains for migratory bats. *Bats,* **13**(3)**,** 3-5.

Walsh, A., Catto, C., Hutson, A.M., Racey, P., Richardson, P. & Langton, S. (2001) *The UK's National Bat Monitoring Programme, Final Report 2001*. Department for the Environment, Food and Rural Affairs, Bristol. 155pp.

Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J.M., Hoegh-Guldberg, O. & Bairlein, F. (2002) Ecological responses to recent climate change. *Nature,* **416,** 389-395.

Waluda, C.M., Rodhouse, P.G., Podestá, G.P., Trathan, P.N. & Pierce, G.J. (2001) Surface oceanography of the inferred hatchling grounds of Illex argentinus (*Cephalopoda: Ommastrephidae)* and influences on recruitment variability. *Marine Biology,* **139,** 671-679.

Warham, J. (1996) *The behaviour, population biology and physiology of the petrels*. Academic Press, New York.

Watkinson, A.R., Gill, J.A. & Hulme, M. (2004) Flying in the face of climate change. *Ibis*, **146** (suppl. 1)**,** 4-10.

Watt, A.D., Carey, P.D. & Versham, B.C. (1998) Implications of climate change for biodiversity. In *Biodiversity in Scotland: Status, Trends and Initiatives*: (eds Fleming, L.V., Newton, A.C., Vickery, J.A. & Usher, M.B.) 147-159. Stationery Office, Edinburgh.

Wauer, R.H. & Wunderle, J.M. (1992) The effect of hurricane Hugo on bird populations on St Croix, United States Virgin Islands. *Wilson Bull*, **104,** 656-673.

Weaver, A.J. & Zwiers, F.W. (2000) Uncertainty in climate change. *Nature,* **407,** 571-572.

Weishampel, J.F., Bagley, D.A. & Ehrhart, L.M. (2004) Earlier nesting by loggerhead sea turtle following sea surface warming. *Global Change Biology,* **10,** 1424-1427.

Wells, R.S. & Scott, M.D. (2002) Bottlenose dolphins. In *Encyclopedia of Marine Mammals.* (Eds Perrin, W.F., Würsig, B. & Thewissen, J.G.M.) 122-128. Academic Press, San Diego.

Wells, R.S., Hansen, L.J., Baldridge, A., Dohl, T.P., Kelly, D.L. & Defran, R.H. (1990) Northward extension of the range of bottlenose dolphins along the California coast. *The Bottlenose Dolphin.* (Eds Leatherwood, S. & Reeves, R.R.) 421-431. Academic Press, San Diego.

Westbrook, J.K., Wolf, W.W., Lingren, P.D., Raulston, J.R., Lopez, J.D., Matis, J.H., Eyster, R.S., Esquivel, J.F. & Schleider, P.G. (1997). Early-season migratory flights of corn earworm (Lepidoptera: Noctuidae). *Environmental Entomology*, **26**, 12-20.

Wetlands Inspectorate Division (2000) Wetland Sector Strategic Plan 2001-2010. Ministry of Water, Land and Environment, Kampala, Uganda.

White, R.W., Gillon, K.W., Black, A.D. & Reid, J.B. (2002) *The distribution of sea birds and marine mammals in Falkland Island waters.* Joint Nature Conservation Committee. Peterborough.

Whitehead, H. (1997) Sea surface temperature and the abundance of sperm whale calves off the Galapagos Islands: implications for the effects of global warming. *Rep. Int. Whal. Commn*., **47,** 941-944.

Whitehead, H. (2002a) Estimates of the current global population size and historical trajectory for sperm whales. *Marine Ecology Progress Series,* **242,** 295-304.

Whitehead, H. (2002b) Sperm whale. In: *Encyclopedia of marine mammals*. (Eds Perrin, W.F., Würsig, B. & Thewissen, J.G.M.). Pp 1165-1172. Academic Press, San Diego.

Whitehead, H. (2003) Sperm whales: *Social evolution in the ocean,* University of Chicago Press.

Whyte, I.J. & Joubert, S.C.J. (1988) Blue wildebeest population trends in the Kruger national park, South Africa and the effects of fencing. *South African Journal of Wildlife Research*,**18**: 78-87.

Wiersma, P. & Piersma, T. (1994) Effects of microhabitat, flocking, climate and migratory goal on energy expenditure in the annual cycle of red knots. *Condor,* **96,** 257-279.

Wiley, D.N. & Clapham, P.J. (1993) Does maternal condition affect the sex ratio of offspring in humpback whales? *Animal Behaviour* **46,** 321-324.

Wilkins, K.T. (1987) Lasiurus seminolus*. Mammalian Species,* **280,** 1-5.

Williams, K.T. (1989) Tadarida brasiliensis. *Mammalian Species,* **331,** 1-10.

Willott, S.J. & Hassall, M. (1998). Life-history responses of British grasshoppers (Orthoptera:Acrididae) to temperature change. *Functional Ecology*, **12**, 232-241.

Wilson, A.M., Ausden, M. & Milsom, T.P. (2004) Changes in breeding wader populations on lowland wet grasslands in England and Wales: causes and potential solutions. *Ibis*, **146,** 32-40.

Wilson, B., Reid, R.J., Grellier, K., Thompson, P.M. & Hammond, P.S. (2004) Considering the temporal when managing the spatial: a population range expansion impacts protected areas-based management for bottlenose dolphins. *Animal Conservation* **7**, 331-338.

Wilson, B., Hammond, P.S., Reid, R.J., Grellier, K. & Thompson, P.M. (in prep.). Recent range expansion in North Sea bottlenose dolphins: evidence and management implications.

Wingate, D.B. (in prep.) First record of the eastern pipistrelle bat, Pipistrellus subflavus, from Bermuda.

Winkel, W. & Hudde, H. (1997) Long-term trends in reproductive traits of tits (*Parus major, P. caeruleus*) and pied flycatchers Ficedula hypoleuca. *J. Avian Biol.*, **28,** 187-190.

Winstanley, D., Spencer, R. & Williamson, K. (1974) Where have all the whitethroats gone? *Bird Study,* **21,** 1-14.

Withgott, J. (1999) Pollination migrates to top of the conservation agenda. *Bioscience,* **49**(11) 857-862.

Witter, M.S. & Cuthill, I.C. (1993) The ecological costs of avian fat storage. *Philosophical Transactions of the Royal Society of London, Series B,* **340,** 73-92.

Wolanski, E., Gereta, E., Borner, M. & Mduma, S. (1999) Water, migration and the Serengeti ecosystem. *American Scientist*, **87,** 526-533.

Wullich, M. (1994) *Algunos de dicen Doctor Batman. La Nacion [Argentina].* 3 December 1994, section 3, p. 8.

Würsig, B., Reeves, R.R. & Ortega-Ortiz, J.G. (2002) Global climate change and marine mammals. In: *Marine mammals: biology and conservation.* (Eds Evans, P.G.H. & Raga, J.A.) Pp 589-608. Kluwer Academic/Plenum Publishers, New York.

WWF (1999) *Endocrine Disrupting Chemicals*, www.wwfcanada.org. 2001.

WWF (2005) *No place to hide: Effects of climate change on protected areas*. Berine, Germany: WWF Climate Change Programme.

Yalden, D.W. & Pearce-Higgins, J.W. (1997) Density-dependence and winter weather as factors affecting the size of a population of Golden Plovers *Pluvialis apricaria*. *Bird Study,* **44,** 227-234.

Zagorodniuk, I. & Negoda, V. (2001) Pipistrelle bats of the genus Pipistrellus and genus Hypsugo. Pp 65-72 in I.Zagorodniuk (ed), Migration Status of Bats in Ukraine. *Novitates Theriologicae,* **6,** 1-172.

Zheng, X., Pierce, G.J., Reid, D.G. & Jolliffe, I.T. (2002) Does the North Atlantic current affect spatial distribution of whiting? Testing environmental hypotheses using statistical and GIS techniques. *ICES Journal of Marine Science,* **59,** 239-253.

Zöckler, C. & Lysenko, I. (2000) Water birds on the edge: first circumpolar assment of climate change impact on Arctic breeding wader birds. *WCMC Biodiversity Series*, **11,** 1-20.

Zwarts, L. & Wanink, J.H. (1993) How the food supply harvestable by waders in the Wadden Sea depends on the variation in energy density, body weight, biomass, burying depth and behaviour of tidal-flat invertebrates. *Neth. J. Sea Res.,* **31,** 441-476.

Appendix 1. Occurrence of Species in the United Kingdom, and its Overseas Territories and a summary of the impacts of climate change on them.

Contents

Table 1. The occurrence, migration and diet (if relevant to area, i.e. thought to be feeding there regularly) of marine mammals and turtles in UK waters (including Atlantic Frontier) and the potential effects of climate change on occurrence (unknown = ?; increase in occurrence= ↑; decrease in occurrence = ↓). Species names, IUCN and CMS status are listed in Table 7.

Species	Occurrence, migration and diet (where available)	Potential Climate Effect
Northern right whale	Rare vagrant, with only a few sightings between May and August. Distributed predominantly in NW Atlantic, generally between 20^{o} and 65^{o}N. Migrates between winter breeding grounds in south and northern summer feeding grounds. Main prey: Calanoid copepods and euphausiids	?
Humpback whale	Regular-occasional, with most sightings during summer months, in deeper waters, possibly on migration between high-latitude feeding grounds in summer and winter grounds in lower latitudes. Also observed in coastal waters of North Sea. Detect in acoustic surveys off north and west Britain and Ireland between mid-October and late March, therefore may use some areas during winter. May use some areas during winter, e.g. NW Scotland. Main prey: small schooling fish, euphausiids and copepods.	?
Minke whale	Regular occurrence, most common baleen whale in UK. Occurs year round, with most sightings during summer. Possible migration into British waters to feed during summer, although migration is less well defined and predictable than other migratory balaenopterids. Widely distributed along Atlantic coasts of Britain & Ireland, also occurs throughout northern and central North Sea. Seasonal distribution probably related to prey. Main prey consists of fish, including sandeels, sprat, herring, mackerel, whiting and haddock, and euphausiids.	?
Sei whale	Occasional sightings, generally during summer, in deep water, but hard to identify at sea. In NE Atlantic thought to winter off NW Africa, Spain, Portugal and Bay of Biscay and migrate to summer grounds off Shetland, Faroes, Norway and Svalbard. Main prey: copepods, euphausiids, schooling fish and squid.	?
Fin whale	Regular. Recorded all year in some areas, possible feeding and breeding/nursery areas, but majority of sightings during summer. General migration, possibly along shelf edge, towards polar waters in summer for feeding, and towards more subtropical and temperate waters in winter for breeding. Main prey includes schooling fish; squid; euphausiids; copepods.	?
Blue whale	Occasional, generally in deep offshore waters, possibly on migration route. Although may be present all year in some areas. Migrates between summer feeding grounds in cold temperate and polar waters to breeding areas in warm temperate and subtropical in winter, although no breeding grounds have been identified. Food availability probably dictates distribution for most of the year. Main prey is euphausiids, may also take copepods, cephalopods and small fish.	?
Sperm whale	Regular occurrence. Recorded through out the year, but mainly between July and December, possibly on migration route to and from higher latitudes. Only males migrate into the higher latitudes, with females and younger males ranging up to ~45-50^{o}N. Movements and distribution influenced by prey availability as can not fast for extended periods of time. Distributional limits during winter and the limits of females and young males in summer, correspond roughly with 15^{o}C sea surface isotherm. Predominantly feeds on medium to large sized mesopelagic cephalopods, such as histioteuthids, as well as demersal and mesopelagic fish.	?
Pygmy sperm whale	Rare. Strandings recorded in Ireland and Scotland. Generally found in tropical, sub-tropical and warm temperate waters, therefore at northern limit of range.	?↑

Species	Occurrence, migration and diet (where available)	Potential Climate Effect
Cuvier's beaked whale	Occasional, sightings suggest a possible summer movement into British waters. Possibly present all year in southern UK waters, strandings in Scotland also recorded during winter. Deep water species and diet consists mainly of deep-water cephalopods.	?
Northern bottlenose whale	Regular-occasional, although may spend some time in UK waters. Generally found in deep; cold arctic to temperate waters. Possible north-south seasonal movements. Deep divers feeding predominantly on squid of the genus *Gonatus*, also other squid species and fish.	↓
True's beaked whale	Rare vagrant. Generally found in warm temperate to tropical waters. Strandings recorded in Ireland and NW Scotland. Probably at northern end of range.	?↑
Gervais' beaked whale	Rare vagrant. Generally found in warm temperate to tropical waters of the Atlantic. Stranding recorded in Ireland. Probably at northern end of range.	?↑
Sowerby's beaked whale	Regular, possibly present all year. Sightings mainly from NW Britain and Ireland. In Scotland has highest incidence of strandings for all beaked whales, recorded in most moths of the year and various locations around the coast. Diet: fish and squid.	?
Blainville's beaked whale	Rare vagrant. Generally found in warm temperate to tropical waters. Strandings recorded in Scotland and Wales. Probably at northern end of range.	?↑
Beluga	Vagrant. Generally restricted to Arctic and sub-arctic waters. Migrate seasonal, as the ice recedes in spring enter summer grounds in specific coastal locations, including river estuaries, shallow inlets and bays. In winter are believed to migrate in the direction of the advancing polar ice front. Sightings recorded from NW Scotland, northern Isles and North Sea.	↓
Narwhal	Very rare vagrant (last stranding recorded in UK in 1949). Generally only occur in Arctic Ocean, where they migrate between high Arctic summer grounds and lower Arctic winter grounds, with spatial and temporal patterns linked to the cyclic seasonal changes in Arctic waters. General distribution and abundance on wintering grounds is related to prey, which may be influenced by bottom temperature.	↓
Bottlenose dolphin	Regular. Present all year. Distributed around most of the UK, for example along much of the east coast, south coast, SW England, NW Scotland, and Shetland. Resident populations are found in the NE Scotland (Moray Firth), Irish Sea (Cardigan Bay) and W Ireland (Shannon Estuary). Generally coastal but also recorded on continental shelf edge and deep ocean waters. Seasonal movements, include possible inshore-offshore, and along coasts, for example along the NE coast of Scotland and south coast of England. Diet consists of a variety of fish and cephalopod species, with regional, seasonal and annual variations.	?
Striped dolphin	Occasional. Strandings in Scotland from most months throughout the year, in Ireland majority of strandings appear to be in spring/winter. Increase in strandings in recent years on UK west coast. Majority of reported sightings from SW Channel and S Ireland and near-shore sightings are generally between July and December. Possible seasonal movements.	?↑
Common dolphin	Regular, occurring throughout year. Probably one of the most numerous offshore cetacean species in NE Atlantic. Frequently seen off SW England, SW & W Ireland, also NW Scotland and occasionally in North Sea. Seasonal movements and abundance patterns. Diet consists of a range of fish and cephalopod species, varying with location and season.	?↑
Fraser's dolphin	Very rare vagrant. Generally found in warm temperate to tropical waters. Stranding record from W Scotland and mass stranding in N Brittany, France.	?↑

Species	Occurrence, migration and diet (where available)	Potential Climate Effect
White-beaked dolphin	Regular. Present over the UK continental shelf and near-shore waters all year, frequently recorded in NW and E Scotland. Possible seasonal movements, with higher sightings between June and October. Diet includes variety of fish species, such as cod, whiting and other gadids, and cephalopods. Possible recent decrease in range on UK west coast.	?↓
White-sided dolphin	Regular. Generally inhabits cold-temperate waters of the N Atlantic, and usually encountered over continental shelf and slope, also extending into deeper oceanic waters and coastal areas. Mostly recorded off N Scotland. Present throughout the year, with possible seasonal movements related to prey, such as mackerel. Diet includes variety of fish species and cephalopods.	?↓
Risso’s dolphin	Regular. Present all year with most sightings from NW Scotland also recorded in Shetland, Orkney and Ireland. Seasonal patterns of occurrence suggest possible offshore movement in winter and inshore movements during summer. Diet consists mostly of cephalopod species, along with some fish.	?
Melon-headed whale	Very rare vagrant. Generally found in tropical waters. One record in UK from skull found in Cornwall.	?↑
False killer whale	Vagrant. Generally found in warm temperate to tropical water. Mass strandings events in Scotland, Wales and east coast (between 1927-35). Few recorded sightings from W & NE Scotland and Cornwall.	?↑
Killer whale	Regular. Occur all year, with an increase in numbers during summer. Most sightings from NW Scotland and Shetland. Seasonal distribution and abundance probably reflects prey, such as breeding seals, mackerel and herring. Varied diet including fish, squid, seals and other cetaceans.	?
Long-finned pilot whale	Frequently recorded, especially in deeper water and along continental shelf. Most sightings from north of Scotland. Diet consists predominantly of cephalopods and fish.	?
Harbour porpoise	Regular, present all year. Distribution around the UK is almost continuous. Generally inhabit coastal and continental shelf waters, although also present in the deep and offshore waters. Seasonal movements or migratory patterns NE Atlantic and North Sea are not well understood, possible onshore/offshore migrations and movements parallel to the coast. Diet consists of predominantly fish, such as whiting and sandeels and some cephalopod species, with regional, seasonal and annual variations.	?
Grey seal	Extensive movements between haul-out and feeding sites, generally related to prey. Diet consists of a variety of fish and cephalopod species.	?↓
Harbour seal	Extensive movements between haul-out and feeding sites, generally related to prey. Diet consists of a variety of fish and cephalopods species, with geographical, seasonal and annual variations.	?
Green turtle	Vagrant	?↑
Loggerhead turtle	Vagrant-occasional	?↑
Hawksbill turtle	Vagrant	?↑
Kemp’s Ridley turtle	Vagrant	?↑
Olive Ridley Turtle	Vagrant	?↑
Leatherback turtle	Occasional	?↑

References: Evans 1980; Kawakami 1980; Lockyer 1981; Gaskin 1982; Ridgeway and Harrison 1989; Klinowska 1991; Pierce *et al.* 1991; Evans 1992; Northridge *et al.* 1995; Berrow *et al.* 1996; Rogan and Berrow 1996; Berrow and Rogan 1997; Brown and Pierce 1998; Rice 1998; Santos 1998; Mann *et al.* 2000; Pollock *et al.* 2000; Anderson *et al.* 2001; Bjørge and Tolley 2002; Hammond *et al.* 2002; Perrin *et al.* 2002; Whitehead 2002; MacLeod *et al.* 2003; Reid *et al.* 2003b; Evans and Hammond 2004; Laidre *et al.* 2004; Macleod *et al.* 2004; Pierce *et al.* 2004; Santos *et al.* 2004; Procter and Fleming 1999; Pierpoint 2000..

Table 2. The occurrence, migration and diet (if relevant to area, i.e. thought to be feeding there regularly) of marine mammals and turtles in Gibraltar (Gib.) and Sovereign Base Areas (SAFB) on Cyprus (occurrence in area: ? = possible; V = vagrant; Y = recorded; *egg-laying beaches recorded) and the potential effects of climate change (unknown = ?; increase in occurrence= ↑; decrease in occurrence = ↓).Species names, IUCN and CMS status are listed in Table 7

Species	**Gib.**	**SAFB**	**Occurrence, migration and diet (where available)**	**Potential Climate Effect**
Northern right whale	?		Gibraltar is within range and on migration route, although no records from the Mediterranean	?↓
Humpback whale	V		Rare vagrant in Mediterranean. Migration between high-latitude feeding grounds in summer and winter grounds in tropics	?
Minke whale	Y		Range includes western Mediterranean. Appears to be a general south-north migration, although it is not as well defined and predictable as other migratory balaenopterids. May remain in some areas all year.	?
Bryde's whale	Y?		Occurs worldwide in warm temperate to tropical waters. Strait of Gibraltar at northern end of range.	↑?
Sei whale	V		Rare vagrant in north-western Mediterranean. Migrate considerable distances between high latitude summer grounds and low latitude winter grounds	?
Fin whale	Y	?	Although a migratory species they are present year round in north-western Mediterranean. Rare in the eastern Mediterranean. Main prey includes schooling fish; squid; euphausiids; copepods.	?
Blue whale	?		Vagrant. Within range and possibly on migration route. Generally found in deep water	?
Sperm whale	Y	Y	Common throughout the Mediterranean. Possible seasonal movements and segregation of sexes during summer. General distribution and abundance probably reflects prey e.g. mesopelagic squid.	?
Dwarf sperm whale	Y	Y?	Range includes Mediterranean. Generally found in warm temperate to tropical waters.	?↑
Cuvier's beaked whale	Y	Y?	Range includes Mediterranean. Worldwide distribution in cold temperate to tropical waters.	?
Northern bottlenose whale	V		Vagrant to western Mediterranean. Southern end of range generally extends to England. Inhabits arctic and cold temperate waters.	↓
True's beaked whale	?	?	Inhabits temperate waters of the N Atlantic.	?
Gervais' beaked whale	?	?	Occurs in warm temperate to tropical waters of the Atlantic, but most records from US.	?
Sowerby's beaked whale	?	?	Occurs in sub-polar to warm temperate of N Atlantic. Possible vagrant in Mediterranean.	?
Blainville's beaked whale	Y?		Distributed throughout warm temperate to tropical waters worldwide. Range includes western Mediterranean.	?
Rough-toothed dolphin	Y	Y	Range includes Mediterranean. Warm-temperate to tropical species, usually found in oceanic waters. Diet includes a variety of fish and cephalopod species.	?
Bottlenose dolphin	Y	Y	Widely distributed throughout the Mediterranean. Present all year round in some areas. Possible seasonal movements.	?
Striped dolphin	Y	Y	Widely distributed throughout the Mediterranean. Present all year round in Gibraltar Straits. Diet consist of a variety of pelagic or benthopelagic fish and squid.	?
Common dolphin	Y	Y	Widely distributed throughout the Mediterranean. Present all year round in Gibraltar Straits. Diet consists of a range of fish and cephalopod species, varying with location and season.	?
White-beaked dolphin	V		Vagrant to the Strait of Gibraltar. Endemic to the temperate and sub-arctic N Atlantic.	↓

Species	Gib.	SAFB	Occurrence, migration and diet (where available)	Potential Climate Effect
Atlantic white-sided dolphin	Y		Vagrant to the Strait of Gibraltar at southern end of range	↓
Risso's dolphin	Y	Y?	Range includes Mediterranean	?
False killer whale	?	?	Within possible range. Generally found in warm temperate to tropical waters worldwide	?↑
Killer whale	Y	?	Range includes Mediterranean	?
Long-finned pilot whale	Y		Range includes western Mediterranean	?
Short-finned pilot whale	?		Absent from Mediterranean?	?
Harbour porpoise	?		Occasional in Strait of Gibraltar,	↓
Mediterranean monk seal	Y	Y	Current distribution is severely contracted and fragmented, with the largest population (ca. 250-300 seals) in the Eastern Mediterranean, on the Islands in the Aegean and Ionian Seas, and along the coasts of Greece and Turkey. Only two breeding populations are know in the Atlantic, one at the Cap Blanc peninsula in the Western Sahara and Mauritania (ca. 100 seals) and a smaller group in the Deserts islands at the Madeira Islands (ca. 20 seals). Requires undisturbed beaches or caves for pup rearing and resting; and adequate prey resources within close proximity to haul-out sites.	↓
Green turtle	Y	Y*	*egg-laying beaches on Cyprus	?
Loggerhead turtle	Y	Y*	*egg-laying beaches on Cyprus	?
Hawksbill turtle	Y		Recorded in Gibraltar but no indication of any breeding sites	?
Leatherback turtle	Y		Recorded in Gibraltar but no indication of any breeding sites	?

References: Ridgeway and Harrison 1985; Ridgeway and Harrison 1989; Rice 1998; Procter and Fleming 1999; Perrin *et al.* 2002; Drouot *et al.* 2004; IUCN website; CMS website.

Table 3. The occurrence, migration and diet (if relevant to area, i.e. thought to be feeding there regularly) of marine mammals and turtles in Anguilla, Bermuda, British Virgin Islands, Cayman Islands, Montserrat, Turks and Caicos, Caribbean Sea and West Atlantic Ocean (occurrence in area: ? = possible; V = vagrant; Y = recorded; *egg-laying beaches recorded) and the potential effects of climate change (unknown = ?; increase in occurrence= ↑; decrease in occurrence = ↓). Species names, IUCN and CMS status are listed in Table 7.

Species	Anguilla	Bermuda	British Virgin Islands	Cayman Islands	Montserrat	Turks and Caicos	Occurrence, migration and diet (where available)	Potential Climate Effect
Northern right whale		Y					Probably vagrant as wintering calving grounds between Florida and South Carolina mark southern end of range. Main prey consists of copepods and euphausiids	↓
Humpback whale	Y	Y	Y	Y	Y	Y	Migration between winter (calving) grounds in the Caribbean and summer (feeding) grounds between New England, the west coast of Greenland, and Iceland. Possible breeding ground off Turk and Caicos	?
Minke whale	Y	Y	Y				In NW Atlantic winter range includes Florida Keys, Gulf of Mexico and West Indies. Winter grounds are poorly documented but have been recorded during winter at Anguilla and Virgin Isles.	?
Bryde's whale	?	?	?	?	?	?	Within range as generally found throughout tropical and warm temperate waters of ~16°C or warmer year round, between 40°N and 40°S. Short migration generally towards equator in winter and to higher latitudes in summer. Diet includes pelagic schooling fish; cephalopods and crustaceans, including euphausiids and copepods	?
Sei whale	Y		Y	?	?	?	Winter range includes northern Caribbean Sea and near Anguilla. Migrate considerable distances between high latitude summer grounds and low latitude winter grounds.	?
Fin whale				?			Winter range is poorly defined but southern end includes Gulf of Mexico and the Greater Antilles. General migration from polar waters to more subtropical and temperate waters in winter for breeding.	?
Blue whale		Y	Y	Y?	Y	Y	Within range and migratory routes. No specific breeding grounds have been identified.	?
Sperm whale	Y	Y	Y	Y	Y	Y	Occasional occurrence. Worldwide distribution including the deeper basins of the Caribbean Sea. Also possibly on migration route.	?
Pygmy sperm whale	?	?	?	?	?	?	Within range. Frequent strandings recorded around Florida and Gulf of Mexico, also recorded in Cuba and Lesser Antilles. No clear evidence of seasonal changes in distribution of migrations. Squid dominate diet, also includes benthic fish and crustaceans.	?
Dwarf sperm whale	?	?	?	?	?	?	Within range. Strandings recorded in Florida, Gulf of Mexico and Lesser Antilles. No clear evidence of seasonal changes in distribution of migrations. Squid dominate diet, also includes benthic fish and crustaceans.	?
True's beaked whale		Y					Generally found in warm temperate to tropical waters	

Species	Anguilla	Bermuda	British Virgin Islands	Cayman Islands	Montserrat	Turks and Caicos	Occurrence, migration and diet (where available)	Potential Climate Effect
Cuvier's beaked whale		Y					Distributed worldwide in cold temperate to tropical waters, with strandings recorded in the Caribbean.	?
Gervais' beaked whale	?	?	?	?	?	?	Inhabits warm temperate to tropical waters of the Atlantic, with strandings recorded in the Caribbean, including, Cuba, Jamaica and Trinidad.	?
Blainville's beaked whale	?	?	?	?	?	?	Worldwide distribution in warm temperate to tropical waters, with stranding recorded in Caribbean.	?
Rough-toothed dolphin	?	?	?	?	?	?	Normal range includes the Caribbean Sea. Warm-temperate to tropical species, usually found in oceanic waters. Diet includes a variety of fish and cephalopod species.	?
Bottlenose dolphin	?	?	?	?	?	?	Within range. Worldwide distribution in temperate and tropical waters.	?
Pantropical spotted dolphin	?	?	?	?	?	?	Within range	?
Atlantic spotted dolphin	?	?	?	?	?	?	Within range. Commonly seen around the '100-fathom curve' along the south-eastern and Gulf coasts of the United States, in the Caribbean and off West Africa. Endemic to the tropical and warm-temperate Atlantic, range extends from 50^{o}N to about 25^{o}S.	?
Spinner dolphin	?	?	?	?	?	?	Within range. Occurs in all tropical and most subtropical waters around the world between roughly 30-40^{o}N and 20-30^{o}S.Diet varies with location	?
Clymene dolphin				Y			Within range. Only found in tropical to warm temperate waters of the Atlantic. Most sightings have been in deep, offshore waters. Diet consists of mesopelagic fishes and squid.	?
Striped dolphin	?	?	?	?	?	?	Within range. Occurs in warm-temperate to tropical waters around the world. Diet consist of a variety of pelagic or benthopelagic fish and squid.	?
Fraser's dolphin	?	?	?	?	?	?	Tropical species distributed between 30^{o}N and 30^{o}S, typically oceanic. Range includes the Lesser Antilles. Diet includes variety of fish and squid, including deep water species, varies with location.	?
Risso's dolphin	Y	Y	Y	Y			Within range	?
Melon-headed whale	?	?	?	?	?	?	Within range	?
Pygmy killer whale	?	?	?	?	?	?	Within range. Occurs in tropical and sub-tropical waters worldwide. Possibly present all year round in the Lesser Antilles.	?
False killer whale	?	?	?	?	?	?	Within range. Generally found in warm temperate to tropical waters worldwide	?
Killer whale	?	?	?	?	?	?	Within range, but rare in tropical waters.	?
Short-finned pilot whale		Y					Within range	?

Species	Anguilla	Bermuda	British Virgin Islands	Cayman Islands	Montserrat	Turks and Caicos	Occurrence, migration and diet (where available)	Potential Climate Effect
Manatee			Y			Y	The Antillean manatee (*T. m. manatus*) occupies coastal and riverine habitats from the mid-Atlantic region of the United States, throughout the Gulf of Mexico and wider Caribbean Sea, including the Greater Antilles and Lesser Antilles. Distribution is influenced by temperature (>20^{o}C), and perhaps, by access to fresh drinking water. Diet consists predominantly of vegetation such as marsh and sea grasses as well as leafy plants.	?
Green turtle	Y*	Y	Y*	Y*	Y*	Y*	*Egg-laying beaches recorded in Anguilla, British Virgin Islands, Cayman Islands, Montserrat, Turks and Caicos.	
Loggerhead turtle	Y	Y	Y	Y*	Y	Y*	*Egg-laying beaches recorded in Turks and Caicos and Cayman Islands	
Hawksbill turtle	Y*	Y	Y*	Y	Y*	Y*	*Egg-laying beaches recorded in Anguilla, British Virgin Islands, Montserrat, Turks and Caicos	
Kemp's Ridley turtle		Y	Y	Y	Y	Y	Recorded but no indication of any breeding sites	
Leatherback turtle	Y*	Y	Y*	Y	Y	Y	*Egg-laying beaches recorded in Anguilla, British Virgin Islands,	

References: Ridgeway and Harrison 1985; Ridgeway and Harrison 1989; Rice 1998; Procter and Fleming 1999; Perrin *et al.* 2002; IUCN website; CMS website

Table 4. The occurrence, migration and diet (if relevant to area, i.e. thought to be feeding there regularly) of marine mammals and turtles in Ascension Islands, St Helena and Tristan da Cunha and the potential effects of climate change (unknown = ?; increase in occurrence= ↑; decrease in occurrence = ↓). Species names, IUCN and CMS status are listed in Table 7.

Species	Ascension Islands	St Helena	Tristan da Cunha	Occurrence, migration and diet (where available)	Potential Climate Effect
Southern right whale		?	Y	Within migration range from southern polar waters to northern wintering ground, including area centred round Tristan da Cunha. Main prey includes calanoid copepods and euphausiids	↓
Humpback whale	?	Y	Y	Migration between high-latitude feeding grounds in summer and winter grounds in tropics.	?
Antarctic minke whale	?	?	?	Within northern limit of winter range	↓
Bryde's whale	?	?	?	Within range. Present in tropical and warm temperate waters of ~16^{o}C or warmer year round, inc. S Atlantic between 40^{o}N and 40^{o}S. Short migration generally towards equator in winter and to higher latitudes in summer. Diet includes pelagic schooling fish; cephalopods and crustaceans, including euphausiids and copepods	?
Sei whale	?	?	?	Possibly within northern limit of winter range of Southern Ocean sei whales. Migrations are relatively diffuse and can vary from year to year in response to changing environmental conditions.	?
Fin whale	?	?	?	Possibly within northern limit of winter range of Southern Ocean fin whales	?
Blue whale	Y	Y	Y	Possibly within northern limit of winter range of Antarctic blue whales. No specific breeding grounds have been identified.	?
Sperm whale	Y	Y		Within range and migration routes.	?
Pygmy sperm whale	?	?	?	Possibly within range as inhabits warm temperate to tropical waters worldwide.	?
Dwarf sperm whale	?	?	?	Possibly within range as inhabits warm temperate to tropical waters worldwide.	?
Cuvier's beaked whale	?	?	?	Possibly within range as inhabits cold temperate to tropical waters worldwide	?
Shepherd's beaked whale			Y	Within known range. Specimen collected in Tristan da Cunha.	?
Southern bottlenose whale			?	Possibly within range. Occurrence is circumpolar in the S hemisphere from Antarctic to about 30^{o}S.	?
Hector's beaked whale	?	?	?	Occurs in cold temperate to sub-tropical waters of S hemisphere	?
Gervais' beaked whale	Y			Occurs in warm temperate to tropical waters of Atlantic. Strandings reports from Ascension Islands, which is probably at the southern end of range.	?
Gray's beaked whale	?	?	?	Occurs in cold to warm temperate waters of S hemisphere.	?
Andrew's beaked whale	?	?	?	Possibly within range	
Blainville's beaked whale	?	?	?	Occurs in temperate to tropical waters in all of the southern oceans.	?
Rough-toothed dolphin		Y		Within range. Warm-temperate to tropical species, usually found in oceanic waters. Diet includes a variety of fish and cephalopod species.	?
Bottlenose dolphin	Y	Y		Small number present in coastal waters of St Helena.	?
Pantropical spotted dolphin		Y		Large number present in coastal waters of St Helena	?

Species	Ascension Islands	St Helena	Tristan da Cunha	Occurrence, migration and diet (where available)	Potential Climate Effect
Atlantic spotted dolphin	?	Y		St Helena at southern end of range. Endemic to the tropical and warm-temperate Atlantic, range extends from 50^{o}N to about 25^{o}S.	?
Spinner dolphin		Y		Occasional at St Helena which is at southern end of range. Generally found in tropical and subtropical waters between 30-40^{o}N and 20-30^{o}S. Diet varies with location	?↑
Clymene dolphin	?	?	?	Within range?	?
Striped dolphin	?	?	?	Within range. Occurs in warm-temperate to tropical waters around the world. Has been reported in waters of 10-26^{o}C, with most records from about 18-22^{o}C. Diet consist of a variety of pelagic or benthopelagic fish and squid.	?↑
Common dolphin	?	?	?	Within range. Distribution is generally in warm-temperate and tropical waters from about 40-60^{o}N to about 50^{o}S	?↑
Fraser's dolphin	?	?	?	Within range. Tropical species distributed between 30^{o}N and 30^{o}S, typically oceanic.	?↑
Dusky dolphin			Y?	Recorded offshore of Tristan da Cunha	↓
Peale's dolphin	?	?	?	Possibly within range – limited information available to determine if species is present in area	
S. right whale dolphin	?	?	?	Possibly within range – limited information available to determine if species is present in area	
Risso's dolphin	?	?	?	Possibly within range – limited information available to determine if species is present in area	
Melon-headed whale	?	?	?	Possibly within range – limited information available to determine if species is present in area	
Pygmy killer whale	?	?	?	Occurs in tropical and sub-tropical waters worldwide.	?
False killer whale	?	?	?	Generally found in warm temperate to tropical waters worldwide	?
Killer whale		?		Within range	?
Long-finned pilot whale	?	?	?	Possibly within range – limited information available to determine if species is present in area	
Short-finned pilot whale	?	?	?	Possibly within range – limited information available to determine if species is present in area	
Subantarctic fur seal			Y/B	Population on Tristan da Cunha	↓
Southern elephant seal			Y/B	Population on Tristan da Cunha	↓
Green turtle	Y*	Y		* Egg-laying beaches recorded in Ascension Islands	
Loggerhead turtle	?	?	?	Possibly within range – limited information available to determine if species is present in area	
Hawksbill turtle	Y			Recorded but no indication of any breeding sites	

References: Ridgeway and Harrison 1985; Ridgeway and Harrison 1989; Rice 1998; Procter and Fleming 1999; Perrin *et al.* 2002; IUCN website; CMS website

Table 5. The occurrence, migration and diet (if relevant to area, i.e. thought to be feeding there regularly) of marine mammals and turtles in Falkland Islands, South Georgia, South Sandwich Island and British Antarctic Territory, South Atlantic and Southern Ocean (occurrence in area: ? = possible; V = vagrant; Y = recorded; Y/B = breeding site; Y*egg-laying beaches recorded) and the potential effects of climate (unknown = ?; increase in occurrence= ↑; decrease in occurrence = ↓). Species names, IUCN and CMS status are listed in Table 7.

Species	**British Antarctic Territory**	**Falkland Islands**	**South Georgia**	**South Sandwich Islands**	**Occurrence, Migration and Diet (where available)**	**Potential Climate Effects**
Southern right whale	?	Y	Y	Y	Rare/occasional, possibly present all year. Whales which possibly winter off Argentina & S Africa, spend the summer foraging over the continental shelf of S Georgia. Main prey includes calanoid copepods & euphausiids.	?
Pygmy right whale		Y			Restricted to S hemisphere temperate waters, between about 30 and 52^{o}S. Main prey: Calanoid copepods	?
Humpback whale	?	Y	Y	Y	Occasional, recorded during summer (Oct-Mar). Migrate between high latitude summer feeding grounds and winter calving grounds in the tropics. Main prey: schooling fish; euphausiids; esp. *Euphausia superba* in the Antarctic	?
Antarctic minke whale	?	Y	Y	Y	Scarce/occasional. Recorded in all months, with majority of sightings during summer (Sep-Apr). During summer enter pack ice and free-ice coastal areas in Antarctic. Main prey consists of euphausiids, esp. *Euphausia superba* and schooling fish	↓
Sei whale	?	Y	Y	Y	Scarce/occasional. Majority of sightings during summer (Nov-Apr), but occasionally seen at other times of year. Migrations are relatively diffuse and can vary from year to year in response to changing environmental conditions. Main Prey: *Euphausia superba* and copepods, including *Calanus* in S hemisphere.	?
Fin whale	Y?	Y	Y	Y	Scarce/occasional. Majority of sightings during summer (Nov-Jan), but occasionally seen at other times of year. Annual migration towards polar waters in summer for feeding. Main prey: *Euphausia superba* and other euphausiids	?
Blue whale	Y?	Y	Y	Y	Feed extensively in the Antarctic during summer. Diet is predominantly euphausiids. Associated with areas of cold current upwellings.	?
Sperm whale	Y	Y	Y	Y	Regular/occasional. Recorded throughout the year. Generally males migrate into the Southern Ocean during summer, and feed between the pack-ice and open ocean, females remain north of the polar front/Subtropical Convergence (~40^{o}S) throughout the year. Diet in most oceans is dominated by mesopelagic squids.	?
Cuvier's beaked whale		Y	?	?	Worldwide distribution in cold temperate to tropical waters	?
Arnoux's beaked whale	?	Y	Y	?	Rare. Circumpolar distribution in the S hemisphere from Antarctic continent and ice edge (78^{o}S) north to about 34^{o}S in the southern Pacific, southern Atlantic and Indian Ocean.	?

Species	British Antarctic Territory	Falkland Islands	South Georgia	South Sandwich Islands	Occurrence, Migration and Diet (where available)	Potential Climate Effects
Southern bottlenose whale	?	Y	Y	Y	Occasional-regular. Recorded during summer (Sep-Feb). Range is circumpolar in the S hemisphere from Antarctic to about 30°S.	?
Hector's beaked whale		Y	?	?	Occurs in cold temperate to sub-tropical waters of S hemisphere and recorded in the Falkland Islands	?
Gray's beaked whale		Y	Y	Y	Occurs in cold to warm temperate waters of S hemisphere.	?
Strap-toothed beaked whale	?	Y	Y	Y	Occurs in polar to sub-tropical waters of S hemisphere, with stranding records form the Falkland Islands.	?
Commerson's dolphin	?	Y	Y	Y	Regularly recorded, present throughout the year in Falklands. Also found in the inshore waters of Argentina and the Strait of Magellan, and has an isolated population 8500 km away at the Kerguelen Islands, in the Indian Ocean. No evidence for large scale migration. Diet consists of a variety of coastal prey species, such as benthic and pelagic schooling fish and squid	?
Bottlenose dolphin		Y			Worldwide distribution in temperate and tropical waters. Limits to range may be directly or indirectly related to temperature, generally found in temperatures between 10-32°C	?
Common dolphin		?			At very end of southern limit of range, distribution is generally in warm-temperate and tropical waters from about 40-60°N to about 50°S.	?↑
Dusky dolphin	?	Y	Y	Y	Regular/occasional.	?
Peale's dolphin	?	Y	Y	Y	Regularly recorded, present throughout the year.	?
Hourglass dolphin	?	Y	Y	?	Regularly recorded, seasonal occurrence, majority of records during summer (Sep-Mar). Circumpolar distribution in the Southern Ocean, in both Antarctic and sub-Antarctic waters, from about 45°S to near the ice pack. Possible seasonal movements. Diet includes fish, squid and crustaceans.	?↓
S. right whale dolphin	?	Y	Y	Y	Rare/occasional, recorded throughout the year	?
Killer whale	Y?	Y	Y	Y	Regular/occasional. Recorded throughout the year. Higher occurrence in summer, probably related to prey, such as breeding fur seals and penguins.	?
Long-finned pilot whale	?	Y	Y	?	Regularly recorded, present throughout the year, possibly more abundant in winter.	?
Spectacled porpoise		Y	Y	Y	Frequent/occasional.	?↓
Antarctic fur seal		Y/B			Population on Falkland Islands.	?↓
Subantarctic fur seal		Y/B			Population on Falkland Islands. Pup in December and moult completed by May. No clear migration, but may move away from breeding colonies from midwinter.	?↓
South American fur seal		Y/B			Population on Falkland Islands. Pup in December and moult completed by May. No clear migration, but may move away from breeding colonies from midwinter.	?

Species	British Antarctic Territory	Falkland Islands	South Georgia	South Sandwich Islands	Occurrence, Migration and Diet (where available)	Potential Climate Effects
South American sea lion		Y/B			Population on Falkland Islands.	?
Southern elephant seal		Y/B	Y/B		Population on Falkland Islands and South Georgia.	?
Leopard seal		Y			Recorded annually as a non-breeding visitor	?↓

References: Ridgeway and Harrison 1989; Kasamatsu and Joyce 1995; Rice 1998; Moore *et al.* 1999; Procter and Fleming 1999; Hucke-Gaete 2000; Perrin *et al.* 2002; White *et al.* 2002; IUCN website; CMS website

Table 6. The occurrence, migration and diet (if relevant to area, i.e. thought to be feeding there regularly) of marine mammals and turtles in Pitcairn, South Pacific and British Indian Ocean Territory (occurrence in area: Y = recorded; Y*egg-laying beaches recorded) and the potential effects of climate change (unknown = ?; increase in occurrence= ↑; decrease in occurrence = ↓). Species names, IUCN and CMS status are listed in Table 7.

Species	British Indian Ocean Territory	Pitcairn Islands	Occurrence, migration and diet (where available)	Potential Climate Effects
Humpback whale	Y	Y	Migrate from summer range in Antarctic zone north to various winter calving grounds, including Tonga, Fiji and Cook Islands; around the islands in French Polynesia; and Mozambique and Madagascar.	?
Bryde's whale	?	?	Within range as generally occur throughout the tropical and warm temperate waters ~16°C or warmer year round, inc. S Pacific and Indian Ocean, between 40°N and 40°S. Short migration generally towards equator in winter and to higher latitudes in summer. Diet includes pelagic schooling fish; cephalopods and crustaceans, including euphausiids and copepods.	?
Sei whale	?	?	Within range.	?
Fin whale	?	?	Within range and migratory routes	?
Blue whale	Y	Y	Within range and migratory routes	?
Sperm whale	?	?	Range includes widespread distribution of both sexes in the Indian Ocean, including the Gulf of Aden, Arabian Sea Bay of Bengal and Andaman Sea, and south Pacific. Extensive north-south migrations in both the northern and southern hemispheres. Mesopelagic squids generally dominate the diet in almost all oceans.	?
Dwarf sperm whale	?	?	Within range. Occurs in warm temperate to tropical waters worldwide	?
Cuvier's beaked whale	Y		Within range. Occurs in temperate to tropical water worldwide	?
Longman's beaked whale	?	?	Possibly within range. Occurs in tropical waters of Indian Ocean and SW Pacific.	?
Hector's beaked whale	?	?	Within range. Occurs in cold temperate to sub-tropical waters of S hemisphere	?
Gray's beaked whale	?	?	Within range. Occurs in cold to warm temperate waters of S hemisphere.	?
Ginko-toothed beaked whale	?	?	Within reported range, occurring in temperate and tropical waters of N Pacific and Indian Ocean	?
Blainville's beaked whale	?	?	Occurs in temperate to tropical waters in all of the southern oceans.	?
Rough-toothed dolphin	?	?	Within range. Warm-temperate to tropical species, usually found in oceanic waters. Diet includes a variety of fish and cephalopod species.	?
Bottlenose dolphin	?	?	Within range. Worldwide distribution in temperate and tropical waters.	?
Pantropical spotted dolphin	?	?	Within range	?
Spinner dolphin	Y		Within range. Occurs in all tropical and most subtropical waters around the world between roughly 30-40°N and 20-30°S. Diet varies with location.	?

Species	British Indian Ocean Territory	Pitcairn Islands	Occurrence, migration and diet (where available)	Potential Climate Effects
Striped dolphin	?	?	Within range. Occurs in warm-temperate to tropical waters around the world. Has been reported in waters of 10-26^{o}C, with most records from about 18-22^{o}C. Diet consist of a variety of pelagic or benthopelagic fish and squid.	?
Common dolphin	?	?	Within range. Distribution is generally in warm-temperate and tropical waters from about 40-60^{o}N to about 50^{o}S	?
Fraser's dolphin	?	?	Within range. Tropical species distributed between 30^{o}N and 30^{o}S, typically oceanic.	?
Risso's dolphin	?	?	Possibly within range – limited information available to determine if species is present in area	
Melon-headed whale	?	?	Possibly within range – limited information available to determine if species is present in area	
Pygmy killer whale	?	?	Occurs in tropical and sub-tropical waters worldwide.	?
False killer whale	?	?	Generally found in warm temperate to tropical waters worldwide	?
Killer whale	?	?	Possibly within range – limited information available to determine if species is present in area	?
Short-finned pilot whale	Y		Within range	?
Green turtle	Y*	Y*	* Egg-laying beaches recorded in British Indian Ocean Territory and Pitcairn	
Hawksbill turtle	Y*	Y*	* Egg-laying beaches recorded in British Indian Ocean Territory and Pitcairn	

References: Ridgeway and Harrison 1985; Ridgeway and Harrison 1989; Rice 1998; Procter and Fleming 1999; Perrin *et al.* 2002; Gannier 2004; .IUCN website; CMS website

Table 7. Cetacean species recorded in water of the United Kingdom (UK) and its overseas territories (UKOT). Conservation status, as listed by the IUCN, and the occurrence on CMS appendices are also given.

Family and Species Name	Common Name	Distribution: temperature range preference	UK	UKOT	IUCN[1]	CMS	Migratory
Mysticeti	**Baleen Whales**						
Balaenidae	**Right Whales**						
Balaena mysticetus	Bowhead whale	N hemisphere: Arctic waters, circumpolar	No	No	LR:cd	I	Yes
Balaena glacialis	Northern right whale	N Atlantic & Pacific: sub-polar to tropical	Yes	?	EN (D)	I	
Balaena australis	Southern right whale	S hemisphere: Antarctic to temperate	No	Yes	LR:cd	I	
Neobalaenidae	**Pygmy right whale**						
Caperea marginata	Pygmy right whale	S hemisphere: circumpolar, cold temperate	No	Yes		II	
Eschrichtiidae	**Gray Whale**						
Eschrichtius robustus	Gray whale	N Pacific: warm temperate to arctic	No	No	LR:cd		Yes
Balaenopteridae	**Rorquals**						
Megaptera novaeangliae	Humpback whale	Worldwide: cold temperate/polar to tropical	Yes	Yes	VA (A)	I	Yes
Balaenoptera acutorostrata	Minke whale[2]	Worldwide: polar to tropical	Yes	Yes	LR:nt		Yes
Balaenoptera bonaerensis	Antarctic minke whale[2]	S hemisphere: polar to tropical	No	Yes	LR:cd	II	Yes
Balaenoptera edeni/brydei	Bryde's whale	Worldwide: warm temperate to tropical	No	?	DD	II	Yes
Balaenoptera borealis	Sei whale	Worldwide: cold temperate to tropical	Yes	Yes	EN (A)	I & II	Yes
Balaenoptera physalus	Fin whale	Worldwide: polar to tropical	Yes	Yes	EN (A)	I & II	Yes
Balaenoptera musculus	Blue whale	Worldwide: polar to tropical	Yes	Yes	EN (A)	I	Yes
Odontoceti	**Toothed Whales**						
Physeteridae	**Sperm Whale**						
Physeter macrocephalus	Sperm whale	Worldwide: polar to tropical	Yes	Yes	VU (A)	I & II	Yes
Kogiidae	**Pygmy Sperm Whales**						
Kogia breviceps	Pygmy sperm whale	Worldwide: warm temperate to tropical	V?	?	DD		
Kogia sima	Dwarf sperm whale	Worldwide: warm temperate to tropical		Yes			
Ziphiidae	**Beaked Whales**						
Ziphius cavirostris	Cuvier's beaked whale	Worldwide: cold temperate to tropical	Yes	Yes	DD		Yes
Berardius arnuxii	Arnoux's beaked whale	S hemisphere: circumpolar, polar to sub-tropical	No	Yes	LR:cd		
Berardius bairdii	Baird's beaked whale	N Pacific: polar to sub-tropical	No	No	LR:cd	II	
Tasmacetus shepherdi	Shepherd's beaked whale	S hemisphere: warm temperate to sub-polar	No	Yes	DD		
Indopacetus pacificus	Longman's beaked whale	Indian Ocean and SW Pacific: tropical waters	No	No	DD		
Hyperoodon ampullatus	Northern bottlenose whale	N Atlantic: arctic to cold temperate waters	Yes	Yes	LR:cd	II	Yes
Hyperoodon planiforms	Southern bottlenose whale	S hemisphere: circumpolar, Antarctic to	No	Yes	LR:cd		

Family and Species Name	Common Name	Distribution: temperature range preference	UK	UKOT	IUCN[1]	CMS	Migratory
		temperate					
Mesoplodon hectori	Hector's beaked whale	S hemisphere: cold temperate to sub-tropical	No	Yes	DD		
Mesoplodon mirus	True's beaked whale	Worldwide: warm temperate to tropical	Yes	?	DD		
Mesoplodon europaeus	Gervais' beaked whale	Atlantic: warm temperate to tropical	Yes	Yes	DD		
Mesoplodon bidens	Sowerby's beaked whale	N Atlantic: sub-polar to warm temperate	Yes	Yes	DD		
Mesoplodon grayi	Gray's beaked whale	S hemisphere: cold to warm temperate	No	Yes	DD		
Mesoplodon peruvianus	Pygmy beaked whale	SE and NE Pacific: cold temperate to tropical	No	No	DD		
Mesoplodon bowdoini	Andrew's beaked whale	S hemisphere: cold temperate to sub-tropical	No	No	DD		
Mesoplodon carlhubbsi	Hubbs' beaked whale	N Pacific: cold temperate to sub-tropical	No	No	DD		
Mesoplodon ginkgodens	Ginko-toothed beaked whale	N Pacific and Indian Ocean: temperate to tropical	No	Yes	DD		
Mesoplodon stejnegeri	Stejneger's beaked whale	N Pacific: warm temperate to, sub-polar	No	No	DD		
Mesoplodon layardii	Strap-toothed beaked whale	S hemisphere: polar to sub-tropical	No	Yes	DD		
Mesoplodon densirostris	Blainville's beaked whale	Worldwide: warm temperate to tropical	V	Yes	DD		
Mesoplodon traversii	Spade-toothed whale	S Pacific: cold temperate to subtropical	No	Yes			
Mesoplodon perrini	Perrin's beaked whale	NE Pacific: warm temperate to subtropical	No	No			
Platanistidae	**Indian River Dolphin**						
Platanista gangetica	Ganges river dolphin	India, Nepal, Bhutan and Bangladesh: freshwater only	No	No	EN (A)	I & II	
Iniidae	**Amazon River Dolphin**						
Inia geoffrensis	Boto	Peru, Ecuador, Brazil, Bolivia, Venézuela, Columbia: freshwater only	No	No	VU (A)	II	
Lipotidae	**Chinese River Dolphin**						
Lipotes vexillifer	Baiji	China: freshwater only	No	No	CR (ACD)		
Pontoporiidae	**La Plata Dolphin**						
Pontoporia blainvillei	Franciscana	Brazil to Argentina: coastal waters from Doce River	No	No	DD	I & II	
Monodontidae	**Beluga & Narwhal**						
Delphinapterus leucas	Beluga or white whale	Circumpolar in arctic seas: arctic to cold temperate	V	No	VU (A)	II	Yes
Monodon monoceros	Narwhal	Arctic Ocean	V	No	DD	II	Yes
Delphinidae	**Dolphins**						
Cephalorhynchus commersonii	Commerson's dolphin	S America, Falkland & Kerguelen Islands:	No	Yes	DD	II	

Family and Species Name	Common Name	Distribution: temperature range preference	UK	UKOT	IUCN[1]	CMS	Migratory
		coastal, sub-polar to cold temperate					
Cephalorhynchus eutropia	Chilean dolphin	S South America: coastal, subpolar to warm temperate	No	No	DD	II	
Cephalorhynchus heavisidii	Heaviside's dolphin	SW Africa: cold to warm temperate	No	No	DD	II	
Cephalorhynchus hectori	Hector's dolphin	New Zealand: coastal waters, cold to warm temperate	No	No	EN (AC)		
Steno bredanensis	Rough-toothed dolphin	Worldwide: warm temperate to tropical	No	Yes	DD		
Sousa teuszii	Atlantic hump-backed dolphin	SE Atlantic: coastal and river mouths, sub-tropical to tropical	No	No	DD	II	
Sousa plumbea	Indian hump-backed dolphin	Indian Ocean: coastal, subtropical to tropical	No	?			
Sousa chinensis	Indo-pacific hump-backed dolphin	Indian Ocean: coastal and rivers, tropical	No	No	DD	II	
Sotalia fluviatilis	Tucuxi	SW Atlantic: coastal, estuaries and rivers, tropical	No	No	DD	II	
Tursiops aduncus	Bottlenose dolphin	Indian and Pacific Ocean: coastal, tropical	No	No	DD	II	
Tursiops truncatus	Bottlenose dolphin	Worldwide: cold temperate to tropical	Yes	Yes	DD	II	SM
Stenella attenuata	Pantropical spotted dolphin	Worldwide: tropical	No	Yes	LR:cd	II	
Stenella frontalis	Atlantic spotted dolphin	Atlantic Ocean: sub-tropical to tropical	No	Yes	DD		
Stenella longirostris	Spinner dolphin	Worldwide: tropical	No	Yes	LR:cd	II	
Stenella clymene	Clymene dolphin	Atlantic Ocean: tropical	No	Yes	DD		
Stenella coeruleoalba	Striped dolphin	Worldwide: cold temperate to tropical	Yes	Yes	LR:cd	II	
Delphinus delphis[3]	Short-beaked common dolphin	Worldwide: temperate and tropical	Yes	Yes		II	Yes/SM
Delphinus capensis[3]	Long-beaked common dolphin	Worldwide: sub-tropical	No	?			
Delphinus tropicalis[3]	Arabian common dolphin	Arabian Sea: coastal waters, tropical	No	No			
Lagenodelphis hosei	Fraser's dolphin	Worldwide: warm temperate to tropical	V?	Yes	DD	II	
Lagenorhynchus albirostris	White-beaked dolphin	N Atlantic: cold temperate	Yes	Yes?		II	
Lagenorhynchus acutus	Atlantic white-sided dolphin	N Atlantic: sub-polar to warm temperate	Yes	Yes		II	
Lagenorhynchus olbliquidens	Pacific white-sided dolphin	N Pacific: cold temperate to sub-tropical	No	?			
Lagenorhynchus obscurus	Dusky dolphin	S hemisphere: cold to warm temperate	No	Yes	DD	II	
Lagenorhynchus australis	Peale's dolphin	S America: sub-polar to warm temperate	No	Yes	DD	II	

Family and Species Name	Common Name	Distribution: temperature range preference	UK	UKOT	IUCN[1]	CMS	Migratory
Lagenorhynchus cruiger	Hourglass dolphin	S hemisphere: polar to warm temperate	No	Yes			
Lissodelphis borealis	N. right whale dolphin	N Pacific: sub-polar to sub-tropical	No	No			
Lissodelphis peronii	S. right whale dolphin	S hemisphere: polar to sub-tropical	No	Yes	DD		
Grampus griseus	Risso's dolphin	Worldwide: cold temperate to tropical	Yes	Yes	DD	II	
Peponocephala electra	Melon-headed whale	Worldwide: tropical	V?	?			
Feresa attenuata	Pygmy killer whale	Worldwide: tropical to warm temperate	No	?			
Pseudorca crassidens	False killer whale	Worldwide: warm temperate to tropical	Yes	?			
Orcinus orca	Killer whale, orca	Worldwide: polar to tropical	Yes	Yes	LR:cd	II	Yes
Globicephala melas	Long-finned pilot whale	Worldwide (ex N Pacific): polar to warm temperate	Yes	Yes		II	Yes
Globicephala macrorhynchus	Short-finned pilot whale	Worldwide: tropical to sub-tropical	No	Yes	LR:cd		
Orcaella brevirostris	Irrawaddy dolphin	SE Asia, N Australia and Papua New Guinea: tropical coastal waters and estuaries	No	No	DD	II	
Phocoenidae	**Porpoises**						
Neophocaena phocaenoides	Finless porpoise	Indo-Pacific: warm temperate to tropical	No	No	DD	II	
Phocoena phocoena	Harbour porpoise	N Pacific & N Atlantic: sub-polar to cold temperate	Yes	?	VU (A)	II	SM
Phocoena sinus	Vaquita	Gulf of California: sub-tropical	No	No	CR (C)		
Phocoena spinipinnis	Burmeister porpoise	S America: coastal cold temperate to sub-tropical	No	No	DD	II	
Phocoena dioptrica	Spectacled porpoise	S hemisphere: polar to cold temperate	No	Yes	DD	II	
Phocoenoides dalli	Dall's porpoise	N Pacific: sub-polar to temperate	No	No	LR:cd	II	

References: Ridgeway and Harrison 1985; Rice 1998; Hucke-Gaete 2000; Mann *et al.* 2000; White *et al.* 2002; Reid *et al.* 2003b; Kaschner 2004); IUCN Redlist website; CMS website.

[1] IUCN status (CR = critically endangered; EN = endangered; VU = vulnerable (A = declining population, B = small distribution and decline or fluctuation, C = small population size and decline, D = very small or restricted); NT = near threatened; LR:cd = low risk, conservation dependent; LR:nt = low risk, near threatened; DD = data deficient).
V=vagrant; SM = seasonal movements.

[2] minke whale – several authors refer to two species of minke whale, the Antarctic minke whale (*B. bonaerensis*) and the dwarf minke whale (*B. acutorostrata*), however in the context of this report both are referred to as minke whales.

[3] common dolphins – three species of common dolphins have been identified, the short-beaked common dolphin (*D. delphis*), the long-beaked common dolphin (*D. capensis*) and the Arabian common dolphin (*D. tropicalis*), however in the context of this report all are referred to as common dolphins due to the overlap in distribution of *D. delphis* and *D. capensis*.

Table 8. (a) Pinniped and other non-cetacean marine mammal species and turtles recorded in water of the United Kingdom (UK) and its overseas territories (UKOT). Conservation status, as listed by the IUCN, and the occurrence on CMS appendices are also given.

Family and Species Name	Common Name	Distribution (breeding site)	UK	UKOT	IUCN	CMS	Migratory
Otariidae	**Fur-seals and sea lions**						
Artocephalus pusillus	Cape fur seal	S Africa & S Australia: warm temperate (land)	No	No			
Artocephalus gazelle	Antarctic fur seal	S hemisphere (excluding SE Pacific): polar to subpolar	No	Yes			
Artocephalus tropicalis	Subantarctic fur seal	S hemisphere (excluding SE Pacific): high temperate	No	Yes			
Artocephalus townsendi	Guadalupe fur sea	NE Pacific: warm temperate to tropical (land)	No	No	VU (D)		
Artocephalus philippii	Juan Fernández fur-seal	West coast of South America, Chile: temperate (land)	No	No	VU (D)		
Artocephalus forsteri	New Zealand fur seal	S Australia and New Zealand: temperate (land)	No	No			
Artocephalus australis	South American fur seal	S America and Falklands: sub-polar to temperate (land)	No	Yes		II	
Artocephalus galapagoensis	Galapagos fur seal	Galapagos Islands: equatorial (land)	No	No	VU (A)		
Callorhinus ursinus	Northern fur seal	N Pacific and Bering Sea: sub-polar to temperate (land)	No	No	VU (A)		Yes
Zalophus californianus	California sea lion	NE Pacific: warm temperate to tropical (land)	No	No			
Zalophus wollebaeki	Galapagos sea lion	Galapagos Islands: equatorial (land)	No	No	VU (A)		
Eumetopias jubatus	Steller's sea lion	N Pacific: sub-polar to cold temperate (land)	No	No	EN (A)		
Neophoca cinera	Australian sea lion	SE Indian Ocean, S & SW Australia: temperate (land)	No	No			
Phocarctos hookeri	New Zealand sea lion	SW Pacific, NZ: sub-polar to cold temperate (land)	No	No	VU (D)		
Otaria flavescens	South American sea lion	S America and Falklands: polar to sub-tropical (land)	No	Yes		II	
Odobenidae	**Walrus**						
Odobenus rosmarus	Walrus	Arctic Ocean and adjoining seas	V	No			
Phocidae	**Seals**						
Ergnathus barbatus	Bearded seal	Arctic (pack-ice)	V	No			
Phoca vitulina	Harbour seal	N hemisphere: sub-polar to warm temperate (land)	Yes	No		II	
Phoca largha	Spotted seal	N Pacific, Chukchi Sea: polar (pack-ice)	No	No			
Pusa hispida	Ringed seal	Arctic regions, Baltic Sea: (fast-ice)	V	No			
Pusa caspica	Caspian seal	Caspian Sea: polar to sub-polar (fast-ice)	No	No	VU (B)		
Pusa sibirica	Baikal seal	Lake Baikal, Siberia: polar to sub-polar (fast-ice)	No	No	LR:nt		
Halichoerus grypus	Grey seal	N Atlantic: sub-polar to cold temperate (land, ice)	Yes	No		II	
Histriophoca fasciata	Ribbon seal	N Pacific: polar (pack-ice)	No	No			
Pagophilus groenlandicus	Harp seal	N Atlantic: polar to cold temperate (pack-ice)	V	No			
Cystophora cristata	Hooded seal	N Atlantic: polar to cold temperate (pack-ice)	Yes	No			
Monachus monachus	Mediterranean monk seal	Med. Sea, Black Sea, NW African coast: subtropical (land)	No	Yes	CR (C)	I & II	

Family and Species Name	Common Name	Distribution (breeding site)	UK	UKOT	IUCN	CMS	Migratory
Monachus schauinslandi	Hawaiian monk seal	Hawaiian Islands: tropical (land)	No	No	EN (C)		
Mirounga leonina	Southern elephant seal	Sub-Antarctic, Antarctic, southern S. America (land)	No	Yes			
Mirounga angustirostris	Northern elephant seal	N Pacific: sub-polar to sub-tropical (land)	No	No			
Leptonychotes weddellii	Weddell seal	Antarctic (fast-ice)	No	Yes			
Ommatophoca rossii	Ross seal	Antarctic (fast-ice)	No	Yes			
Lobodon carcinophaga	Crabeater seal	Antarctic (pack-ice)	No	Yes			
Hydrurga leptonyx	Leopard seal	Antarctic (pack-ice)	No	Yes			

References: Rice 1998; Procter and Fleming 1999; Hucke-Gaete 2000; Perrin *et al.* 2002; White *et al.* 2002; Kaschner 2004; IUCN website; CMS website

Table 8. (b) Other Marine Mammal Species (Sirenians, polar bear and otters)

Family and Species Name	Common name	Distribution	UK	UKOT	IUCN	CMS	Migratory
Trichechidae	**Manatees**						
Trichechus manatus	Caribbean manatee	Florida, Caribbean (marine and freshwater)	No	Yes	VU (A)	I & II	
T. m. latirostris	Florida manatee	Florida peninsula, occasionally as far south as Bahamas	No	No			
T. m. manatus	Antillean manatee	Mainland coast from Mexico to Venezuela, and Brazil including the Greater and Lesser Antilles	No	Yes			
Trichechus senegalensis	African manatee	West Africa (marine and freshwater)	No	No	VU (A)	II	
Trichechus inunguis	Amazon manatee	Amazon river (marine and freshwater)	No	No	VU (A)	II	
Dugongidae	**Dugongs**						
Dugong dugon	Dugong	Indian and western Pacific Oceans (marine)	No	?	VU (A)	II	
Ursidae	**Bears**						
Ursus maritimus	Polar bear		No	No	LR:cd		Yes
Mustelidae	**Otters**						
Enhydra lutris	Sea otter	Canada, United States, Mexico, Japan, Russian Federation (terrestrial, marine)	No	No	EN (A)		
Lontra felina	Marine otter	Argentina, Chile, Peru (terrestrial, freshwater, marine)	No	No	EN (A)	I	
Lutra lutra	Common otter	Worldwide (terrestrial, freshwater, marine)	Yes	No	NT		

References: Ridgeway and Harrison 1985; Rice 1998

Table 8. (c) Marine Turtles

Species Name	**Common Name**	**Distribution and diet**	**UK**	**UKOT**	**IUCN status**	**CMS appendix**	**Migratory**
Chelonia mydas	Green turtle	Circumglobal distribution, occurring throughout tropical and to a lesser extent subtropical waters (Atlantic, Indian and Pacific Oceans and Mediterranean Sea) Diet: herbivorous, predominantly seagrasses	V	Y	Endangered	I & II	Yes
Caretta caretta	Loggerhead turtle	Circumglobal distribution, inhabiting continental shelves, bays, lagoons and estuaries in the temperate, subtropical and tropical waters of the Atlantic, Pacific and Indian Oceans and Mediterranean Sea. Diet: variety of benthic invertebrates (molluscs, crustaceans and sponges)	V	Y	Endangered	I & II	Yes
Eretmochelys imbricate	Hawksbill turtle	Distributed throughout the tropical and sub-tropical regions of all oceans. Diet: coral encrusting organisms such as sponges, tunicates, bryozoans, molluscs and algae	V	Y	Critically endangered	I & II	Yes
Lepidochelys kempii	Kemp's Ridley turtle	Occurs mainly in coastal areas of the Gulf of Mexico and the northwestern Atlantic Ocean. Diet: predominantly crabs	V	Y	Critically endangered	I & II	Yes
Lepidochelys olivacea	Olive Ridley turtle	Distributed throughout the tropical waters in Atlantic, Pacific and Indian Oceans Diet: Predominantly shrimps			Critically endangered	I & II	Yes
Dermochelys coriacea	Leatherback turtle	Circumglobal distribution, generally within latitudes 40^{o}N and 35^{o}S, tropical to temperate waters. Only marine turtle to have developed adaptations to cold water. Diet: predominantly jellyfish and tunicates	Y	Y	Critically endangered	I & II	Yes

References: IUCN Redlist website; CMS website; Rice 1998; Procter and Fleming 1999; Pierpoint 2000; Godley *et al.* 2004; Bjorndal 1981.

Table 9. Occurrence in the UK Overseas Territories of migratory bird species listed on CMS. From McWilliams (2003)

		UK Overseas Territories:																	
	CMS	AN	AI	BE	BA	BI	BV	CI	FI	GI	MT	PI	SG	SI	SH	TC	TU	Climate	Other
Procellariiformes																			
DIOMEDEIDAE																			
Wandering Albatross *Diomedea exulans*	II	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	None	F1, H1, P1
Black-browed Albatross *D. melanophris*	II	-	-	-	Y	-	-	-	Y	-	-	-	-	-	-	-	-	None	D1, D2, F1, H1, P1
Yellow-nosed Albatross *D. chlororhynchos*	II	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	C1	F1, P1
Sooty Albatross *Phoebetria fusca*	II	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	C1	P2
Light-mantled Sooty Albatross *P. palpebrata*	II	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	C1	F1, P1
PROCELLARIIDAE																			
Southern Giant Petrel *Macronectus giganteus*	II	-	-	-	-	-	-	-	Y	-	-	-	Y	Y	-	-	-	C1	P1
Northern Giant Petrel *Macronectus halli*	II	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	None	F1, P1
White-chinned Petrel *Procellaria aequinoctialis*	II	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	Y	-	C1	F1, P1
Bermuda Petrel *Pterodroma cahow*	I	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	None	P2
Phoenicopteriformes																			
PHOENICOPTERIDAE																			
Greater Flamingo *Phoenicopterus ruber*[1]	II	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	None	None
Anseriformes																			
ANATIDAE																			
Black-necked Swan *Cygnus melanocorypha*	II	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	None	None
Upland Goose *Chloephaga picta leucoptera*[2]	II	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	None	None
Kelp Goose *Chloephaga hybrida malvinarum*[2]	II	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	None	None
Ashy-headed Goose *Chloephaga poliocephala*	II	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	None	None
Ruddy-headed Goose *Chloephaga rubidiceps*	I	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	None	None
Flying Steamer duck *Tachyeres patachonicus*	II	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	None	None
Chiloë Wigeon *Anas sibilatrix*[2]	II	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	None	None
Mallard *Anas platyrhynchos*	II	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	C2	P3
Speckled Teal *Anas flavirostris*[2]	II	-	-	-	-	-	-	-	Y	-	-	-	Y	-	-	-	-	None	None
Blue-winged Teal *Anas discors*	II	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	C2	H2
Cinnamon Teal *Anas cyanoptera cyanoptera*	II	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	None	None
Crested Duck *Anas specularoides*[2]	II	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	None	None
White-cheeked Pintail *Anas bahamensis*	II	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	C2	H2

	CMS	UK Overseas Territories:																	
		AN	AI	BE	BA	BI	BV	CI	FI	GI	MT	PI	SG	SI	SH	TC	TU	Climate	Other
Yellow-billed Pintail *Anas georgica* [2]	II	-	-	-	-	-	-	-	Y	-	-	-	Y	-	-	-	-	None	None
Silver Teal *Anas versicolor fretensis* [2]	II	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	None	None
Falconiformes																			
CATHARTIDAE																			
Turkey Vulture *Cathartus aura falklandicus* [2]	II	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	None	None
ACCIPITRIDAE																			
Red-tailed Hawk *Buteo jamaicensis* [2]	II	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	None	None
Red-backed Hawk *Buteo polysoma polysoma* [2]	II	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	None	None
FALCONIDAE																			
Peregrine Falcon *Falco peregrinus*	II	-	-	-	-	-	-	-	Y	Y	-	-	-	-	-	-	-	None	None
Lesser Kestrel *Falco naumanni*	I/II	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	None	None
Common Kestrel *Falco tinnunculus* [2]	II	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	None	None
American Kestrel *Falco sparverius* [2]	II	Y	-	-	-	-	Y	-	-	-	Y	-	-	-	-	-	-	None	None
Charadriiformes																			
RECURVIROSTRIDAE																			
Black-necked Stilt *Himantopus mexicanus* [2]	II	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	Y	C2	H2, P2
CHARADRIIDAE																			
Wilson's Plover *Charadrius wilsonia*	II	Y	-	-	-	-	Y	-	-	-	Y	-	-	-	-	-	Y	C2	H2, P2
Killdeer *Charadrius vociferous*	II	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	Y	C2	H2, P2
Kentish Plover *Charadrius alexandrinus*	II	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	Y	C2	H2
Two-banded Plover *Charadrius falklandicus* [2]	II	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	None	None
Rufous-chested Dotterel *Charadrius modestus* [2]	II	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	None	None
SCOLOPACIDAE																			
Willet *Catoptrophorus semipalmatus*	II	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C2	H3
LARIDAE																			
Roseate Tern *Sterna dougallii*	II	Y	-	Y	Y	Y	-	-	-	-	-	-	-	-	-	-	Y	C2	F1, P1
Little Tern *Sterna albifrons*	II	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	C2	F1, P1
Passeriformes																			
MUSCICAPIDAE																			
Robin *Erithacus rubecula* [2]	II	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	None	None
Blue Rock Thrush *Monticola solitarius* [2]	II	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	None	D3
Eastern Bluebird *Sialia sialis* [2]	II	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	None	P3, M1
Red-legged Thrush *Turdus plumbeus coryi* [3]	II	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	None	H2
Blackbird *Turdus merula* [2]	II	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	None	None
Fan-tailed Warbler *Cisticola juncidis* [2]	II	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	None	D3

		UK Overseas Territories:																	
	CMS	**AN**	**AI**	**BE**	**BA**	**BI**	**BV**	**CI**	**FI**	**GI**	**MT**	**PI**	**SG**	**SI**	**SH**	**TC**	**TU**	**Climate**	**Other**
Grasshopper Warbler *Locustella naevia*	II	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	None	D3
Dartford Warbler *Sylvia undata*	II	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	None	D3
Spectacled Warbler *Sylvia conspicillata*	II	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	None	D3
Sardinian Warbler *Sylvia melanocephala*	II	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	None	D3
Blackcap *Sylvia atricapilla*	II	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	None	None
Common Chiffchaff *Phylloscopus collybita*	II	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	None	None

AN=Anguilla; AI=Ascension Island; BE=Bermuda; BA=British Antarctic Territory; BI=British Indian Ocean Territory; BV=British Virgin Islands; CI=Cayman Islands ; FI=Falkland Islands; GI=Gibraltar; MT=Montserrat; PI=Pitcairn Islands; SG=South Georgia; SI=South Sandwich Island; SH=St Helena; TC=Tristan da Cunha; TU=Turks and Caicos Island.

C1 = Decline in krill and squid prey due to sea-warming; C2 = sea-level rise; D1 = pollution; D2 = disturbance by tourists; D3 = disturbance by humans and predators; F1 = long-line fishing mortality; H1 = loss of tussock grass habitat; H2 = loss of habitat due to development; H3 = habitat loss (general); M1 = competition with sparrows and starlings; P1 = predation by rodents; P2 = mammal predation; P3 = predation (general)

[1] Not fully migratory, but some dispersal occurs; [2] Migratory over part of its range, but not in British overseas territories; [3] Appears to be migratory on Cayman Islands, as few seen outside the breeding season, not migratory elsewhere.

Table 10. Lists of migratory bird species listed in the CMS Appendices I and II. Information derived from BirdLife International (2000); Cramp & Perrins (1980-1994); del Hoyo *et al*. (1994-2002).

			Breeding		**Non-breeding**		
		Threat Status	**Range**	**Habitat**	**Range**	**Habitat**	**Population**
Saffron-cowled Blackbird *Agelaius flavus*	I	Vulnerable	Brazil, Paraguay, Uruguay, NE Argentina	Grassland	highly mobile	Seasonally Wet Grassland	2500 - 10,000
Cock-tailed Tyrant *Alectrurus tricolor*	I	Vulnerable	South America	Grassland	South America	Seasonally Wet Grassland	>10,000
Strange-tailed Tyrant *Alectrurus risora*	I	Vulnerable	South America	Grassland	South America	Seasonally Wet Grassland	>10,000
Baikal Teal *Anas formosa*	I	Vulnerable	Eastern Siberia; Russia	Wetland	Japan, South Korea, China &Taiwan	Wetland	210,000
Swan Goose *Anser cygnoides*	I	Endangered	Russia, Mongolia & China	Wetland	N&S. Korea, Central China, Japan, Taiwan	Wetland	30,000-50,000
Grey-cheeked Parakeet *Brotogeris pyrrhopterus*	I	Endangered	Ecuador & NW Peru	Forest, Scrub	Ecuador &NW Peru	Forest, Scrub	15,000
Oriental White Stork *Ciconia boyciana*	I	Endangered	Russia and China	General	China, Taiwan, N&S Korea, Japan	General	2,500
Kirtland's Warbler *Dendroica kirtlandii*	I	Vulnerable	NE USA and Canada	Forest, Scrub	Bahamas, Turks &Caicos Islands	Forest, Scrub	1,806
Short-tailed Albatross *Diomedea albatrus*	I	Vulnerable	Japan	Marine	Northern Pacific Ocean, coasts of Russia, Asia, Alaska	Marine	1,200
Amsterdam Albatross *Diomedea amsterdamensis*	I	Critical	Amsterdam Island, southern Indian Ocean (up to 2,200km away)	Marine	Unknown - Australasia?	Marine	90
Chinese Egret *Egretta eulophotes*	I	Vulnerable	Russia, N&S Korea & China	Wetland	Asia	Wetland	1,800-2,500
Spoon-billed Sandpiper *Eurynorhynchus pygmeus*	I	Vulnerable	NE Russia	Wetland	S&SE Asia	Wetland	2,500-10,000
Japanese Night Heron *Gorsachius goisagi*	I	Endangered	Japan	Forest	Philippines, Indonesia	Forest	250-999
White-naped crane *Grus vipio*	I	Vulnerable	Russia, Mongolia and China	Wetland	North/South Korea, Japan	Wetland	5,500-6,500
Pallas' Sea-Eagle *Haliaeetus leucoryphus*	I	Vulnerable	Central and Southern Asia, Indian Sub-continent	Wetland	Nepal, Afghanistan	Wetland	2,500-10,000
Olrog's Gull *Larus atlanticus*	I	Vulnerable	Argentina	Wetland	Disperses North & reaches Uruguay and Brazil	Wetland	4,600

			Breeding		Non-breeding		
		Threat Status	**Range**	**Habitat**	**Range**	**Habitat**	**Population**
Relict Gull *Larus relictus*	I	Vulnerable	Kazakhstan, Russia, Mongolia, China	Wetland	poorly known - includes South Korea & east coastal China	Wetland	2,500-10,000
Saunder's Gull *Larus saundersi*	I	Vulnerable	China & South and North Korea	Wetland	E&S China, Taiwan, Japan, Vietnam	Estuary	7,000
Peruvian Diving-petrel *Pelecanoides garnotii*	I	Endangered	Peru, Chile	Marine	close to breeding islands, upwelling waters	Marine	25,000-28,000
Andean Flamingo *Phoenicopterus andinus*	I	Vulnerable	High Andean Plateaus W&C South America	Wetland	migrates to food supply	Wetland	33,927
Puna Flamingo *Phoenicopterus jamesi*	I	Lower Risk/Near Threatened	High Andean Plateaus W&S South America	Wetland	?	Wetland	47,619
Black-faced Spoonbill *Platalea minor*	I	Endangered	North & South Korea, China	Wetland	Taiwan, Hong Kong, Vietnam, S. Korea &Japan	Estuary	700
Bermuda Petrel *Pterodroma cahow*	I	Endangered	Bermuda	Marine	North into Atlantic	Marine	180
Galapagos Petrel *Pterodroma phaeopygia*	I	Critical	Galapagos Islands, Ecuador	Coastal	E and N towards S. America and around the islands	Marine	20,000-60,000
Hawaiian Petrel *Pterodroma sandwichensis*	I	Vulnerable	Central pacific, Hawaiian Islands	Coastal	Central Pacific	Coastal	20,000
Pink-footed Shearwater *Puffinus creatopus*	I	Vulnerable	Pacific Ocean, Chile	Coastal	Coast of N. America	Marine	34,000-60,000
Syrian Serin *Serinus syriacus*	I	Lower Risk/Near Threatened	Middle East	Wood	Same and Egypt and Iraq	Wood	4,000
Humboldt Penguin *Spheniscus humboldti*	I	Vulnerable	Peru and Chile	Marine	mainly inshore waters; migrates Peru to North Chile, adults disperse up to 170km in Peru	Marine	3,300-12,000
Chestnut Seedeater *Sporophila cinnamomea*	I	Vulnerable	Eastern South America	Grassland	Brazil, NE Paraguay	Grassland	2,500-10,000
Rufous-rumped Seedeater *Sporophila hypochroma*	I	Lower Risk/Near Threatened	Disjunct range in South America	Grassland	Southern breeding populations migrate north to winter in Brazil	Grassland	?
Marsh Seedeater *Sporophila palustris*	I	Endangered	Eastern South America	Grassland	Brazil, NE Paraguay & N. Argentina	Grassland	1,000-2,499
Zelich's Seedeater *Sporophila zelichi*	I	Critical	Argentina	Grassland	Brazil	Grassland	50-249
Chinese Crested Tern *Sterna bernsteini*	I	Critical	China	Wetland	Indonesia, Malaysia, Thailand & Philippines	Wetland	<50

			Breeding		Non-breeding		
		Threat Status	Range	Habitat	Range	Habitat	Population
Japanese Murrelet *Synthliboramphus wumizusume*	I	Vulnerable	Japan	Marine	Japan	Marine	2,500-10,000
Nordmann's Greenshank *Tringa guttifer*	I	Endangered	Eastern Russia	Wetland	Southern Asia	Wetland	250-999
Aquatic Warbler *Acrocephalus paludicola*	I/II	Vulnerable	North and NE Europe & Western Siberia	Wetland	sub-Saharan west Africa (range poorly known)	Wetland	27,000-42,000
Lesser White-front *Anser erythropus*	I/II	Vulnerable	Northern Fennoscandia, Russia & NE Siberia	Tundra	Balkans and China	Steppe	25,000-30,000
Spanish Imperial Eagle *Aquila aadalberti*	I/II	Vulnerable	Eastern and mid Spain	Upland	Eastern and mid Spain	Upland	262
Greater Spotted Eagle *Aquila clanga*	I/II	Vulnerable	Eastern Europe, Russia, Ukraine, Kazakhstan, China and Mongolia	Forest	Central & E Europe, N&E Africa, Middle East & SE Asia	Forest	2,500-10,000
Imperial Eagle *Aquila heliaca*	I/II	Vulnerable	E. Europe, Middle East, Mongolia and China	Forest	Middle East, E. Africa, Indian sub-continent & SE Asia	Forest	2,500-10,000
Ferruginous Duck *Aythya nyroca*	I/II	Lower Risk/Near Threatened	Europe, Asia & N. Africa	Wetland	Overlaps with breeding but extends to Middle East, W&NE Africa & SE Asia	Wetland	>10,000
Red-breasted Goose *Branta ruficollis*	I/II	Vulnerable	Russia	Wetland	Black Sea	Grassland	88,000
Houbara Bustard *Chlamydotis undulata*	I/II	Lower Risk/Near Threatened	Middle East, and W&C Asia	Grassland	Resident and migratory	Grassland	49,000-62,000
Ruddy-headed Goose *Chloephaga rubidiceps*	I/II	Not Globally Threatened	Falkland Islands, Tierra del Fuego	Coastal	Argentina	Grassland	>100,000
Lesser Kestrel *Falco naumanni*	I/II	Vulnerable	Northern Africa, Southern Europe, Middle East, Russia & China	Open	Southern Spain and Turkey and across Africa	Open	50,000-60,000
Bald Ibis *Geronticus eremita*	I/II	Critical	Morocco	Open	Morocco	Open	220
Manchurian Crane *Grus japonensis*	I/II	Endangered	SE Russia, NE China, Japan	Wetland	China, N&S Korea	Wetland	2,200
Siberian Crane *Grus leucogeranus*	I/II	Critical	Arctic Russia, western Siberia	Wetland	China and India, Iran	Wetland	2,500-3,000
Hooded Crane *Grus monacha*	I/II	Vulnerable	S-central and SE Siberia, Russia	Wetland	Japan, South Korea and China	Wetland	9,150
Black-necked Crane *Grus nigricollis*	I/II	Vulnerable	China, India	Wetland	China, Bhutan, India	Wetland	5,600-6,000
White-tailed Eagle *Haliaeetus albicilla*	I/II	Lower Risk/Near Threatened	NW, North, Eastern & SE Europe, Middle East, China and Japan	Upland	Migratory N&E of breeding range; sedentary elsewhere	Upland	5,000-7,000pairs
Steller's Sea-Eagle *Haliaeetus pelagicus*	I/II	Vulnerable	Kamchatka peninsula, Russia.	Coastal	Japan, NE China, N&S Korea	Coastal	5,000

			Breeding		Non-breeding		
		Threat Status	Range	Habitat	Range	Habitat	Population
Blue Swallow *Hirundo atrocaerulea*	I/II	Vulnerable	south and eastern Africa	Grassland	NE Congo, S Uganda and W Kenya	Grassland	3,000
Audouin's Gull *Larus audouinii*	I/II	Lower Risk/Near Threatened	Spain, SE Europe, Tunisia & Morocco	Coastal	N&W Africa coastline	Coastal	20,000
White-eyed Gull *Larus leucophthalmus*	I/II	Lower Risk/Near Threatened	Egypt, Sudan, Saudi Arabia, Yemen & Somalia	Coastal	Dispersing across breeding range	Marine	20,000
Marbled Teal *Marmaronetta angustirostris*	I/II	Vulnerable	Western and eastern Mediterranean, West and South Asia	Wetland	N & sub-Saharan west Africa, Egypt, Iran, Pakistan and NW India	Wetland	9,000-19,000
Eskimo Curlew *Numenius borealis*	I/II	Critical	Canada	Grassland	Argentina, Uruguay, Brazil, Chile	Wetland	<50
Slender-billed Curlew *Numenius tenuirostris*	I/II	Critical	Russia,	Wetland	Southern Europe and North Africa	Wetland	<50
Great Bustard *Otis tarda*	I/II	Vulnerable	Morocco, Spain, C&E Europe, Middle East, C Asia & China	Grassland	Resident or partially migratory. Some winter in the Ukraine	Grassland	31,000-37,000
White-headed Duck *Oxyura leucocephala*	I/II	Endangered	Spain, Algeria, Tunisia, Russia, Middle East; central Asia.	Wetland	SE Europe, Middle East, Central Asia, Indian Sub-continent	Wetland	2,500-10,000
Dalmatian Pelican *Pelecanus crispus*	I/II	Conservation Dependent	Eastern Europe & east-central Asia	Wetland	Eastern Mediterranean, Russia, Middle East, China & Indian sub-continent	Wetland	15,000-20,000
White Pelican *Pelecanus onocrotalus*	I/II	Not Globally Threatened, Regionally Threatened	E Europe, central Asia, Africa S of the Sahara, India	Wetland	NE Africa, Middle East, North India, Pakistan	Wetland	>100,000
Steller's Eider *Polysticta stelleri*	I/II	Lower Risk/Least Concern	Russia, Alaska	Marine	Russia, northern Japan, Atlantic ocean & Baltic Sea	Marine	>100,000
White-winged Flufftail *Sarothura ayresi*	I/II	Endangered	Ethiopia, Zimbabwe and South Africa	Grassland	may move between Ethiopia and South Africa or two populations - unknown.	Grassland	700
Buff-breasted Sandpiper *Tryngites subruficollis*	I/II	Lower Risk/Near Threatened	Arctic coasts, Alaska, Canada, Russia	Coastal	South America	Grassland	5,000-15,000

			Breeding		Non-breeding		
		Threat Status	Range	Habitat	Range	Habitat	Population
Sociable Plover *Vanellus gregarius*	I/II	Vulnerable	Russia, central Asia & middle east	Grassland	Pakistan, Sri Lanka & Oman	Grassland	2,500-10,000
Levant Sparrowhawk *Accipiter brevipes*	II	Not Globally Threatened	SE Europe, SW Asia, Russia	Open	E of Sahel Zone of sub-Saharan Africa	Open	>100,000
Northern Goshawk *Accipiter gentilis*	II	Not Globally Threatened	Europe, NW Africa, Russia, Asia, North America, USA	Forest	Mainly sedentary; northern most pops migrate south.	Forest	>100,000
European Sparrowhawk *Accipiter nisus*	II	Not Globally Threatened	Europe, Asia, NW Africa	Forest	Northern Europe pops & Asia migrate S to NE Africa, Middle East, S Asia	Forest	>100,000
Grasshopper Warbler *Acrocephalus naevia*	II	Secure	Europe >50% of its global breeding range	Wetland	West Africa, South of the Sahara	Wetland	>100,000
Marsh Warbler *Acrocephalus palustris*	II	Secure	C&E Europe >75% of its global breeding range	Wetland	SE Africa	Wetland	>100,000
Sedge Warbler *Acrocephalus schoenobaenus*	II	Secure	Europe >50% of its global breeding range	Scrub, Wetland	Africa, South of the Sahara	Scrub, Wetland	>100,000
Reed Warbler *Acrocephalus scirpaceus*	II	Secure	Europe >50% of its global breeding range	Wetland	Africa, South of the Sahara	Wetland	>100,000
Griffon Vulture *Aegypius monachus*	II	Not Globally Threatened	Southern Europe, SW Asia, Middle East, N India	Upland	partially migratory. Juveniles winter in N Africa.	Upland	>100,000
Striped Crake *Aenigmatolimnas marginalis*	II	Not Globally Threatened	Locally in Africa,	Grassland, Wetland	imperfectly known	Grassland, Wetland	>100,000
Egyptian Goose *Alopochen aegyptiacus*	II	Not Globally Threatened	Africa south of Sahara, Nile Valley, UK	Grassland, Wetland	local movements due to water supply	Grassland, Wetland	>100,000
Tucuman Amazon Parrot *Amazona tucumana*	II	Not Globally Threatened 'Restricted Range'	South Bolivia & NW Argentina	Forest	moves to lower altitudes	Forest	>100,000
Northern Pintail *Anas acuta*	II	Not Globally Threatened	Most of Nearctic and Palaearctic	Wetland	S to lower latitudes	Wetland	>100,000
Cape Teal *Anas capensis*	II	Not Globally Threatened	Central eastern and southern Africa	Wetland		Wetland	>100,000
Northern Shoveler *Anas clypeata*	II	Not Globally Threatened	Most of Nearctic and Palaearctic	Wetland	S to lower latitudes	Wetland	>100,000
Common Teal *Anas crecca*	II	Not Globally Threatened	Most of north and central Palaearctic	Wetland	S to lower latitudes	Wetland	>100,000
Red-billed Duck *Anas erythrorhyncha*	II	Not Globally Threatened	South and East Africa	Wetland		Wetland	>100,000

			Breeding		Non-breeding		
		Threat Status	Range	Habitat	Range	Habitat	Population
Hottentot Teal *Anas hottentota*	II	Not Globally Threatened	East and south Africa	Wetland		Wetland	>100,000
Eurasian Wigeon *Anas penelope*	II	Not Globally Threatened	Iceland, N Europe, N Asia	Wetland		Wetland	>100,000
Mallard *Anas platyrhynchos*	II	Not Globally Threatened	Most Palaearctic and Nearctic	Wetland		Wetland	>100,000
Garganey *Anas querquedula*	II	Not Globally Threatened	Palaearctic	Wetland	sub-Saharan Africa, Indian Sub-continent, SE Asia	Coastal	>100,000
Gadwall *Anas strepera*	II	Not Globally Threatened	Widespread Palaearctic and Nearctic	Wetland	S to lower latitudes	Wetland	>100,000
Yellow-billed Duck *Anas undulata*	II	Not Globally Threatened	East and south Africa	Wetland	sedentary; small movements to alternative wetlands	Wetland	>100,000
Greater White-front *Anser albifrons*	II	Not Globally Threatened	Russia, Siberia, Canada, Alaska, Greenland	Wetland, Tundra	Europe, Asia and North America	Wetland, Steppe	>100,000
Greylag Goose *Anser anser*	II	Not Globally Threatened	Iceland, N&C Europe	Open	southwards	Wetland, Grassland	>100,000
Pink-footed Goose *Anser brachyrhynchus*	II	Not Globally Threatened	Greenland, Iceland and Svalbard	Tundra	UK and E shores of North Sea	Wetland, Grassland	>100,000
Bean Goose *Anser fabalis*	II	Not Globally Threatened	North Europe and Asia (Taiga and Tundra)	Wetland	NW and Central Europe & E Asia	Wetland, Grassland	>100,000
Golden Eagle *Aquila chrysaetos*	II	Not Globally Threatened	USA, Canada, Europe, North Africa, Russia, Asia	Upland	Northern most populations move south	Upland	>100,000
Steppe Eagle *Aquila nipalensis*	II	Not Globally Threatened	Russia, South Asia	Open	Middle East, Middle East, E&S Africa, S. Asia	Open	>100,000
Lesser Spotted Eagle *Aquila pomarina*	II	Not Globally Threatened	C,E&SE Europe, SW Asia, India, S. Asia	Forest	S&E Africa,	Forest	>100,000
Purple Heron *Ardea purpurea purpurea*	II	Not Globally Threatened	S&E Asia, Europe, N Africa, Central &s Africa	Wetland	Central and Southern Africa	Wetland	>100,000
Malagasy Pond Heron *Ardeola idae*	II	Vulnerable	Madagascar and Aldabra	Wetland	Central and East Africa	Wetland	2,500-10,000
Rufous-bellied Heron *Ardeola rufiventris*	II	Not Globally Threatened	southern Africa	Wetland	movements with seasonal flooding	Wetland	>100,000
Ruddy Turnstone *Arenaria interpres*	II	Not Globally Threatened	Canadian Arctic, Greenland, N Eurasia, Alaska	Coastal, Tundra	W Europe, Africa, S Asia, Australasia, USA, S. America	Coastal	>100,000
Common Pochard *Aythya ferina*	II	Not Globally Threatened	Iceland, Europe, Central Asia, SE Russia, S. Palaearctic, NE China & N. Japan	Wetland	Partially migratory. northernmost populations migrate south	Wetland	>100,000

			Breeding		Non-breeding		
		Threat Status	**Range**	**Habitat**	**Range**	**Habitat**	**Population**
Tufted Duck *Aythya fuligula*	II	Not Globally Threatened	N Palaearctic, Central Europe, N Mongolia & Japan	Wetland	Europe, N & sub-Saharan Africa, Middle East, SE Asia, Indian sub-continent, Japan	Wetland	>100,000
Greater Scaup *Aythya marila*	II	Not Globally Threatened	N. Eurasia, NE Siberia, Alaska, Canada	Wetland	Atlantic and Pacific Coasts of North America, NW Europe, Black & Caspian Seas, Japan, China Seas. Also inland N. America & Europe	Coastal	>100,000
Eurasian Bittern *Botaurus stellaris stellaris*	II	Not Globally Threatened, Currently Considered Near-Threatened	Europe Russia and Eastern Asia, South Africa	Wetland	Northern Europe to S and SE Asia, W,S&SE Europe, E Africa	Wetland	>100,000
Brent Goose *Branta bernicla*	II	Not Globally Threatened	Canada, Greenland, Siberia.	Tundra	NW Europe, E Asia, Atlantic & Pacific coasts of N. America	Estuary	>100,000
Barnacle Goose *Branta leucopsis*	II	Not Globally Threatened	Greenland, Svalbard, Novaya Zemlya	Tundra	Britain, Netherlands	Grassland	>100,000
Common Goldeneye *Bucephala clangula*	II	Not Globally Threatened	N&C Europe, Asia, Russia, NE Asia, North America	Wetland	South America, Europe, S. Russia, E China	Coastal	>100,000
Stone Curlew *Burhinus oedicnemus*	II	Not Globally Threatened	N Africa, W,S&SE Europe, Middle East, SW&S Asia,	Grassland	S of breeding range, locally in Sahel zone, W Africa & Middle East	Grassland	>100,000
Common Buzzard *Buteo buteo*	II	Not Globally Threatened	Europe, Asia	General	Northern pop moves south, Central Europe - E&S Africa & S Asia	General	>100,000
Rough-legged Buzzard *Buteo lagopus*	II	Not Globally Threatened	N Europe, N Russia, Alaska & N Canada	Tundra	C Europe& C&E Asia, C&S USA	Open	>100,000
Long-legged Buzzard *Buteo rufinus*	II	Not Globally Threatened	SE Europe, SW&C Asia, N Africa, Middle East	Steppe	NE Africa ,N India	Open	>100,000
Sanderling *Calidris alba*	II	Not Globally Threatened	Canadian Arctic, Greenland, Svalbard, Alaska	Tundra	USA and S America, W&S Europe, Africa, S Asia and Australasia	Coastal	>100,000
Dunlin *Calidris alpina*	II	Not Globally Threatened	Greenland, Iceland, N Europe, N Russia, Alaska, N Canada	Wetland, Grassland	NW Africa, S&SW Europe, S&SE Asia & NW Africa, USA, South America	Wetland	>100,000

			Breeding		Non-breeding		
		Threat Status	Range	Habitat	Range	Habitat	Population
Red Knot *Calidris canutus*	II	Not Globally Threatened	Siberia, NW Alaska, Canada, Greenland	Tundra	W&S Africa, Australasia, USA & S. America, W. Europe	Estuary	>100,000
Curlew Sandpiper *Calidris ferruginea*	II	Not Globally Threatened	Arctic Siberia	Tundra	Sub-Saharan Africa, Middle East, S Asia & Australasia	Wetland	>100,000
Purple Sandpiper *Calidris maritima*	II	Not Globally Threatened	Arctic & sub-arctic NE Canada, Greenland, Iceland, NW Siberia, N Europe	Tundra	E North America & NW Europe	Coastal	>100,000
Little Stint *Calidris minuta*	II	Not Globally Threatened	N Europe, N Siberia	Tundra	W, SW&SE Africa, Middle East, Indian Subcontinent	Wetland	>100,000
Temminck's Stint *Calidris temminckii*	II	Not Globally Threatened	N Europe, N Siberia	Tundra	SE Europe, Middle East, N Tropical Africa, Indian Subcontinent, S Asia	Wetland	>100,000
Great Knot *Calidris tenuirostris*	II	Not Globally Threatened	NE Siberia	Tundra	SE Asia, Australasia, South Asia, India	Coastal	>100,000
Great White Egret *Casmerodius albus albus*	II	Not Globally Threatened	Central Europe to Central Asia, Middle East	Wetland	N&C Africa, Persian Gulf to S China &S Korea	Wetland	>100,000
Kentish Plover *Charadrius alexandrinus*	II	Not Globally Threatened	W&SE Europe, N&NE Africa, Middle East, S,SW&C Asia, Russia &NE China, USA, N South America	Wetland	Sub-Saharan Africa, S Asia, W Indonesia, South America	Wetland	>100,000
Caspian Plover *Charadrius asiaticus*	II	Not Globally Threatened	W,N&E Caspian Sea, SW Asia	Steppe	E&S Africa	Grassland	>100,000
Little Ringed Plover *Charadrius dubius*	II	Not Globally Threatened	Eurasia, N Africa, Russia, SE Asia, India	Wetland	Africa S of the Sahara, Middle East, S Asia	Wetland	>100,000
Forbes' Plover *Charadrius forbesi*	II	Not Globally threatened	West and Central Africa	Upland		Grassland	>100,000
Common Ringed Plover *Charadrius hiaticula*	II	Not Globally Threatened	NE Canada, Greenland, Iceland, N&NW Europe, N Russia	Wetland	NW Europe, Africa, Middle East, SW Asia	Coastal	>100,000
Greater Sandplover *Charadrius leschenaultii*	II	Not Globally Threatened	Middle East, SE,C,SW Asia	Steppe	SE Europe, SW&S Asia, E&SE Africa, Australasia	Coastal	>100,000
White-fronted Plover *Charadrius marginatus*	II	Not Globally Threatened	Africa S of the Sahara	Coastal	Inland pops may move to coast	Coastal	>100,000
Mongolian Plover *Charadrius mongolus*	II	Not Globally Threatened	E Russia, C&S Asia	Steppe	S&E Africa, Middle East, S Asia, India, Australasia	Coastal	>100,000

			Breeding		Non-breeding		
		Threat Status	Range	Habitat	Range	Habitat	Population
Chestnut-banded Plover *Charadrius pallidus*	II	Not Globally Threatened	Southern Africa	Wetland	some inland birds move to coast	Wetland	>100,000
Kittlitz's Plover *Charadrius pecuarius*	II	Not Globally Threatened	Africa	Coastal	seasonal movements related to rainfall	Coastal	>100,000
Three-banded Plover *Charadrius tricollaris*	II	Not Globally Threatened	Africa	Wetland	normally resident, erratic movements	Wetland	>100,000
White-winged Black Tern *Chlidonias leucopterus*	II	Not Globally Threatened	SW,C&E Europe, E Russia, C&SE Asia	Wetland	Africa, S Asia, Australasia	Wetland	>100,000
Black Tern *Chlidonias niger niger*	II	Not Globally Threatened	C&E Europe, Russia and W Asia, USA	Wetland	Africa, South USA and N South America	Wetland	>100,000
White Stork *Ciconia ciconia*	II	Not Globally Threatened, Currently Considered Near-Threatened	Europe, W Asia, S Africa, Turkistan	Wetland, Grassland	Tropical Africa and South Africa, Iran & India	Wetland, Grassland	>100,000
Woolly-necked Stork *Ciconia episcopus microscelis*	II	Not Globally Threatened	Africa S of the Sahara, India, Southern Asia	Wetland, Grassland		Wetland, Grassland	>100,000
Black Stork *Ciconia nigra*	II	Not Globally Threatened	Palaearctic	Wetland, Grassland	NE & E Africa, South Asia	Wetland, Grassland	>100,000
Short-toed Eagle *Circaetus gallicus*	II	Not Globally Threatened	NW Africa, S&E Europe, Middle East, SW Asia, Indian Sub-continent	General	Western population migrates to Sahel zone	General	>100,000
Marsh Harrier *Circus aeruginosus*	II	Not Globally Threatened	Europe; Middle East, W&C Asia, NW Africa	Wetland	W&S Europe, Africa south of the Sahara, India Sub-continent	Wetland	>100,000
Hen Harrier *Circus cyaneus*	II	Not Globally Threatened	Europe, Asia, Canada, USA,N South America	Open	Europe, NW Africa, South Asia, S to N America	Open	>100,000
Pallid Harrier *Circus microburst*	II	Not Globally Threatened	E Europe, W&C Asia	Grassland	Africa - south of Sahara, India, Sri Lanka, E China, Middle East	General	>100,000
Montagu's Harrier *Circus pygargus*	II	Not Globally Threatened	Europe, SW, W&C Asia	Open	Africa -south of Sahara, Indian Sub-continent	Open	>100,000
Long-tailed Duck *Clangula hyemalis*	II	Not Globally Threatened	whole arctic coasts	Coastal	Northern seas, Coastal Europe, America & Korea	Coastal	>100,000

			Breeding		Non-breeding		
		Threat Status	Range	Habitat	Range	Habitat	Population
Roller *Coracias garrulus*	II	Not Globally Threatened	NW Africa, SW,SC&E Europe, W,SW&C Asia, Middle East, Russia	Open	Africa South of the Sahara	Open	>100,000
Quail *Coturnix coturnix coturnix*	II	Not Globally Threatened	British Isles & NW Africa, Europe, EC Russia & EC India	Grassland	Sahel Zones of Africa & C&S India	Grassland	>100,000
Corncrake *Crex crex*	II	Vulnerable	Europe, W &C Asia	Wetland, Grassland	Sub-Saharan Africa	Grassland	>100,000
Bewick's Swan *Cygnus columbianus*	II	Not Globally Threatened	Arctic Siberia	Tundra	W. Europe, S of Caspian Sea, Echini, Korea, Japan	Coastal	>100,000
Whooper Swan *Cygnus cygnus*	II	Not Globally Threatened	Scandinavia east to NE Siberia	Wetland	W&C Europe, SE Europe east to coastal China	Coastal	>100,000
Mute Swan *Cygnus olor*	II	Not Globally Threatened	Central and N Europe, Central and E Asia. Feral N. America, Japan, South Africa, Australia, New Zealand	Wetland		Wetland	>100,000
Fulvous Whistling-duck *Dendrocygna bicolor*	II	Not Globally Threatened	S USA, South America, central and southern Africa, Indian sub-continent & S Asia	Wetland, Grassland		Wetland, Grassland	>100,000
White-faced Whistling-duck *Dendrocygna viduata*	II	Not Globally Threatened		Wetland	South America, Central & south Africa	Wetland	>100,000
Buller's Albatross *Diomedea bulleri*	II	Vulnerable	New Zealand endemic	Coastal	Disperse across Pacific ocean to west coast of South America	Coastal	58,000
Shy Albatross *Diomedea cauta*	II	Lower Risk/Near Threatened	Australian &New Zealand Islands	Coastal	rarely travel far from breeding grounds	Marine	?
Yellow-nosed Albatross *Diomedea chlororhynchos*	II	Vulnerable	Tristan da Cunha archipelago	Coastal	South Atlantic, coast of Argentina, Brazil, S. Africa	Marine	27,000-46,000 bp
Grey-headed Albatross *Diomedea chrysostoma*	II	Vulnerable	Chile, South Georgia, South Africa, Australia and New Zealand islands, within or south of Antarctic Frontal Zone	Coastal	Southern Oceans	Marine	?
Royal Albatross *Diomedea epomophora*	II	Vulnerable	New Zealand Islands	Coastal	Circumnavigate the Southern Ocean, most NZ and S. American waters	Marine	28,000

		Threat Status	Breeding Range	Habitat	Non-breeding Range	Habitat	Population
Wandering Albatross *Diomedea exulans*	II	Vulnerable	South Georgia, South Africa, French Southern Territories and Australia	Coastal	Disperses widely in Southern Oceans	Marine	28,000
Laysan Albatross *Diomedea immutabilis*	II	Not Globally Threatened	Hawaii, SE Japan,W Mexico	Coastal	Pacific ocean	Marine	>100,000
Waved Albatross *Diomedea irrorata*	II	Vulnerable	Galapagos Islands, Ecuador, Peruvian up-welling region to feed	Coastal	East and SE into waters of Ecuadorian & Peruvian continental shelf	Marine	31,200 - 36,400
Black-browed Albatross *Diomedea melanophris*	II	Vulnerable	Falkland Is., Chile, South Georgia, French Southern Territories, Australia & New Zealand	Coastal		Marine	68,000 pairs
Black-footed Albatross *Diomedea nigripes*	II	Vulnerable	Hawaiian Islands, Japan	Coastal	Disperses widely over north Pacific Ocean.	Marine	>100,000
Crab Plover *Dromas ardeola*	II	Not Globally Threatened	NW Indian Ocean, Persian Gulf & Red Sea	Coastal	Partially migratory. E Africa, India, Indian Ocean islands, S Asia	Coastal	>100,000
Slaty Egret *Egretta vinaceigula*	II	Vulnerable	E&C Africa	Wetland	movements in response to rains	Wetland	3,000-5,000
Eurasian Dotterel *Eudromias morinellus*	II	Not Globally Threatened	N Europe, N Russia, C Asia	Upland	N Africa, Middle East	Grassland	>100,000
Saker Falcon *Falco cherrug*	II	Not Globally Threatened. Currently Considered Near Threatened	C Europe, SW Russia, Middle East, SE Siberia, C Asia	Steppe	SE Europe, NE Africa, Middle East, S Asia, NW India	Steppe	>100,000
Eleonora's Falcon *Falco eleonorae*	II	Not Globally Threatened	Rocky coast N Africa & SE Europe	Coastal	E Africa, Madagascar	General	>100,000
Peregrine Falcon *Falco peregrinus*	II	Not Globally Threatened	Worldwide	General	worldwide - Highly migratory in N Temperate and Arctic zones	General	>100,000
Gyr Falcon *Falco rusticolus*	II	Not Globally Threatened. Considered Near Threatened	Arctic regions of Europe, Asia, N America, Greenland and Iceland	Upland	Sedentary. Some movements to food supply. White morphs from Greenland to Iceland. N America to Siberia.	Open	>100,000

			Breeding		Non-breeding		
		Threat Status	Range	Habitat	Range	Habitat	Population
Eurasian Hobby *Falco subbuteo*	II	Not Globally Threatened	Europe, NW Africa, Asia	Steppe, Grassland	C&S Africa & S Asia	Savannah	>100,000
Common Kestrel *Falco tinnunculus*	II	Not Globally Threatened	Europe, Asia, N Africa; Africa S of the Sahara	Open	partially migratory.	Open	>100,000
Red-footed Falcon *Falco vespertinus*	II	Not Globally Threatened	E Europe, W&NC Asia	Open	SW Africa	Savannah	>100,000
Merlin *Falcon columbarius*	II	Not Globally Threatened	N Europe, N&C Asia, Canada, N USA	General	C,E,S &W Europe, S Asia, S USA, N South America	General	>100,000
Collared Flycatcher *Ficedula albicollis*	II	Secure	E&C Europe 100% of global breeding range	Forest	Africa, south of the equator (trans Saharan migrant)	Forest	>100,000
Pied Flycatcher *Ficedula hypoleuca*	II	Secure	Europe >75% of its global breeding range	Forest	W Africa, south of the Sahara	Forest	>100,000
Common Coot *Fulica atra atra*	II	Not Globally Threatened	Europe, N Africa, Asia, Australasia	Wetland	Resident in warm climates. Migratory elsewhere	Wetland	>100,000
Common Snipe *Gallinago gallinago*	II	Not Globally Threatened	Europe, NC Eurasia, E Russia, Canada, N USA	Wetland	Europe, equatorial Africa, Middle East, India, South Asia, NW,C&S USA, N South America	Wetland	>100,000
Great Snipe *Gallinago media*	II	Lower Risk/Near Threatened	Russia, Belarus, Scandinavia & NE Europe	Wetland	Africa	Wetland	>100,000
White-billed Diver *Gavia adamsii*	II	Not Globally Threatened	Holarctic, coasts of arctic ocean	Wetland	coastal waters NW&NE Pacific & NW Norway	Coastal	>100,000
Black-throated Diver *Gavia arctica arctica*	II	Not Globally Threatened	E Palaearctic E of River Lena	Wetland	NW Europe, SE Europe	Coastal	>100,000
Black-throated Diver *Gavia arctica suschkini*	II			Wetland		Coastal	
Great Northern Diver *Gavia immer immer*	II	Not Globally Threatened	North America, Greenland, Iceland, Scotland	Wetland	N Atlantic, NE Pacific	Coastal	>100,000
Red-throated Diver *Gavia stellata*	II	Not Globally Threatened	Holarctic, high arctic	Wetland	Atlantic and Pacific coasts, Great Lakes, SE Europe	Coastal	>100,000
Black-winged Pratincole *Glareola nordmanni*	II	Data Deficient	Russia, SE Europe/Middle East	Steppe	Southern Africa	Steppe	>100,000
Collared Pratincole *Glareola pratincola*	II	Not Globally Threatened	S Europe, SW&C Asia, Middle East, N& sub-Saharan Africa	Steppe	Sub-Saharan Africa	Steppe	>100,000

			Breeding		Non-breeding		
		Threat Status	Range	Habitat	Range	Habitat	Population
Wattled Crane *Grus carunculatus*	II	Vulnerable	Ethiopia, Central Africa, South Africa	Wetland	Ethiopia, Central Africa, South Africa	Wetland	13,000-15,000
Common Crane *Grus grus*	II	Not Globally Threatened	N&NE Europe, Russia, Asia	Wetland	SW Europe, NW&NE Africa, Middle East, S Asia	Wetland	>100,000
Blue Crane *Grus paradisea*	II	Vulnerable	South Africa, Namibia, Swaziland	Grassland	South Africa, Namibia, Swaziland	Grassland	21,000
Demoiselle Crane *Grus virgo*	II	Not Globally Threatened	C Eurasia, &NE China, NW Africa, SE Europe	Steppe	Indian sub-continent, Sub-Saharan Africa	Grassland, Wetland	>100,000
Booted Eagle *Hieraaetus pennatus*	II	Not Globally Threatened	SW& E Europe, NW Africa, SE and C Asia, South Africa	Forest	Africa -south of Sahara, S Asia, India	Forest	>100,000
Black-winged Stilt *Himantopus himantopus*	II	Not Globally Threatened	SE&S Europe, N &Sub-Saharan Africa, E, C&S Asia, Australasia, W&S USA, South America	Wetland	Sedentary in places. N populations to Africa, Central &south America	Wetland	>100,000
Little Bittern *Ixobrychus minutus minutus*	II	Not Globally Threatened	C & S Europe, N Africa, W Siberia, Middle East, NE India	Wetland	Africa to India	Wetland	>100,000
African Dwarf Bittern *Ixobrychus sturmii*	II	Not Globally Threatened	Africa south of Sahara	Wetland	Movements relate to changes in water levels	Wetland	>100,000
Armenian Gull *Larus armenicus*	II	Not Globally Threatened, Maybe Vulnerable	Armenia, Turkey, Iran	Coastal	Black Sea, E Mediterranean, Red Sea	Coastal	23-25,000 bp
Slender-billed Gull *Larus genei*	II	Not Globally Threatened	isolated localities, SE Europe, SW&C Asia, Middle East	Coastal	Sedentary; or S to Horn of Africa	Coastal	75,000-125,000 bp
Sooty Gull *Larus hemprichii*	II	Not Globally Threatened	NE Africa, Middle East, SW Asia	Coastal	Many sedentary, others S to E Africa	Coastal	50,000 - 100,000 bp
Great Black-headed Gull *Larus ichthyaetus*	II	Not Globally Threatened	scattered localities, Black Sea, SW &C Asia	Coastal	Coasts of SE Europe, E Africa, Middle East, S Asia	Wetland	?
Mediterranean Gull *Larus melanocephalus*	II	Not Globally Threatened	SW Asia, locally in Europe,	Wetland	Europe, SW Asia, NW Africa	Wetland	>100,000
Broad-billed Sandpiper *Limicola falcinellus*	II	Not Globally Threatened	N Europe & NW&N Russia	Tundra	E&S Africa, SW,S&SE Asia, Australasia	Wetland	>100,000
Bar-tailed Godwit *Limosa lapponica*	II	Not Globally Threatened	N Europe, N Russia, W Alaska	Tundra	NW&W Europe, Africa, Middle East, S&SE Asia, Australasia	Wetland	>100,000

			Breeding		Non-breeding		
		Threat Status	Range	Habitat	Range	Habitat	Population
Black-tailed Godwit *Limosa limosa*	II	Not Globally Threatened	Iceland, Europe, E Russia, E&C Asia	Wetland	Europe, sub-Saharan Africa, Middle East, SW&S Asia, Australasia	Wetland	>100,000
Jack Snipe *Lymnocryptes minimus*	II	Not Globally Threatened	N&NE Europe, N&NE Siberia,	Wetland, Tundra	NW,W,SE Europe, N&C Africa, Middle East, S Asia	Wetland	>100,000
Southern Giant Petrel *Macronectes giganteus*	II	Vulnerable	Antarctica and the Southern Ocean islands	Coastal	post breeding dispersal extensive	Coastal	62,000
Northern Giant Petrel *Macronectes halli*	II	Lower Risk/Near Threatened	Antarctica and the Southern Ocean islands	Coastal	Antarctica and the Southern Ocean islands	Coastal	11,500 bp
Velvet Scoter *Melanitta fusca*	II	Not Globally Threatened	Scandinavia, NE Europe, Central Siberia	Wetland, Tundra	NW Europe, Mediterranean, SE Europe	Coastal	>100,000
Common Scoter *Melanitta nigra*	II	Not Globally Threatened	Iceland, Northern Europe, Siberia	Wetland	Atlantic coast of Europe & N. Africa, SE Europe	Coastal	>100,000
Smew *Mergellus albellus*	II	Not Globally Threatened	Sweden E to E Siberia	Wetland	West and Central Europe, SE Europe, Middle East, E Asia	Wetland	>100,000
Goosander *Mergus merganser*	II	Not Globally Threatened	North America, Europe, Russia, C&E Asia	Wetland	Northern most populations move south	Wetland	>100,000
Red-breasted Merganser *Mergus serrator*	II	Not Globally Threatened	North America, Greenland N Europe, NE China & N Japan	Wetland	partially migratory; Atlantic and Pacific coasts, SE Europe, S Russia, E Asia	Coastal	>100,000
Bee-eater *Merops apiaster*	II	Not Globally Threatened	NW Africa, SW,S,SE Europe, W Russia, C&SW Asia, Middle East, S Africa.	Open	W and S Africa	Open	>100,000
Black Kite *Milvus migrans*	II	Not Globally Threatened	Africa, Europe, Asia, Australasia	Open	migrants - Sub-Saharan Africa, Middle East	Open	>100,000
Red Kite *Milvus milvus*	II	Insufficiently Known	Europe	Open	N&C Europe migratory, some to N Africa	Open	>100,000
Spotted Flycatcher *Muscicapa striata*	II	Depleted	Europe <50% its global breeding range	Wood	Sub-Saharan Africa, south of the Equator	Wood	>100,000
Yellow-billed Stork *Mycteria ibis*	II	Not Globally Threatened	Africa south of the Sahara	Wetland	West Africa moves N for wet season	Wetland	>100,000
Egyptian Vulture *Neophron percnopterus*	II	Not Globally Threatened	S Europe, SW and C Asia, NW India, N Africa, Middle East	Steppe	N of range migratory, S to Africa	Steppe	>100,000
Southern Pochard *Netta erythrophthalma*	II	Not Globally Threatened	South and east Africa, north South America	Wetland	moves with water supply in dry climates	Wetland	>100,000

			Breeding		Non-breeding		
		Threat Status	Range	Habitat	Range	Habitat	Population
Red-crested Pochard *Netta rufina*	II	Not Globally Threatened	Europe, West Asia	Wetland	Mediterranean Basin, SW Russia, Middle East, Indian-subcontinent& SE Asia	Wetland	>100,000
African Pygmy-goose *Nettapus auritus*	II	Not Globally Threatened	Central and South Africa	Wetland	moves with water supply during dry season	Wetland	>100,000
Eurasian Curlew *Numenius arquata*	II	Not Globally Threatened	W,NW&N Europe, W&C Russia	Wetland	Europe, Africa, Middle East, SW&S Asia	Wetland	>100,000
Whimbrel *Numenius phaeopus*	II	Not Globally Threatened	NW&N Europe, NW,N&NE Russia, SW Asia, Alaska, N Canada	Tundra	SW Europe, Africa, Middle East, S Asia, Australasia, S USA& N South America	Coastal	>100,000
Osprey *Pandion haliaetus*	II	Not Globally Threatened	Worldwide	Wetland	Resident in tropical & subtropical regions. Migratory elsewhere, moving to latitudes near the equator	Wetland	>100,000
Honey Buzzard *Pernis apivorus*	II	Not Globally Threatened	Europe, W Asia	Forest	Africa S of the Sahara	Forest	>100,000
Socotra Cormorant *Phalacrocorax nigrogularis*	II	Vulnerable	Persian Gulf, Oman	Coastal	movements related to fish migration	Coastal	>100,000
Pygmy Cormorant *Phalacrocorax pygmeus*	II	Lower Risk/Near Threatened	SE Europe, Russia, Middle East, central Asia	Wetland	SE Europe and middle East	Wetland	25,000 bp
Grey Phalarope *Phalaropus fulicaria*	II	Not Globally Threatened	Circumpolar, Arctic Ocean coasts	Tundra	Pelagic off W South America, and W&SW Africa	Marine	>100,000
Red-necked Phalarope *Phalaropus lobatus*	II	Not Globally Threatened	Circumpolar, Arctic Ocean coasts & NW Britain	Tundra	Pelagic off CW South America, Arabian Sea, South Asia	Marine	>100,000
Ruff *Philomachus pugnax*	II	Not Globally Threatened	NW,N&NE Europe, N&C Russia, NW Asia	Wetland	W,SW&SE Europe, sub-Saharan Africa, Middle East, S Asia	Wetland	>100,000
Sooty Albatross *Phoebetria fusca*	II	Vulnerable	Islands in South Atlantic and Indian Oceans	Coastal	subtropical waters	Coastal	42,000
Light-mantled Sooty Albatross *Phoebetria palpebrata*	II	Lower Risk/Near Threatened	Islands in South Atlantic and Indian Oceans	Coastal	South Atlantic and Indian Oceans	Coastal	58,000

			Breeding		Non-breeding		
		Threat Status	Range	Habitat	Range	Habitat	Population
Lesser Flamingo *Phoenicopterus minor*	II	Lower Risk/Near Threatened	Africa, India and Pakistan	Wetland	sub-Saharan countries	Wetland	>100,000
Greater Flamingo *Phoenicopterus ruber*	II	Not Globally Threatened	S Europe, SE Asia, coasts of Africa, Middle East, India	Wetland	Partially migratory	Wetland	>100,000
Chiffchaff *Phylloscopus collybita*	II	Secure	Europe < 50% of its global breeding range	Forest	Resident or migratory. Afrotropics, Arabia ,North India	Forest	>100,000
Wood Warbler *Phylloscopus sibilatrix*	II	Declining	Europe >75% of its global breeding range	Forest	Sub-Saharan Africa	Forest	>100,000
Willow Warbler *Phylloscopus trochilus*	II	Secure	Europe (except S) <50% of its breeding range	Wood	Sub-Saharan Africa	Wood	>100,000
African Spoonbill *Platalea alba*	II	Not Globally Threatened	Central, East and South Africa	Wetland	Little known	Wetland	>100,000
Eurasian Spoonbill *Platalea leucorodia*	II	Not Globally Threatened	Europe, C&E Asia, India & Sri Lanka, coast of Red Sea	Wetland	W&E Africa & SE China	Wetland	>100,000
Spur-winged Goose *Plectropterus gambensis*	II	Not Globally Threatened	Africa	Wetland, Grassland	movements related to water supply	Wetland, Grassland	>100,000
Glossy Ibis *Plegadis falcinellus*	II	Not Globally Threatened	S Europe, C and S Asia, Africa, N. America West Indies, Australia	Wetland	Migratory and dispersive. Sub-Saharan Africa, movement to water.	Wetland	>100,000
Eurasian Golden Plover *Pluvialis apricaria*	II	Not Globally Threatened	Greenland, NW,N&NE Europe, NW&N Russia	Tundra	NW,W,S&SE Europe, N Africa, CW Asia	Grassland, Coastal	>100,000
Grey Plover *Pluvialis squatarola*	II	Not Globally Threatened	Arctic Russia, Alaska, N Canada	Tundra	N&S America, W Europe, Africa, S Asia, Australasia	Coastal	>100,000
Slavonian Grebe *Podiceps auritus*	II	Not Globally Threatened	Northern Europe, Russia, Canada, Alaska, NC USA	Wetland	North Sea, SE Asia, Japan, China, Southern America	Marine	>100,000
Red-necked Grebe *Podiceps grisegena grisegena*	II	Not Globally Threatened	E Europe, E & W Asia, N Japan, Canada, NW USA	Wetland	North Sea, SW&SE Asia, E USA, S.USA	Marine	>100,000
Bearded Tachuri *Polystictus pectoralis pectoralis*	II	Lower Risk/Near Threatened	Andes, locally in South America	Grassland	summer visitor in C-E Argentina	Grassland	?
Little Crake *Porzana parva parva*	II	Not Globally Threatened	Europe, W Russia, WC Asia	Wetland	SE Europe, W&E Africa, Middle East, S Asia	Wetland	>100,000
Spotted Crake *Porzana porzana*	II	Not Globally Threatened	Europe, W&C Russia, Iran, W&C Asia	Wetland	SE Europe, Middle East, W,E&S Africa, S Asia	Wetland	>100,000

			Breeding		**Non-breeding**		
		Threat Status	**Range**	**Habitat**	**Range**	**Habitat**	**Population**
Baillon's Crake *Porzana pusilla intermedia*	II	Not Globally Threatened	W,S&E Europe, N&S Africa, W,C&E Asia, Australasia	Wetland	SE Europe, Africa, S Asia, Australasia	Wetland	>100,000
White-chinned Petrel *Procellaria aequinoctialis*	II	Vulnerable	Islands in South Atlantic and Indian Oceans, forages north to sub-tropics and south to Antarctic pack ice, disperses widely in all Southern Oceans	Coastal	All southern oceans	Coastal	5,000,000
Spectacled Petrel *Procellaria aequinoctialis conspicillata*	II	Critical	Tristan da Cunha	Coastal	Waters of Southern Brazil & South Africa	Coastal	2,500-10,000
Grey Petrel *Procellaria cinerea*	II	Lower Risk/Near Threatened	Islands in South Atlantic and Indian Oceans	Coastal	South Atlantic and Indian Oceans	Coastal	?
Black Petrel *Procellaria parkinsoni*	II	Vulnerable	Little & Great Barrier Islands, New Zealand	Coastal	Eastern pacific oceans	Marine	5,000
Westland Petrel *Procellaria westlandica*	II	Vulnerable	New Zealand	Coastal	Central pacific and Eastern New Zealand waters & off S. America	Marine	<20,000
Dinelli's Doradito *Pseudocolopteryx dinellianus*	II	Lower Risk/Near Threatened Species	N. Argentina	Wetland, Grassland	Argentina	Wetland, Grassland	
Pied Avocet *Recurvirostra avosetta*	II	Not Globally Threatened	Europe, W,C&S Asia, Russia, N,E&S Africa	Wetland	West Europe, Africa, Middle East, S Asia	Wetland	>100,000
Firecrest *Regulus ignicapilla*	II	Secure	WC&S Europe >75%global breeding range	Forest	Resident to partial migrant. N&E populations heading S&W Europe.	Forest	>100,000
Goldcrest *Regulus regulus*	II	Secure	Europe >50% of its global breeding range	Forest	Resident or migratory. Most Northern populations move S in winter	Forest	>100,000
Comb Duck *Sarkidiornis melanotos*	II	Not Globally Threatened	Tropical Africa, SE Asia, India, S China	Wetland	seasonal movements related to water	Wetland	>100,000
Streaky-breasted Flufftail *Sarothura boehmi*	II	Not Globally Threatened	Scattered, C and Southern Africa	Grassland	S tropics to equatorial regions in dry season	Grassland	>100,000
Common Eider *Somateria mollissima*	II	Not Globally Threatened	NW Europe, NE Siberia, Coastal N America, Alaska, Greenland	Coastal	Wintering at sea, N and NW Europe, Iceland, Greenland, NE North America	Coastal	>100,000

			Breeding		Non-breeding		
		Threat Status	Range	Habitat	Range	Habitat	Population
King Eider *Somateria spectabilis*	II	Not Globally Threatened	Arctic coasts	Coastal	Northern Europe, Iceland, Greenland, NE America, Alaska.	Marine	>100,000
African Penguin *Spheniscus demises*	II	Vulnerable	24 islands & 3 mainland sites in South Africa and Namibia	Coastal	within 40km of the shore of Southern Africa	Coastal	>100,000
Dark-throated Seedeater *Sporophila ruficollis*	II	Lower Risk/Near Threatened	Locally in South America	Grassland	?	Grassland	?
Little Tern *Sterna albifrons*	II	Not Globally Threatened	Europe, W,S,&E Asia, Australasia, C Africa	Wetland	E Africa, Middle East, S Asia, Australasia	Coastal	>100,000
Damara Tern *Sterna balaenarum*	II	Lower Risk/Near Threatened	south Africa	Coastal	Central Africa	Coastal	13,500
Lesser Crested Tern *Sterna bengalensis*	II	Not Globally Threatened	N&NE Africa, Middle East, S Asia, Australasia	Coastal	W African coast, S Africa, S Asia, Australasia	Coastal	>100,000
Great Crested Tern *Sterna bergii*	II	Not Globally Threatened	W&S Africa, Australasia, Middle East, S Asia	Coastal	Mostly Resident. Middle East to E Africa	Coastal	>100,000
Caspian Tern *Sterna caspia*	II	Not Globally Threatened	N American Europe, Africa, C&S Asia, Australasia	Wetland	Africa, SE USA, Mexico, Australasia, S Europe	Wetland	>100,000
Roseate Tern *Sterna dougallii*	II	Not Globally Threatened	E&SE USA, NW Europe, E&S Africa, Australasia, S Asia	Coastal	mid-Atlantic, W Africa, N South America, Australasia	Coastal	>100,000
Common Tern *Sterna hirundo hirundo*	II	Not Globally Threatened	N&S America, N South America, Europe, N&W Africa, Middle East, W,C&E Asia, Russia	Wetland	S of Tropic of Cancer, Indian Ocean, SE Asia, Australasia	Coastal	>100,000
Royal Tern *Sterna maxima albidorsalis*	II	Not Globally Threatened	W Africa, N&C America. South America	Coastal	SE Africa, South America	Coastal	>100,000
Gull-billed Tern *Sterna nilotica nilotica*	II	Not Globally Threatened	S Europe, N Africa, Middle East, S&C Asia, Australasia, C America, South America	Coastal	Africa, S&SE Asia, C America, South America	Wetland	>100,000
Arctic Tern *Sterna paradisaea*	II	Not Globally Threatened	Iceland, NW&N Europe, N Russia, N of Arctic Circle. Alaska, Greenland, Canada, N USA	Wetland	Antarctica	Marine	>100,000
White-cheeked Tern *Sterna repressa*	II	Not Globally Threatened	NE Africa, Middle East, SW Asia	Coastal	NE Africa, Middle East, SW India	Coastal	>100,000

			Breeding		Non-breeding		
		Threat Status	Range	Habitat	Range	Habitat	Population
Sandwich Tern *Sterna sandvicensis sandvicensis*	II	Not Globally Threatened	Europe, Middle East, E North America, South America	Coastal	SE Europe, W&S Asia, W&S Africa, Middle East, E North America, South America	Coastal	>100,000
Saunder's Tern *Sterna saundersi*	II	Not Globally Threatened	NE Africa, Middle East, SW Asia	Coastal	NE Africa, Middle East and SW&S Asia	Coastal	>100,000
Turtle Dove *Streptopelia turtur turtur*	II	Not Globally Threatened	Europe, Russia, WC&C Asia	Wood	Sahel Zone	Savannah	>100,000
Blackcap *Sylvia atricapilla*	II	Secure	Europe >75% of its global breeding range	Wood	Resident or migratory. Sub-Saharan Africa, Britain, SW Norway	Wood	>100,000
Garden Warbler *Sylvia borin*	II	Secure	Europe >75% of its global breeding range	Wood	Africa	Wood	>100,000
Whitethroat *Sylvia communis*	II	Secure	Europe >50% of its global breeding range	Wood	Sub-Saharan Africa, & south to South Africa	Wood	>100,000
Lesser Whitethroat *Sylvia curruca*	II	Secure	Europe <50% of its global breeding range	Wood	Africa, South of the Sahara	Wood	>100,000
South African Shelduck *Tadorna cana*	II	Not Globally Threatened	Southern Africa	Wetland	movements related to water supply	Wetland	>100,000
Ruddy Shelduck *Tadorna ferruginea*	II	Not Globally Threatened	SE Europe, Central Asia, NW Africa	Wetland	Asian pop moves S in winter	Wetland	>100,000
Common Shelduck *Tadorna tadorna*	II	Not Globally Threatened	NW&SE Europe, Central Eastern Asia, NE China, Middle East	Wetland	Northern pops move S, migrate to moult.	Coastal	>100,000
White-backed Duck *Thalassornis leuconotus*	II	Not Globally Threatened	West, East and south Africa	Wetland	local movements to water availability	Wetland	>100,000
Sacred Ibis *Threskiornis aethiopicus aethiopicus*	II	Not Globally Threatened	Africa S of the Sahara, SE Iraq	Grassland	Migrants N-S within Africa S of the Sahara, SE Iraq	Wetland	?
Terek Sandpiper *Tringa cinerea*	II	Not Globally Threatened	S Finland, Russia, Ukraine	Tundra	SW,S&E Africa, Middle East, S Asia, Australasia	Coastal	>100,000
Spotted Redshank *Tringa erythropus*	II	Not Globally Threatened	N Europe, NW,N&NE Russia	Tundra	W, SE Europe, Equatorial Africa, Middle East, SE&S Asia	Tundra	>100,000
Wood Sandpiper *Tringa glareola*	II	Not Globally Threatened	N Europe, Russia	Forest, Tundra	W,C&S Africa, S Asia, Australasia	Wetland	>100,000
Common Sandpiper *Tringa hypoleucos*	II	Not Globally Threatened	Europe, C Asia, Russia	Wetland	W Europe, Africa, Middle East, S Asia, Australasia	Wetland	>100,000

			Breeding		Non-breeding		
		Threat Status	Range	Habitat	Range	Habitat	Population
Common Greenshank *Tringa nebularia*	II	Not Globally Threatened	N Europe, C Asia, Russia	Tundra	W,S&SE Europe, Middle East, Africa, S Asia, Australasia	Wetland	>100,000
Green Sandpiper *Tringa corpus*	II	Not Globally Threatened	N&E Europe, C Asia, Russia	Wetland	W,S&SE Europe, Middle East, Africa, S Asia	Wetland	>100,000
Marsh Sandpiper *Tringa stagnatilis*	II	Not Globally Threatened	CW&E Russia, Ukraine, China	Steppe	N & Sub-Saharan Africa, Middle East, S Asia and Australasia	Wetland	>100,000
Common Redshank *Tringa totanus*	II	Not Globally Threatened	Europe, C&E Asia, Russia	Wetland	Europe, Africa, S,SE&E Asia	Wetland	>100,000
White-headed Lapwing *Vanellus albiceps*	II	Not Globally Threatened	Africa	Wetland	Africa - moves to drier areas during floods	Wetland	>100,000
Crowned Lapwing *Vanellus coronatus*	II	Not Globally Threatened	E&S Africa	Steppe	follow dry season fires	Steppe	>100,000
White-tailed Plover *Vanellus leucurus*	II	Not Globally Threatened	C&SE Turkey, C Asia, Middle East	Wetland	NE Africa, Middle East, S Asia	Wetland	>100,000
Wattled Lapwing *Vanellus lugubris*	II	Not Globally Threatened	W,C,CE&S Africa	Steppe	Africa - related to bush fires	Steppe	>100,000
Black-winged Lapwing *Vanellus melanopterus*	II	Not Globally Threatened	E&S Africa	Grassland	migrates to lower altitudes	Grassland	>100,000
Senegal Lapwing *Vanellus senegallus*	II	Not Globally Threatened	Africa south of the Sahara	Grassland		Grassland	>100,000
Spur-winged Plover *Vanellus spinosus*	II	Not Globally Threatened	E Mediterranean, Middle East, Nile, CE,C&CW Africa	Grassland	moves to drier areas	Grassland	>100,000
Brown-chested Lapwing *Vanellus superciliosus*	II	Not Globally Threatened	C Africa	Grassland	C Africa	Grassland	>100,000
Northern Lapwing *Vanellus vanellus*	II	Not Globally Threatened	Europe, Middle East, Russia, C Asia	Wetland	W&S Europe, N Africa, Middle East, SW&SE Asia	Wetland, Coastal	>100,000

Table 11. Possible climate induced threats and other identified threats to populations of bird species listed on the CMS Appendices. Species occurring in habitats which are particularly vulnerable to climate change induced impacts (coastal, montane, tundra and wetland habitats) are noted; these species may be especially at risk. Climate threats were identified by expert opinion and from information in del Hoyo *et al.* (1994-2002), Cramp *et al.* (80-1994), www.birdlife.net and www.groms.de. Other threats were identified from Birdlife International (2004).

[1] Habitat: C Coastal; M Montane; T Tundra, W Wetland; [2] S Spatial (changes in range of prey), T Temporal (mismatch with timing of peak abundance)

		Climate Effects						**Other Threats**								
	Habitat[1]	**Higher Storm Frequency**	**Lower Water Tables**	**Altered Prey Distribution[2]**	**Sea Level Rise**	**Higher Drought Frequency**	**Habitat Shifts**	**Hunting / Persecution**	**Habitat Loss / Degradation**	**Anthropogenic Chemicals**	**Agricultural Intensification**	**Overgrazing**	**Introduced spp.**	**Over-fishing**	**Human Disturbance**	**Direct Mortality**
CMS Appendix I																
Saffron-cowled Blackbird *Agelaius flavus*	W	-	Y	-	-	-	-	Y	Y	Y	Y	Y	-	-	-	-
Cock-tailed Tyrant *Alectrurus tricolor*	WM	-	-	T	-	-	-	-	Y	-	Y	Y	-	-	-	-
Strange-tailed Tyrant *Alectrurus risora*	W	-	Y	ST	-	-	-	-	Y	Y	Y	Y	-	-	-	-
Baikal Teal *Anas formosa*	W	-	Y	-	-	Y	Y	Y	Y	Y	-	Y	-	-	-	-
Swan Goose *Anser cygnoides*	CW	-	Y	-	-	-	-	Y	Y	Y	-	Y	-	-	-	-
Grey-cheeked Parakeet *Brotogeris pyrrhopterus*		-	-	T	-	-	-	Y	Y	-	Y	Y	-	-	-	-
Oriental White Stork *Ciconia boyciana*	CW	-	Y	-	-	Y	-	Y	Y	-	-	-	-	-	Y	-
Kirtland's Warbler *Dendroica kirtlandii*		Y	-	ST	-	-	Y	-	Y	-	-	-	-	-	-	-
Short-tailed Albatross *Diomedea albatrus*	C	Y	-	ST	-	-	-	-	-	-	-	-	-	Y	-	-
Amsterdam Albatross *Diomedea amsterdamensis*	C	Y	-	ST	-	-	-	-	Y	-	Y	-	-	Y	Y	Y
Chinese Egret *Egretta eulophotes*	CW	-	-	-	Y	-	-	Y	Y	Y	-	-	-	-	Y	-
Spoon-billed Sandpiper *Eurynorhynchus pygmeus*	TCW	-	-	ST	Y	-	Y	Y	Y	Y	Y	-	-	-	Y	Y
Japanese Night Heron *Gorsachius goisagi*	CWM	-	Y	-	-	-	Y	Y	Y	-	-	-	Y	-	-	-
White-naped Crane *Grus vipio*	CW	-	Y	-	-	Y	-	Y	Y	Y	-	Y	-	-	Y	-
Pallas' Sea-Eagle *Haliaeetus leucoryphus*	WM	-	Y	-	-	-	-	Y	Y	Y	-	Y	-	Y	Y	-
Olrog's Gull *Larus atlanticus*	CW	-	-	T	Y	-	-	-	Y	Y	-	Y	-	Y	Y	-
Relict Gull *Larus relictus*	CW	Y	Y	-	Y	-	-	-	Y	-	-	-	-	-	Y	-
Saunder's Gull *Larus saundersi*	CW	Y	-	-	Y	-	-	Y	Y	Y	-	-	-	-	Y	-
Peruvian Diving-petrel *Pelecanoides garnotii*	C	-	-	ST	-	-	-	Y	Y	-	-	-	Y	Y	-	-
Andean Flamingo *Phoenicopterus andinus*	WM	-	Y	T	-	-	-	Y	-	-	-	-	-	-	Y	-
Puna Flamingo *Phoenicopterus jamesi*	WM	-	Y	T	-	-	-	Y	-	-	-	-	-	-	-	-

		Climate Effects						Other Threats								
	Habitat[1]	Higher Storm Frequency	Lower Water Tables	Altered Prey Distribution[2]	Sea Level Rise	Higher Drought Frequency	Habitat Shifts	Hunting / Persecution	Habitat Loss / Degradation	Anthropogenic Chemicals	Agricultural Intensification	Overgrazing	Introduced spp.	Over-fishing	Human Disturbance	Direct Mortality
Black-faced Spoonbill *Platalea minor*	CW	-	-	-	Y	-	-	Y	Y	Y	-	-	-	-	Y	-
Bermuda Petrel *Pterodroma cahow*	C	Y	-	-	Y	-	-	-	Y	Y	-	-	-	-	Y	-
Galapagos Petrel *Pterodroma phaeopygia*	C	-	-	S	-	-	-	-	Y	-	Y	Y	Y	-	-	Y
Hawaiian Petrel *Pterodroma sandwichensis*	CM	Y	-	S	-	-	-	-	-	-	-	-	Y	-	-	Y
Pink-footed Shearwater *Puffinus creatopus*	C	-	-	ST	-	-	-	-	Y	-	-	-	Y	Y	-	Y
Syrian Serin *Serinus syriacus*		-	Y	-	-	-	Y	-	-	-	Y	-	-	-	-	-
Humboldt Penguin *Spheniscus humboldti*	C	-	-	ST	-	-	-	-	-	Y	-	-	Y	Y	Y	Y
Chestnut Seedeater *Sporophila cinnamomea*		-	Y	-	-	-	-	Y	Y	Y	-	Y	-	-	-	-
Rufous-rumped Seedeater *Sporophila hypochroma*	W	-	Y	-	-	-	-	Y	Y	-	Y	Y	-	-	-	-
Marsh Seedeater *Sporophila palustris*	W	-	Y	-	-	-	-	Y	Y	Y	Y	Y	-	-	-	-
Zelich's Seedeater *Sporophila zelichi*	W	-	Y	-	-	-	-	Y	Y	Y	-	-	-	-	-	-
Chinese Crested Tern *Sterna bernsteini*	C	-	-	-	Y	-	-	Y	-	-	-	-	-	-	Y	-
Japanese Murrelet *Synthliboramphus wumizusume*	C	-	-	ST	Y	-	-	-	-	-	-	-	Y	Y	-	Y
Nordmann's Greenshank *Tringa guttifer*	CW	-	Y	-	Y	-	Y	Y	Y	Y	Y	-	-	-	Y	-
CMS Appendix I & II																
Aquatic Warbler *Acrocephalus paludicola*	W	-	Y	-	-	Y	-	-	Y	-	-	Y	-	-	-	-
Lesser White-front *Anser erythropus*	T	-	-	-	-	-	Y	Y	Y	-	-	Y	-	-	-	-
Spanish Imperial Eagle *Aquila adalberti*	M	-	Y	-	-	-	-	Y	Y	Y	-	Y	-	-	-	Y
Greater Spotted Eagle *Aquila clanga*		-	Y	-	-	-	-	Y	Y	Y	-	Y	-	-	Y	-
Imperial Eagle *Aquila heliaca*	M	-	Y	-	-	-	-	Y	Y	Y	-	-	-	-	Y	Y
Ferruginous Duck *Aythya nyroca*	W	-	Y	-	-	-	-	Y	Y	-	-	-	-	-	-	-
Red-breasted Goose *Branta ruficollis*	TCW	-	-	-	-	-	Y	Y	Y	Y	-	-	-	-	-	-
Houbara Bustard *Chlamydotis undulata*		-	-	T	-	Y	-	Y	Y	-	-	Y	-	-	-	-
Ruddy-headed Goose *Chloephaga rubidiceps*	C	-	-	-	-	-	-	Y	-	-	-	-	Y	-	-	-
Lesser Kestrel *Falco naumanni*		-	-	-	-	Y	-	-	Y	Y	-	Y	-	-	Y	-
Bald Ibis *Geronticus eremita*	C	-	-	-	-	Y	-	Y	Y	Y	-	Y	-	-	Y	-
Manchurian Crane *Grus japonensis*	CW	-	Y	-	-	-	-	-	Y	Y	-	Y	-	-	Y	-
Siberian Crane *Grus leucogeranus*	W	-	Y	-	-	-	Y	Y	Y	Y	-	Y	-	-	Y	-
Hooded Crane *Grus monacha*	CWM	-	Y	-	Y	-	Y	Y	Y	Y	-	Y	-	-	Y	-
Black-necked Crane *Grus nigricollis*	WM	-	Y	-	-	-	Y	Y	Y	Y	Y	Y	-	-	Y	-

		Climate Effects						Other Threats								
	Habitat[1]	Higher Storm Frequency	Lower Water Tables	Altered Prey Distribution[2]	Sea Level Rise	Higher Drought Frequency	Habitat Shifts	Hunting / Persecution	Habitat Loss / Degradation	Anthropogenic Chemicals	Agricultural Intensification	Overgrazing	Introduced spp.	Over-fishing	Human Disturbance	Direct Mortality
White-tailed Eagle *Haliaeetus albicilla*	CWM	-	-	-	-	-	-	-	Y	Y	-	-	-	-	Y	-
Steller's Sea-Eagle *Haliaeetus pelagicus*	CWM	-	-	-	-	-	-	Y	Y	Y	-	-	-	Y	Y	Y
Blue Swallow *Hirundo atrocaerulea*	M	-	Y	T	-	-	-	-	Y	-	Y	Y	Y	-	Y	-
Audouin's Gull *Larus audouinii*	CW	-	-	-	Y	-	-	Y	-	-	-	-	-	-	Y	-
White-eyed Gull *Larus leucophthalmus*	C	-	-	-	Y	-	-	Y	-	Y	-	-	-	-	Y	-
Marbled Teal *Marmaronetta angustirostris*	W	-	Y	-	-	-	-	Y	Y	Y	-	Y	-	-	-	-
Eskimo Curlew *Numenius borealis*	TCW	-	Y	ST	-	-	Y	Y	Y	-	-	Y	-	-	-	-
Slender-billed Curlew *Numenius tenuirostris*	W	-	Y	-	Y	Y	-	Y	Y	-	-	-	-	-	-	-
Great Bustard *Otis tarda*		-	-	-	-	Y	-	Y	Y	Y	Y	Y	-	-	Y	-
White-headed Duck *Oxyura leucocephala*	W	-	Y	-	-	-	-	Y	Y	Y	-	-	Y	-	-	-
Dalmatian Pelican *Pelecanus crispus*	CW	-	Y	-	Y	-	-	Y	Y	Y	-	-	-	Y	Y	Y
White Pelican *Pelecanus onocrotalus*	W	-	Y	-	-	-	-	Y	Y	Y	-	-	-	-	Y	-
Steller's Eider *Polysticta stelleri*	TC	-	-	-	Y	-	Y	-	-	-	-	-	-	-	-	-
White-winged Flufftail *Sarothura ayresi*	W	-	Y	-	-	-	Y	-	Y	-	Y	Y	-	-	Y	Y
Buff-breasted Sandpiper *Tryngites subruficollis*	TC	-	-	-	Y	-	Y	-	Y	-	-	-	-	-	-	-
Sociable Plover *Vanellus gregarius*		-	Y	-	-	Y	Y	-	Y	-	Y	Y	-	-	Y	-
CMS Appendix II																
Levant Sparrowhawk *Accipiter brevipes*		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Northern Goshawk *Accipiter gentilis*		-	-	-	-	-	-	Y	-	Y	-	-	-	-	-	-
European Sparrowhawk *Accipiter nisus*		-	-	-	-	-	-	Y	Y	Y	-	-	-	-	-	-
Grasshopper Warbler *Acrocephalus naevia*	W	-	Y	T	-	Y	-	-	Y	-	-	-	-	-	-	-
Marsh Warbler *Acrocephalus palustris*	W	-	Y	T	-	Y	-	-	-	-	-	-	-	-	-	-
Sedge Warbler *Acrocephalus schoenobaenus*	W	-	Y	T	-	Y	-	-	-	-	-	-	-	-	-	-
Reed Warbler *Acrocephalus scirpaceus*	W	-	Y	T	-	Y	-	-	-	-	-	-	-	-	-	-
Griffon Vulture *Aegypius monachus*	M	-	-	-	-	Y	-	Y	-	-	-	-	-	-	-	Y
Striped Crake *Aenigmatolimnas marginalis*	W	-	Y	-	-	Y	-	-	Y	-	Y	-	-	-	-	-
Egyptian Goose *Alopochen aegyptiacus*	W	-	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-
Tucuman Amazon Parrot *Amazona tucumana*	M	-	-	ST	-	-	-	Y	-	-	-	-	-	-	-	-
Northern Pintail *Anas acuta*	CW	-	Y	-	-	Y	-	Y	-	-	-	-	Y	-	-	-
Cape Teal *Anas capensis*	W	-	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-

		Climate Effects						Other Threats								
	Habitat[1]	Higher Storm Frequency	Lower Water Tables	Altered Prey Distribution[2]	Sea Level Rise	Higher Drought Frequency	Habitat Shifts	Hunting / Persecution	Habitat Loss / Degradation	Anthropogenic Chemicals	Agricultural Intensification	Overgrazing	Introduced spp.	Over-fishing	Human Disturbance	Direct Mortality
Northern Shoveler *Anas clypeata*	CW	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Common Teal *Anas crecca*	CW	-	Y	-	-	Y	-	Y	Y	-	-	-	-	-	-	-
Red-billed Duck *Anas erythrorhyncha*	W	-	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-
Hottentot Teal *Anas hottentota*	W	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Eurasian Wigeon *Anas penelope*	CW	-	Y	-	-	Y	-	Y	Y	-	-	-	-	-	-	-
Mallard *Anas platyrhynchos*	CW	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Garganey *Anas querquedula*	CW	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-
Gadwall *Anas strepera*	CW	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-
Yellow-billed Duck *Anas undulata*	CW	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Greater White-front *Anser albifrons*	TCW	-	Y	-	-	Y	Y	-	Y	-	-	-	-	-	-	-
Greylag Goose *Anser anser*	CW	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-
Pink-footed Goose *Anser brachyrhynchus*	TC	-	Y	-	-	-	Y	-	-	-	-	Y	-	-	-	-
Bean Goose *Anser fabalis*	TW	-	Y	-	-	Y	Y	Y	Y	-	-	-	-	-	-	-
Golden Eagle *Aquila chrysaetos*	M	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	Y
Steppe Eagle *Aquila nipalensis*	M	-	-	-	-	Y	-	Y	Y	-	-	-	-	-	-	Y
Lesser Spotted Eagle *Aquila pomarina*	M	-	Y	-	-	Y	-	Y	Y	-	-	-	-	-	-	-
Purple Heron *Ardea purpurea purpurea*	W	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Malagasy Pond Heron *Ardeola idae*	W	-	Y	-	-	-	-	Y	-	-	-	-	Y	-	-	-
Rufous-bellied Heron *Ardeola rufiventris*	W	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Ruddy Turnstone *Arenaria interpres*	TCW	-	-	-	Y	-	Y	-	-	-	-	-	-	-	-	-
Common Pochard *Aythya ferina*	CW	-	Y	-	-	Y	-	Y	Y	-	-	-	-	-	-	-
Tufted Duck *Aythya fuligula*	CW	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-
Greater Scaup *Aythya marila*	CW	-	Y	S	-	-	Y	-	-	Y	-	-	-	-	-	-
Eurasian Bittern *Botaurus stellaris stellaris*	W	-	Y	-	-	-	-	Y	Y	Y	-	-	-	-	-	-
Brent Goose *Branta bernicla*	TCW	-	Y	-	Y	-	Y	Y	-	-	-	-	-	-	Y	-
Barnacle Goose *Branta leucopsis*	TCW	-	Y	-	Y	-	Y	-	-	-	-	-	-	-	-	-
Common Goldeneye *Bucephala clangula*	CW	-	Y	-	-	-	-	-	-	Y	-	-	-	-	-	-
Stone Curlew *Burhinus oedicnemus*	C	-	-	-	-	Y	-	Y	Y	-	-	Y	-	-	Y	Y
Common Buzzard *Buteo buteo*	M	-	-	-	-	-	-	Y	Y	Y	-	-	-	-	-	-
Rough-legged Buzzard *Buteo lagopus*		-	-	-	-	-	Y	-	Y	-	-	-	-	-	-	-

		Climate Effects						Other Threats								
	Habitat[1]	**Higher Storm Frequency**	**Lower Water Tables**	**Altered Prey Distribution[2]**	**Sea Level Rise**	**Higher Drought Frequency**	**Habitat Shifts**	**Hunting / Persecution**	**Habitat Loss / Degradation**	**Anthropogenic Chemicals**	**Agricultural Intensification**	**Overgrazing**	**Introduced spp.**	**Over-fishing**	**Human Disturbance**	**Direct Mortality**
Long-legged Buzzard *Buteo rufinus*		-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Sanderling *Calidris alba*	TC	-	-	ST	Y	-	Y	-	-	-	-	-	-	-	Y	-
Dunlin *Calidris alpina*	TCW	-	-	ST	Y	-	Y	-	Y	Y	-	-	-	-	-	-
Red Knot *Calidris canutus*	TC	-	-	ST	Y	-	Y	Y	Y	-	-	-	-	Y	Y	-
Curlew Sandpiper *Calidris ferruginea*	TCW	-	-	ST	Y	-	Y	-	-	-	-	-	-	-	-	-
Purple Sandpiper *Calidris maritima*	TC	-	-	ST	-	-	-	-	-	-	-	-	-	-	-	-
Little Stint *Calidris minuta*	TCW	-	Y	ST	Y	-	Y	-	-	-	-	-	-	-	-	-
Temminck's Stint *Calidris temminckii*	TCW	-	Y	ST	-	-	-	-	-	-	-	-	-	-	-	-
Great Knot *Calidris tenuirostris*	TC	-	-	ST	Y	-	Y	Y	Y	-	-	-	-	-	-	-
Great White Egret *Casmerodius albus albus*	W	-	Y	-	Y	-	-	Y	-	-	-	-	-	-	-	-
Kentish Plover *Charadrius alexandrinus*	CW	-	-	-	Y	Y	-	-	Y	-	-	-	-	-	Y	-
Caspian Plover *Charadrius asiaticus*	C	-	-	-	-	Y	-	-	-	-	Y	Y	-	-	-	-
Little Ringed Plover *Charadrius dubius*	W	-	Y	-	-	Y	-	-	Y	Y	-	-	-	-	-	-
Forbes' Plover *Charadrius forbesi*		-	-	T	-	-	-	-	-	-	-	-	-	-	-	-
Common Ringed Plover *Charadrius hiaticula*	CW	-	-	-	Y	Y	Y	-	-	-	-	-	-	-	Y	-
Greater Sandplover *Charadrius leschenaultii*	CW	-	-	-	Y	-	-	-	Y	-	-	-	-	-	-	-
White-fronted Plover *Charadrius marginatus*	CW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mongolian Plover *Charadrius mongulus*	CW	-	-	-	Y	-	Y	-	-	-	-	-	-	-	-	-
Chestnut-banded Plover *Charadrius pallidus*	CW	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
Kittlitz's Plover *Charadrius pecuarius*	CW	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
Three-banded Plover *Charadrius tricollaris*	CW	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
White-winged Black Tern *Chlidonias leucopterus*	CW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Black Tern *Chlidonias niger niger*	CW	-	Y	-	Y	-	-	-	Y	Y	-	Y	-	-	Y	-
White Stork *Ciconia ciconia*	W	-	Y	-	-	-	-	Y	Y	Y	-	Y	-	-	-	Y
Woolly-necked Stork *Ciconia episcopus microscelis*	W	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-
Black Stork *Ciconia nigra*	W	-	Y	-	-	-	-	Y	-	Y	-	-	-	-	-	-
Short-toed Eagle *Circaetus gallicus*	M	-	-	-	-	Y	-	Y	Y	-	-	Y	-	-	-	-
Marsh Harrier *Circus aeruginosus*	CW	-	Y	-	-	-	-	Y	Y	Y	-	-	-	-	-	-
Hen Harrier *Circus cyaneus*	CW	-	-	-	-	-	-	Y	Y	Y	-	Y	-	-	-	-
Pallid Harrier *Circus macrourus*	M	-	-	-	-	-		-	Y	Y	-	Y	-	-	-	-

		Climate Effects						Other Threats								
	Habitat[1]	Higher Storm Frequency	Lower Water Tables	Altered Prey Distribution[2]	Sea Level Rise	Higher Drought Frequency	Habitat Shifts	Hunting / Persecution	Habitat Loss / Degradation	Anthropogenic Chemicals	Agricultural Intensification	Overgrazing	Introduced spp.	Over-fishing	Human Disturbance	Direct Mortality
Montagu's Harrier *Circus pygargus*		-	-	-	-	-		-	Y	-	-	Y	-	-	-	-
Long-tailed Duck *Clangula hyemalis*	CW	-	-	-	-	Y		Y	Y	Y	-	-	-	Y	-	Y
Roller *Coracias garrulus*		-	-	-	-	-		Y	-	-	-	-	-	-	-	-
Quail *Coturnix coturnix coturnix*		-	-	-	-	-		Y	-	Y	-	Y	-	-	-	-
Corncrake *Crex crex*		-	-	-	-	-		-	Y	-	-	Y	-	-	-	-
Bewick's Swan *Cygnus columbianus*	TCW	-	Y	-	-	Y		Y	-	-	-	-	-	-	-	-
Whooper Swan *Cygnus cygnus*	TCW	-	Y	-	-	Y		Y	Y	-	-	-	-	-	-	-
Mute Swan *Cygnus olor*	CW	-	Y	-	-	-		-	-	-	-	-	-	-	-	Y
Fulvous Whistling-duck *Dendrocygna bicolor*	W	-	Y	-	-	-		Y	-	Y	-	-	-	-	-	-
White-faced Whistling-duck *Dendrocygna viduata*	W	-	Y	Y	-	-		-	-	-	-	-	-	-	-	-
Buller's Albatross *Diomedea bulleri*	C	Y	-	-	-	-		-	-	-	-	-	Y	Y	-	Y
Shy Albatross *Diomedea cauta*	C	Y	-	ST	-	-		-	-	-	Y	-	Y	Y	Y	Y
Yellow-nosed Albatross *Diomedea chlororhynchos*	C	Y	-	-	-	-		-	-	-	-	-	-	Y	-	Y
Grey-headed Albatross *Diomedea chrysostoma*	C	Y	-	-	-	-		-	-	-	-	-	-	Y	-	Y
Royal Albatross *Diomedea epomophora*	C	Y	-	ST	-	-		-	Y	-	-	-	Y	Y	Y	Y
Wandering Albatross *Diomedea exulans*	C	Y	-	-	-	-		-	-	-	-	-	-	Y	-	Y
Laysan Albatross *Diomedea immutabilis*	C	Y	-	-	-	-		Y	-	-	-	-	-	Y	Y	Y
Waved Albatross *Diomedea irrorata*	C	Y	-	ST	-	-		Y	-	Y	-	-	Y	Y	-	Y
Black-browed Albatross *Diomedea melanophris*	C	Y	Y	ST	-	-		-	-	-	-	-	-	Y	-	Y
Black-footed Albatross *Diomedea nigripes*	C	Y	-	-	-	-		-	-	Y	-	-	Y	Y	-	Y
Crab Plover *Dromas ardeola*	C	-	-	ST	Y	-		-	-	Y	-	-	Y	-	Y	-
Slaty Egret *Egretta vinaceigula*	W	-	Y	S	-	-		-	Y	-	-	Y	-	-	Y	-
Eurasian Dotterel *Eudromias morinellus*	TM	-	-	ST	-	Y		Y	-	-	-	-	-	-	-	-
Saker Falcon *Falco cherrug*	M	-	-	-	-	-		Y	-	-	-	-	-	-	-	-
Eleonora's Falcon *Falco eleonorae*	CW	-	-	-	-	Y		Y	-	-	-	-	-	-	Y	-
Peregrine Falcon *Falco peregrinus*	M	-	-	-	-	-	Y	Y	-	Y	-	-	-	-	-	-
Gyr Falcon *Falco rusticolus*	TM	-	-	S	-	-	Y	Y	-	-	-	-	-	-	-	-
Eurasian Hobby *Falco subbuteo*		-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
Common Kestrel *Falco tinnunculus*		-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
Red-footed Falcon *Falco vespertinus*		-	-	-	-	Y	-	-	-	Y	-	-	-	-	-	-

		Climate Effects						Other Threats								
	Habitat^1	Higher Storm Frequency	Lower Water Tables	Altered Prey Distribution^2	Sea Level Rise	Higher Drought Frequency	Habitat Shifts	Hunting / Persecution	Habitat Loss / Degradation	Anthropogenic Chemicals	Agricultural Intensification	Overgrazing	Introduced spp.	Over-fishing	Human Disturbance	Direct Mortality
Merlin *Falco columbarius*	M	-	-	-	-	-	-	-	Y	Y	-	-	-	-	-	Y
Collared Flycatcher *Ficedula albicollis*		-	-	T	-	Y	-	-	-	-	-	-	-	-	-	-
Pied Flycatcher *Ficedula hypoleuca*		-	-	T	-	Y	-	-	-	-	-	-	-	-	-	-
Common Coot *Fulica atra atra*	W	-	Y	-	-	Y	-	Y	-	Y	-	-	-	-	-	-
Common Snipe *Gallinago gallinago*	CW	-	Y	-	-	Y	-	-	Y	-	-	-	-	-	-	-
Great Snipe *Gallinago media*	TW	-	Y	-	-	Y	Y	Y	Y	-	-	Y	-	-	-	-
White-billed Diver *Gavia adamsii*	TCW	-	-	-	-	-	Y	-	-	Y	-	-	-	Y	-	Y
Black-throated Diver *Gavia arctica arctica*	TCW	-	-	-	-	-	Y	-	Y	Y	-	-	-	Y	Y	Y
Black-throated Diver *Gavia arctica suschkini*	TCW	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Great Northern Diver *Gavia immer immer*	TCW	-	-	-	-	-	Y	Y	-	Y	-	-	-	Y	Y	Y
Red-throated Diver *Gavia stellata*	TCW	-	-	-	-	-	-	-	-	Y	-	-	-	Y	Y	Y
Black-winged Pratincole *Glareola nordmanni*		-	Y	ST	-	Y	-	-	Y	-	-	Y	Y	-	-	Y
Collared Pratincole *Glareola pratincola*	W	-	Y	ST	-	Y	-	Y	-	Y	-	Y	-	-	Y	-
Wattled Crane *Grus carunculatus*	WM	-	Y	-	-	Y	-	Y	Y	Y	-	Y	-	-	Y	Y
Common Crane *Grus grus*	W	-	Y	-	-	-	-	Y	Y	-	-	Y	-	-	Y	-
Blue Crane *Grus paradisea*		-	Y	-	-	-	-	Y	Y	Y	-	-	-	-	-	Y
Demoiselle Crane *Grus virgo*	W	-	-	-	-	Y	-	Y	Y	Y	-	Y	-	-	Y	-
Booted Eagle *Hieraaetus pennatus*	M	-	-	-	-	Y	-	Y	Y	-	-	-	-	-	-	-
Black-winged Stilt *Himantopus himantopus*	CW	-	Y	-	-	-	-	-	Y	-	-	-	-	-	-	-
Little Bittern *Ixobrychus minutus minutus*	W	-	Y	T	-	Y	-	-	Y	Y	-	-	-	-	-	-
African Dwarf Bittern *Ixobrychus sturmii*	W	-	Y	T	-	-	-	-	-	-	-	-	-	-	-	-
Armenian Gull *Larus armenicus*	CW	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Slender-billed Gull *Larus genei*	CW	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
Sooty Gull *Larus hemprichii*	C	-	-	-	Y	-	-	Y	-	Y	-	-	-	-	Y	-
Great Black-headed Gull *Larus ichthyaetus*	CW	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Mediterranean Gull *Larus melanocephalus*	CW	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
Broad-billed Sandpiper *Limicola falcinellus*	TCW	-	-	ST	Y	-	Y	-	-	-	-	-	-	-	-	-
Bar-tailed Godwit *Limosa lapponica*	TCW	-	-	ST	Y	Y	Y	-	Y	Y	-	-	-	-	Y	-
Black-tailed Godwit *Limosa limosa*	CW	-	Y	ST	Y	Y	-	-	Y	-	-	Y	-	-	-	-
Jack Snipe *Lymnocryptes minimus*	TCW	-	Y	-	-	Y	Y	Y	Y	-	-	Y	-	-	-	-

		Climate Effects						Other Threats								
	Habitat^1	Higher Storm Frequency	Lower Water Tables	Altered Prey Distribution^2	Sea Level Rise	Higher Drought Frequency	Habitat Shifts	Hunting / Persecution	Habitat Loss / Degradation	Anthropogenic Chemicals	Agricultural Intensification	Overgrazing	Introduced spp.	Over-fishing	Human Disturbance	Direct Mortality
Southern Giant Petrel *Macronectes giganteus*	C	-	-	-	-	-	-	Y	-	-	-	-	-	Y	Y	Y
Northern Giant Petrel *Macronectes halli*	C	-	-	ST	-	-	-	-	Y	-	-	-	-	Y	-	Y
Velvet Scoter *Melanitta fusca*	TCW	-	-	-	-	-	Y	-	-	Y	-	-	-	Y	-	Y
Common Scoter *Melanitta nigra*	TCW	-	-	-	-	-	Y	-	Y	Y	-	-	Y	-	-	-
Smew *Mergellus albellus*	CW	-	-	-	-	-	Y	Y	-	Y	-	-	-	-	-	-
Goosander *Mergus merganser*	W	-	-	-	-	-	-	Y	-	-	-	-	-	Y	-	-
Red-breasted Merganser *Mergus serrator*	CW	-	-	-	-	-	-	Y	-	Y	-	-	-	Y	-	-
Bee-eater *Merops apiaster*	W	-	-	T	-	Y	-	Y	Y	Y	-	Y	-	-	-	-
Black Kite *Milvus migrans*		-	-	-	-	-	-	Y	-	Y	-	-	-	-	-	-
Red Kite *Milvus milvus*		-	-	-	-	-	-	Y	Y	-	-	-	-	-	-	-
Spotted Flycatcher *Muscicapa striata*		-	-	T	-	-	-	-	Y	Y	-	-	-	-	-	-
Yellow-billed Stork *Mycteria ibis*	W	-	Y	T	-	Y	-	-	-	-	-	-	-	-	-	-
Egyptian Vulture *Neophron percnopterus*		-	-	-	-	-	-	Y	-	Y	-	-	-	-	-	-
Southern Pochard *Netta erythrophthalma*	CW	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Red-crested Pochard *Netta rufina*	CW	-	-	-	-	-	-	Y	Y	-	-	-	-	-	-	-
African Pygmy-goose *Nettapus auritus*	W	-	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-
Eurasian Curlew *Numenius arquata*	CW	-	Y	-	Y	Y	-	Y	Y	Y	-	Y	-	-	Y	-
Whimbrel *Numenius phaeopus*	TCW	-	Y	T	Y	Y	Y	-	-	-	-	-	-	-	-	-
Osprey *Pandion haliaetus*	CW	-	Y	T	-	Y	-	Y	-	Y	-	-	-	-	-	-
Honey Buzzard *Pernis apivorus*		-	-	T	-	Y	-	Y	-	-	-	-	-	-	-	-
Socotra Cormorant *Phalacrocorax nigrogularis*	C	-	-	-	Y	-	-	Y	Y	Y	-	-	Y	Y	Y	-
Pygmy Cormorant *Phalacrocorax pygmeus*	CW	-	Y	-	-	-	-	Y	Y	-	-	-	-	-	-	-
Grey Phalarope *Phalaropus fulicaria*	TCW	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Red-necked Phalarope *Phalaropus lobatus*	TCW	-	Y	ST	-	Y	Y	Y	-	-	-	-	-	-	-	-
Ruff *Philomachus pugnax*	CW	-	Y	ST	-	Y	Y	-	Y	-	-	-	-	-	-	-
Sooty Albatross *Phoebetria fusca*	C	Y	-	-	-	-	-	-	-	-	-	-	Y	Y	-	Y
Light-mantled Sooty Albatross *Phoebetria palpebrata*	C	Y	-	-	-	-	-	-	-	-	-	-	Y	Y	-	Y
Lesser Flamingo *Phoenicopterus minor*	W	-	Y	-	Y	-	-	-	Y	Y	-	-	-	-	Y	-
Greater Flamingo *Phoenicopterus ruber*	CW	-	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-

		Climate Effects						**Other Threats**								
	Habitat[1]	**Higher Storm Frequency**	**Lower Water Tables**	**Altered Prey Distribution**[2]	**Sea Level Rise**	**Higher Drought Frequency**	**Habitat Shifts**	**Hunting / Persecution**	**Habitat Loss / Degradation**	**Anthropogenic Chemicals**	**Agricultural Intensification**	**Overgrazing**	**Introduced spp.**	**Over-fishing**	**Human Disturbance**	**Direct Mortality**
Chiffchaff *Phylloscopus collybita*		-	-	T	-	Y	-	-	-	-	-	-	-	-	-	-
Wood Warbler *Phylloscopus sibilatrix*		-	-	T	-	Y	-	-	-	-	-	-	-	-	-	-
Willow Warbler *Phylloscopus trochilus*		-	-	T	-	Y	-	-	-	-	-	-	-	-	-	-
African Spoonbill *Platalea alba*	W	-	Y	-	-	-	-	-	-	-	-	-	-	-	Y	-
Eurasian Spoonbill *Platalea leucorodia*	W	-	Y	-	-	-	-	Y	-	Y	-	-	-	-	-	-
Spur-winged Goose *Plectropterus gambensis*	W	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Glossy Ibis *Plegadis falcinellus*	W	-	Y	-	-	Y	-	Y	Y	Y	-	-	-	-	Y	-
Eurasian Golden Plover *Pluvialis apricaria*	TCW	-	-	ST	-	-	Y	Y	Y	-	-	Y	-	-	-	-
Grey Plover *Pluvialis squatarola*	TCW	-	-	ST	Y	-	Y	-	Y	-	-	-	-	-	-	-
Slavonian Grebe *Podiceps auritus*	CW	-	Y	-	-	-	-	-	-	Y	-	-	-	Y	Y	-
Red-necked Grebe *Podiceps grisegena grisegena*	CW	-	-	T	-	-	-	-	-	Y	-	-	-	-	-	-
Bearded Tachuri *Polystictus pectoralis pectoralis*	W	-	Y	ST	-	Y	-	-	Y	-	Y	Y	-	-	-	-
Little Crake *Porzana parva parva*	CW	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-
Spotted Crake *Porzana porzana*	W	-	Y	-	-	Y	-	-	Y	-	-	-	-	-	-	-
Baillon's Crake *Porzana pusilla intermedia*	W	-	Y	-	-	Y	-	-	Y	-	Y	Y	-	-	-	-
White-chinned Petrel *Procellaria aequinoctialis*	C	-	-	ST	-	-	-	-	-	-	-	-	-	Y	-	Y
Spectacled Petrel *Procellaria aequinoctialis conspicillata*	C	-	-	ST	-	-	-	-	-	-	-	-	Y	Y	-	Y
Grey Petrel *Procellaria cinerea*	C	-	-	ST	-	-	-	-	-	-	-	-	Y	Y	-	Y
Black Petrel *Procellaria parkinsoni*	C	-	-	ST	-	-	-	-	-	-	-	-	Y	Y	-	Y
Westland Petrel *Procellaria westlandica*	C	-	-	ST	-	-		-	-	-	-	Y	Y	-	-	Y
Dinelli's Doradito *Pseudocolopteryx dinellianus*		-	Y	ST	--	-		-	-	-	-	Y	-	-	-	-
Pied Avocet *Recurvirostra avosetta*	CW	-	Y	-	Y	Y		-	Y	Y	-	-	-	-	-	-
Firecrest *Regulus ignicapilla*		-	-	ST	-	-		-	-	-	-	-	-	-	-	-
Goldcrest *Regulus regulus*		-	-	-		-		-	-	-	-	-	-	-	-	-
Comb Duck *Sarkidiornis melanotos*	W	-	Y	-	-	-		Y	-	Y	-	-	-	-	-	-
Streaky-breasted Flufftail *Sarothrura boehmi*	W	-	Y	-	-	-		-	Y	-	Y	-	-	-	-	-
Common Eider *Somateria mollissima*	CW	-	-	ST	Y	-		-	-	Y	-	-	-	-	-	-
King Eider *Somateria spectabilis*	CW	-	Y	-	-	-		-	-	Y	-	-	-	-	-	-
African Penguin *Spheniscus demersus*	C	-	-	ST	-	-		Y	-	Y	-	-	Y	Y	Y	Y

		Climate Effects						Other Threats								
	Habitat[1]	Higher Storm Frequency	Lower Water Tables	Altered Prey Distribution[2]	Sea Level Rise	Higher Drought Frequency	Habitat Shifts	Hunting / Persecution	Habitat Loss / Degradation	Anthropogenic Chemicals	Agricultural Intensification	Overgrazing	Introduced spp.	Over-fishing	Human Disturbance	Direct Mortality
Dark-throated Seedeater *Sporophila ruficollis*		-	-	-	-	-		Y	Y	Y	-	Y	-	-	-	-
Little Tern *Sterna albifrons*	CW	Y	-	-	Y	-		-	Y	-	-	-	Y	-	Y	-
Damara Tern *Sterna balaenarum*	C	-	-	ST	-	-		Y	Y	-	-	-	-	-	Y	-
Lesser Crested Tern *Sterna bengalensis*	C	Y	-	ST	Y	-		-	-	-	-	-	-	-	-	-
Great Crested Tern *Sterna bergii*	C	Y	-	ST	Y	-		Y	-	-	-	-	-	-	Y	-
Caspian Tern *Sterna caspia*	CW	-	-	-	Y	-		Y	Y	Y	-	-	-	-	Y	-
Roseate Tern *Sterna dougallii*	C	Y	-	ST	Y	-		Y	-	-	-	-	-	Y	-	Y
Common Tern *Sterna hirundo hirundo*	C	-	Y	-	Y	-		Y	Y	Y	-	-	-	-	Y	-
Royal Tern *Sterna maxima albidorsalis*	C	Y	-	ST	Y	-		-	-	Y	-	-	-	-	-	-
Gull-billed Tern *Sterna nilotica nilotica*	CW	-	-	-	Y	-		Y	Y	Y	-	-	-	-	Y	-
Arctic Tern *Sterna paradisaea*	CW	-	-	-	Y	-		Y	-	Y	-	-	-	Y	-	-
White-cheeked Tern *Sterna repressa*	C	-	-	ST	-	-		Y	-	-	-	-	-	-	-	-
Sandwich Tern *Sterna sandvicensis sandvicensis*	C	Y	-	-	Y	-		Y	-	Y	-	-	-	-	Y	-
Saunder's Tern *Sterna saundersi*	C	Y	-	-	Y	-		-	-	-	-	-	-	-	-	-
Turtle Dove *Streptopelia turtur turtur*		-	-	ST	-	Y		Y	Y	Y	-	Y	Y	-	Y	-
Blackcap *Sylvia atricapilla*		-	-	-	-	Y		-	-	-	-	-	-	-	-	-
Garden Warbler *Sylvia borin*		-	-	T	-	Y		-	-	-	-	-	-	-	-	-
Whitethroat *Sylvia communis*		-	-	T	-	Y	-	-	-	-	-	-	-	-	-	-
Lesser Whitethroat *Sylvia curruca*		-	-	T	-	Y	-	-	-	-	-	-	-	-	-	-
South African Shelduck *Tadorna cana*	W	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Ruddy Shelduck *Tadorna ferruginea*	W	-	Y	-	-	-	-	Y	-	-	-	-	-	-	Y	-
Common Shelduck *Tadorna tadorna*	W	-	-	ST	Y	-	-	-	-	-	-	-	-	-	-	-
White-backed Duck *Thalassornis leuconotus*	W	-	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-
Sacred Ibis *Threskiornis aethiopicus aethiopicus*	W	-	Y	T	Y	-	-	Y	-	-	-	-	-	-	Y	-
Terek Sandpiper *Tringa cinerea*	TCW	-	-	ST	Y	Y	Y	-	-	-	-	-	-	-	-	-
Spotted Redshank *Tringa erythropus*	TCW	-	Y	ST	-	Y	Y	-	-	-	-	-	-	-	-	-
Wood Sandpiper *Tringa glareola*	TW	-	Y	-	-	Y	Y	Y	Y	-	-	Y	-	-	-	-
Common Sandpiper *Tringa hypoleucos*	CW	-	Y	-	-	Y	-	-	Y	-	-	-	-	-	-	-
Common Greenshank *Tringa nebularia*	TCW	-	Y	ST	Y	Y	Y	-	-	-	-	-	-	-	-	-
Green Sandpiper *Tringa ochropus*	TW	-	Y	-	-	Y	Y	-	-	-	-	-	-	-	-	-

		Climate Effects						Other Threats									
	Habitat[1]	Higher Storm Frequency	Lower Water Tables	Altered Prey Distribution[2]	Sea Level Rise	Higher Drought Frequency	Habitat Shifts	Hunting / Persecution	Habitat Loss / Degradation	Anthropogenic Chemicals	Agricultural Intensification	Overgrazing	Introduced spp.	Over-fishing	Human Disturbance	Direct Mortality
Marsh Sandpiper *Tringa stagnatilis*	TW	-	Y	-	-	Y	-	Y	Y	-	-	Y	-	-	-	-
Common Redshank *Tringa totanus*	CW	-	Y	-	Y	Y	-	-	Y	-	-	Y	-	-	Y	-
White-headed Lapwing *Vanellus albiceps*	W	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Crowned Lapwing *Vanellus coronatus*		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
White-tailed Plover *Vanellus leucurus*		-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Wattled Lapwing *Vanellus lugubris*	C	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
Black-winged Lapwing *Vanellus melanopterus*	CM	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
Senegal Lapwing *Vanellus senegallus*	W	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
Spur-winged Plover *Vanellus spinosus*		-	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-
Brown-chested Lapwing *Vanellus superciliosus*		-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
Northern Lapwing *Vanellus vanellus*	W	-	Y	-	-	-	-	-	Y	-	-	Y	-	-	-	-

Table 12. Occurrence of Bats in the Caribbean UK Overseas Territories

Species	IUCN status[1]	Anguilla	Bermuda	BVI	Cayman	Montserrat	TCI	Global[2]	Caribbean distribution
Noctilionidae									
Noctilio leporinus	LC			*		*		Ca, Ce, S	G & L Antilles, S Bahamas, TCI
Phyllostomidae									
Macrotus waterhousii	LC				*		*	Ca, Ce, N	Bahamas, Cayman, Cuba, Jamaica
Monophyllus plethedon	NT	*				*		Ca	L Antilles (Antigua-StVincent)
Monophyllus redmani	LC						*	Ca	G Antilles, TCI, Bahamas
Sturnira thomasi	EN B1+2c					*		Ca	L Ant (Guadeloupe, Montserrat)
Chiroderma improvisum	EN A2C, B1+2c					*		Ca	L Ant (Guadeloupe, Montserrat)
Artibeus jamaicensis	LC	*		*	*	*	*	Ca, Ce, S	G & L Antilles
Ardops nichollsi	NT					*		Ca	L Ant (St Eustatius - St Vincent)
Phyllops falcatus	NT				*			Ca	Cayman, Cuba, Hispaniola
Brachyphylla cavernarum	LC	*		*		*		Ca	L Antilles
Brachyphylla nana	NT				*		*	Ca	G Ant (C,H,J), Cayman, TCI, Bahamas
Erophylla sezekorni	LC				*		*	Ca	G Ant, Cayman, TCI, Bahamas
Natalidae									
Natalus stramineus	LC	*				*	(*)	Ca, Ce, S	L Ant, Cuba, Hisp, Jam
Vespertilionidae									
Eptesicus fuscus	LC		*		*			Ca, Ce, N, S	G Ant, Bahamas, Dominica, Barbados (LA), Bermuda
Lasionycteris noctivagans	LC		*				*	Ca, Ce, N	TCI, Bermuda
Lasiurus borealis	LC		*				*	Ca, Ce, N, S	G Ant, Bermuda, Bahamas, Trin & Tab
Lasiurus cinereus	LC		*					Ca, Ce, N, S	Cuba, Hispaniola, Bermuda
Lasiurus seminolus	LC		*					N	Bermuda
Myotis nigricans	LC					?*		Ca, Ce, S	L Ant: Grenada, Trin & Tab, ?Montserrat
Pipistrellus subflavus	LC		*					N	(Bermuda)
Molossidae									
Molossus molossus	LC	*		*	*	*		Ca, Ce, S	G & L Ant, Neth Ant, Trin & Tab
Tadarida brasiliensis	NT				*	*	(*)	Ca, Ce, N, S	G & L Ant

---

[1] from Hutson, Mickleburgh & Racey (2001)

[2] Global distribution: Ce = Central America, Ca = Caribbean, N = North America, S = South America

[3] Caribbean distribution: G Ant: Greater Antilles L Ant / LA: Lesser Antilles & Leeward Islands Neth Ant: Netherlands Antilles

Table 13. Occurrence of European Bat Species with information on biological traits relevant to their migration and climate change

Species	IUCN status 2004	UK	Isle of Man	Channel Is.	Gibraltar	Cyprus
Pteropodidae						
Rousettus aegyptiacus	LC					*
Emballonuridae						
Taphozous nudiventris	LC					
Rhinolophidae						
Rhinolophus blasii	VU A2c					*
Rhinolophus euryale	VU A2c					*
Rhinolophus ferrumequinum	NT	*		*		*
Rhinolophus hipposideros	NT	*			?*	*
Rhinolophus mehelyi	VU A2c					*
Vespertilionidae						
Barbastella barbastellus	VU A2c	*				
Barbastella leucomelas	NT					
Eptesicus bottae	LC					
Eptesicus nilssonii	LC	(*)				
Eptesicus serotinus	LC	*		*		*
Hypsugo savii	LC	(*)				*
Myotis alcathoe	NT					
Myotis aurascens	LC					
Myotis bechsteinii	VU A2c	*				
Myotis blythii	LC					*
Myotis brandtii	LC	*				
Myotis capaccinii	VU A2c					*
Myotis dasycneme	VU A2c					
Myotis daubentonii	LC	*	*			
Myotis emarginatus	VU A2c					*
Myotis hajastanicus	EN A2c, B1a+biii					
Myotis myotis	NT	*			*	
Myotis mystacinus	LC	*	*			
Myotis nattereri	LC	*	*	*		*
Myotis nipalensis	LC					
Myotis cf. punicus	NT					
Myotis schaubi	EN A2c, B1+2a+biii					
Nyctalus azoreum	EN A2c, B1a+biii, ?C1					
Nyctalus lasiopterus	NT					
Nyctalus leisleri	LC	*	*	*		

Species	**IUCN status 2004**	**UK**	**Isle of Man**	**Channel Is.**	**Gibraltar**	**Cyprus**
Nyctalus noctula	LC	*				*
Otonycteris hemprichii	LC					
Pipistrellus kuhlii	LC	(*)		*	?*	*
Pipistrellus maderensis	VU A2c, B1a+biii					
Pipistrellus nathusii	LC	*		*		
Pipistrellus pipistrellus	LC	*	*	*	*	
Pipistrellus pygmaeus	LC	*	*	*		
Plecotus auritus	LC	*	*	*		
Plecotus austriacus	LC	*		*		*
Plecotus macrobullaris	NT					
Plecotus sardus	EN B2a+biii					
Plecotus teneriffae	NT					
Vespertilio murinus	LC	(*)				
Miniopterus schreibersii	NT				*	*
Molossidae						
Tadarida teniotis	LC	(*)			*	*

Table 14. Migratory status, diet, roost size and location of bats occurring in the Caribbean Overseas Territories. From Nowak (1994), Barbour & Davis (1969), Fleming & Eby (2003) and pers. comm. to A.M. Hutson.

Species	**Migration**	**Migration type**	**Design for long-range flight**	**Food**	**Roost**	**Colony size**
Noctilionidae						
Noctilio leporinus	Sedentary	n/a	L	Insects, Other	C, T	1s-10s
Phyllostomidae						
Macrotus waterhousii	Sedentary	n/a	L	Insects	B, C	1s-10s
Monophyllus plethedon	Sedentary	n/a	L	Flowers	C	10s-100s
Monophyllus redmani	Sedentary	n/a	L	Flowers	C	10s-100s
Sturnira thomasi	Sedentary	n/a	L	Fruit	?C	10s
Chiroderma improvisum	Sedentary	n/a	L	Fruit	T	?
Artibeus jamaicensis	short range	partial, both sexes	L	Fruit	C, T	1s-10s
Ardops nichollsi	Sedentary	n/a	L		C	
Phyllops falcatus	Sedentary	n/a	L			
Brachyphylla cavernarum	Sedentary	n/a	L	Fruit	C	10s-100s
Brachyphylla nana	Sedentary	n/a	L	Fruit	C	10s-1000s
Erophylla sezekorni	Sedentary	n/a	L	Flowers	C	1s-10s
Natalidae						
Natalus stramineus	Sedentary	n/a	L	Insects	C	10s-100s
Vespertilionidae						
Eptesicus fuscus	medium range	both sexes	L	Insects	B	10s-100s
Lasionycteris noctivagans	long range	both sexes +/-	H	Insects	T	1s
Lasiurus borealis	long range	both sexes +/-	H	Insects	T	1s
Lasiurus cinereus	long range	both sexes	H	Insects	T	1s
Lasiurus seminolus	long range	both sexes	H	Insects	T	1s
Myotis nigricans	?Sedentary	n/a	M	Insects	C, T	10s-100s
Molossidae						
Molossus molossus	?Sedentary	n/a	H	Insects	B	10s-100s
Tadarida brasiliensis	long range	partial, more female	H	Insects	B	10s-100s

[1] Design for long range flight (high aspect ratio): L = low, M = medium, H = high
[2] Food type: fruit/flowers (F), insects (I)
[3] Roosts: underground sites (C), building (B), tree (T), other (O)
[4] Colony size (in the Caribbean): normal number of individuals (extremes in brackets)

Table 15. Migratory status, diet, roost size and location of European bats. Information taken from Krapp (2001, 2004).

Species	Migration	Migration by	Design for long-range flight[1]	Food[2]	Summer Roost[3]	Colony Size[4]	Winter Roost[3]
Pteropodidae							
Rousettus aegyptiacus	sedentary	n/a	H	Fruit	C	<800	C
Rhinolophidae							
Rhinolophus blasii	sedentary	n/a	L	Insects	C	<300	C
Rhinolophus euryale	sedentary	n/a	L	Insects	C (B)	50-400	C
Rhinolophus ferrrumequinum	sedentary	n/a	L	Insects	CB	<200	C
Rhinolophus hipposideros	sedentary	n/a	L	Insects	CB	10-100 (<800)	C
Rhinolophus mehelyi	sedentary	n/a	L	Insects	C	50-500 (<2000)	C
Vespertilionidae							
Barbastella barbastellus	medium range	both sexes	M	Insects	T(B)	10-30 (<100)	TC
Eptesicus nilssonii	sedentary/medium	both sexes	M	Insects	B	20-60	CB
Eptesicus serotinus	sedentary/medium	both sexes	M	Insects	B	10-50 (300+)	B C
Hypsugo savii	?short range	?	M	Insects	B (O)	5-70	O (BT)
Myotis bechsteinii	sedentary	n/a	M	Insects	TB	10-30 (<80)	TC
Myotis blythii	medium range	both sexes	M	Insects	CB	<5000	C
Myotis brandtii	?short range	both sexes	M	Insects	BT	20-60	C
Myotis capaccinii	short range	both sexes	M	Insects	C	<500	C
Myotis daubentonii	medium range	both sexes	M	Insects	TBC	20-50 (200)	C
Myotis myotis	medium range	both sexes	M	Insects	CB	<2000	C
Myotis mystacinus	sedentary	n/a	M	Insects	BT	20-70	C
Myotis nattereri	short range	both sexes	M	Insects	TB	20-80 (<200)	CT
Nyctalus leisleri	long range	?mainly female	H	Insects	TB	20-50 (500+)	TO
Nyctalus noctula	long range	mainly female	H	Insects	T(B)	20-50 (>100)	TO
Pipistrellus kuhlii	?sedentary	n/a	M	Insects	B	30-100	?BO
Pipistrellus nathusii	long range	mainly female	M	Insects	TB	50-200	TBCO
Pipistrellus pipistrellus	(sedentary)	n/a	M	Insects	BT	20-50 (>100)	BTC
Pipistrellus pygmaeus	?sedentary	n/a	M	Insects	BT	50-150 (>1000)	BT

[1] Design for long range flight (high aspect ratio): L = low, M = medium, H = high

[2] Food type: fruit/flowers (F), insects (I)

[3] Roosts: underground sites (C), building (B), tree (T), other (O)

[4] Colony size: normal number of individuals (extremes in brackets)

Appendix 2. Climate Change and Migratory Species, Summary of Workshop Discussions, Madingley Hall, Cambridge, 16-17 March 2005

1. Background provided to participants

Climate change is one of the major factors likely to affect the earth's ecosystems in the coming years and centuries and there is already compelling evidence that animals and plants have been affected by recent climate change. Migrant wildlife, by travelling large distances, being subject to a wide range of environmental influences and relying on a wide range of natural resources are particularly likely to be affected by climate change at some point of their life cycles. The Bonn Convention on the Conservation of Migratory Species of Wild Animals (1979) (CMS, www.cms.int) seeks to promote and maintain the conservation status of migrant species of wildlife and Defra takes a lead role for the Government in these areas. The conclusions from this meeting will be used to inform Defra of the possible impacts of climate change with respect to migratory wildlife by reviewing the likely range of effects and to consider how migrant conservation status could be affected by projected changes. Of particular concern are the potential impacts that may affect the conservation of species listed in Appendices 1 & 2 of the Convention.

This section summarises the results of the breakout discussion groups at the workshop. In all there were 11 of these groups arranged into three sessions. The first of these assessed gaps in knowledge and action priorities across the different species groups (Birds, Bats, Terrestrial Mammals, Marine Mammals and Marine Ectotherms), while the second identified gaps in knowledge and action priorities in different functional areas (Physiological Mechanisms, Population Dynamics, Community Composition and Socio-economic Interactions), which were likely to be particularly impacted by changing climatic factors. This re-grouping of participants was aimed at providing the greatest cross-fertilisation of knowledge experience among the participants. Finally, a series of three groups looked at existing policies and opportunities for future developments, focusing in three areas: Requirements for Climate Change Adaptation, Assessing Monitoring and Action Priorities and Addressing Uncertainty Within the Policy Framework.

2. Session 1: Impacts on Species

Discussion 1.1: Birds

Convener: Dr Charles Francis (Canadian Wildlife Service, Canada)

Habitat alteration was identified as the major threat to migratory bird populations, particularly in terms of loss of stop-over sites. Habitats particularly affected in this regard were coastal (because of changes in sea-level) and freshwater (changes in water levels) areas, which were used primarily by migratory species. Coastal development is a particular problem in eastern Asia where economic growth is prompting the development of many coastal stopover areas. Wetland areas either side of the Sahara, particularly in the Sahel, were identified as being particularly important as they provided resources for crossing a major ecological barrier, but were vulnerable to climate change impacts and were already threatened by anthropogenic factors. Additionally, loss of tundra (and montane) habitat were seen as areas of concern, as these are utilised primarily by migratory species and species dependent on such habitats were unlikely to be able to adapt by range-shift.

Climate impacts, mainly through changing prey distributions, were also likely to have effects on a wide range of seabird species, but adaptation measures were difficult to envisage. Such impacts were likely to be greatest in the breeding season, when birds were attending breeding colonies and raising chicks (often energetically expensive for many seabirds, with only one or two chicks being raised per year). Location of breeding colonies for ground-nesting (i.e. most) seabirds is often limited by the presence of, usually introduced, predators, such as rats.

A further key issue for migratory species applied particularly to long-distance (trans-continental) migrants. Such migrants depend on local cues on the wintering grounds to determine their departure dates for the summering grounds to arrive when conditions were suitable for breeding. There is some evidence that these cues may be becoming decoupled, so migrants would be likely to depart at sub-optimal times. Short-distance migrants are likely to be less affected in this regard in that the cues used for departure (although changed phenologically) still pertain to conditions on the breeding grounds.

Methods for adaptation

Migratory species need a coherent network of sites to facilitate interchange between breeding and wintering areas. Enforcing existing site designations and protections, together with targeted new site designation will be an important tool for maintaining flyway integrity with future climate change.

Eradication of nest predators, particularly on small islands, would encourage the creation of additional seabird colonies (although difficult, this has proved successful in the past, particularly on smaller islands). This would give populations much more flexibility to adapt themselves to changing climatic conditions.

The ability of anthropogenic adaptation to changing climate for the conservation of migratory species (and others) will be limited. Consequently it is important that large populations are maintained, so that there is sufficient genetic variability for species to adapt biologically themselves.

Knowledge Gaps

a. Understanding the mechanisms behind the observed responses to climate change to better implement adaptation measures.

b. Understanding the strength and prevalence of density-dependent factors (and the role of population limiting factors more generally) in regulating population processes. This is necessary if accurate modelling of future population changes is to be achieved.

c. Understanding the importance and need for genetic variability for populations to respond to climate change. Currently, very little is known in this area.

Discussion 1.2: Marine Mammals

Convener: Dr Prof. John Harwood (Centre for Research into Ecological and Environmental Modelling, University of St Andrews UK)

Marine mammals are large, long-lived warm-blooded animals that show considerable behavioural plasticity. This plasticity allows many species to respond to environmental changes within a single generation, and these species are unlikely to be affected physiologically by moderate changes in the physical characteristics of their environment. Their apparent reliance on behavioural responses to environmental changes, some of which can be transmitted culturally, means that low genetic diversity – which has been demonstrated for some species – does not necessarily affect their ability to respond to such changes. It also means that match-mismatch problems are less likely to occur than in other taxa.

However, some migratory marine mammals, particularly those that rely on ice or the environment close to the ice edge, are vulnerable to the direct effects of climate change. Seals that rely on ice for breeding are likely to suffer considerable habitat loss over the coming decade, particularly those that are confined to inland seas and lakes (such as the Caspian Seal *P. siberica*, and the three subspecies of *P. hispida* that occur in the Baltic Sea, Lake Ladoga and Lake Saimaa). Similarly, large baleen whale species that undertake long distance migrations from tropical breeding grounds to high-latitude feeding grounds close to the ice edge (such as Blue Whales *Balaenoptera musculus* and Antarctic Minke Whales *B. acutorostrata*) may be at risk as the polar ice caps retreat. The longer migration paths that will be required will increase the costs of movement and reduce the duration of the feeding season.

Endangered marine mammal species which have restricted geographical distributions with no opportunity for range expansion in response to climate change (such as the Vaquita *Phocoena sinus* and Baiji *Lipotes vexillifer*) may also be at risk, as will species like the Mediterranean Monk Seal (*Monachus monachus*) which is reliant on a small number of caves or narrow beaches for breeding. These breeding sites could easily be destroyed or rendered unusable by sea level rise and increased storm frequency.

However, the greatest threat to marine mammals probably comes from changes in their food resources as a result of climate change. For example, many species appear to rely on particular sets of environmental conditions to concentrate their prey. If climate change affects the geographic distribution of these oceanographic conditions, this could have serious consequences for reproduction and survival.

Methods for adaptation

The effects on breeding habitat may be reduced by creating protected areas for the remaining habitat, if it can be identified. However, the main method for adapting to change in the wider environment will be to manage human impacts on the resources required by marine mammal species through some form of ecosystem based management. One way to achieve this would be to designate marine protected areas ('no-take zones') for the prey of marine mammals. However, the location of such areas is likely to change over time i.e. with climate change, and this will require very different legislation than anything that has been developed to date.

Knowledge gaps

a. Although marine mammals do show considerable behavioural plasticity, the limits to this plasticity are not known.

b. There is no formal framework that can be used for providing scientific advice on ecosystem based management (indeed, the concept itself is still rather poorly defined).

c. We do not have a good theoretical basis for identifying and tracking areas where the prey of marine mammals should be protected, but we know that this will have to take account of prey availability and prey quality, as well as simple prey density.

Discussion 1.3: Marine Fish, Squid and Turtles

Convener: Dr Graeme Hays, University of Wales, UK

For all these marine species, climate change is likely to result in range shifts and distributional changes in abundance. This will result in a shifting regional focus for conservation (e.g. Turtles are becoming much more frequent in UK territorial waters). A further consideration is the impact of anthropogenic factors, particularly harvesting (either of eggs or adults), which represent both a direct threat, but also one that is likely to shift in regional importance with changing distributions.

Predictions of the effects of climatic change on populations of marine fish and squid were hampered by a lack of knowledge in three key areas. Firstly, the movements and distribution of many migratory species is poorly understood. However, the technology required to do this was available and deploying it would help in understanding the shifting regional focus of adaptation requirements. Secondly, interactions between trophic layers (particularly distribution of prey species) were seen as very important in determining distribution. For example, shifts in the plankton community (which is sensitive to changes in water temperature) in the North Sea have had large effects on the distribution of fish. Long-term monitoring, particularly the Continuous Plankton Recorder (CPR) has provided much valuable information in this regard, both for documenting changes and providing a basis for future predictions. Thirdly, the effects of episodic events (e.g. storms) are poorly understood, but might have large impacts on recruitment into populations.

The greatest threats to turtle populations stemmed from habitat degradation (particularly of coral reefs, sea-grass communities and spawning beaches), and understanding the consequences of such degradation and reducing it were of primary importance in conserving turtle populations. The nature of this degradation, and its impact on turtle populations, may shift with climate change, and research and conservation policies need to be flexible to adapt to such changes. A potential effect of climate change that could affect turtle populations would be through increased temperatures changing sex-ratios, under extreme scenarios the possibility of single sex populations may arise. (The sex of turtle hatchlings, as many other reptiles, is determined by the temperature at which the eggs are incubated.) It is unclear to what extent turtle populations can adapt to these changes.

Discussion 1.4: Terrestrial Animals

Convener: Prof. Paul Racey (University of Aberdeen)
Rapporteur: Dr Humphrey Crick (British Trust for Ornithology, UK)

Invertebrates

Very little is known about the migration ecology or physiology of migratory invertebrates, except for some essentially irruptive pest species such as Desert Locust. In addition, very little is known about their wintering grounds either, but it is possible that increased dryness may be detrimental in north

Africa and southern Europe. It was noted that examples of supposed migration may be nothing of the sort, for example occasional swarms of ladybirds and hoverflies on UK coasts may in fact be locally produced and, having exhausted their prey, populations moved to the coast where they become stranded by prevailing on-shore winds. The key example migrant species is the Monarch Butterfly, but this is now very widespread with many self-sustaining populations and is apparently very adaptable. So, although it is possible that its Mexican wintering sites may be vulnerable to adverse change, the species, as a whole, is not.

Generally, migratory invertebrates are very abundant, very adaptable, and use a wide range of habitats. So it seems unlikely that they will be detrimentally affected by climate change. If anything, their populations are likely to be enhanced, as warming will tend to promote extra generations per year. The only possible problems that might affect migratory invertebrates are: (a) changes to wind directions, such that they oppose the normal migration direction instead of facilitating migration; (b) increased extreme events, such as drought or flood, that may affect survival and reproduction of whole cohorts; (c) increased susceptibility to pathogens due to changes in temperatures and humidity.

Bats

If one considers the life cycle of a typical temperate zone migratory bat then the key critical phase is the lactation period in early summer. During this period, females have to forage to maintain body weight and to produce sufficient milk for their dependent offspring. A short period of inclement weather during this period will lead to large-scale desertions by females of their offspring. For example, four days may be sufficient to cause desertion by female Mouse-eared Bats. The second critical period is in late summer when any decrease in invertebrate food supplies will affect the pre-migratory fattening of bats. This will be especially detrimental to males who require energy to compete for mating attempts with females. The third critical period is in the early spring, when bats emerge from hibernation, because poor weather in the hour after dusk can lead to starvation. However, warmer, wetter early spring weather, as likely with climate change, may be beneficial if it leads to raised abundance of invertebrate prey populations. The final problem period might occur in winter and concerns the temperature in hibernacula. Sperm stored by females from the autumn, for fertilisation after ovulation in the spring, lose their viability with warmth. This is an experimental result and it may not apply in the field because hibernacula are generally well insulated from changes in external temperatures. Finally, it was noted that earlier phenology in the spring was likely to be beneficial because it would enhance the survival prospects of young by promoting better physical condition prior to migration in the autumn.

In general, long-distance migratory bats were not considered to be particularly threatened by climate change because they tend to be both widespread and adaptable. Probably the key issue is moisture availability to promote populations of their invertebrate prey. There is a need to ensure that there is a good network of wetlands and moist woodlands for foraging *en route* (although too little, is known about this stage in bats). The concept of promoting environmentally sensitive flood-plain management and river corridor management in Europe would almost certainly be beneficial. The siting of traditional large hibernacula in relation to changes in the climate envelope for migratory bats is unlikely to be a threat, because hibernacula must be abundant to support existing populations of bats, although their characteristics are poorly known. Caribbean bats are likely to be threatened by increased frequencies of hurricanes that might destroy habitat and kill bats directly. Afrotropical bats appear to depend on the large-scale fruiting of key species at certain times of the year. If drought became more prevalent in southern Africa, then this might pose problems for migratory bats that depend on these food sources. Australian bats appear to be relatively nomadic and are probably adaptable enough to cope with climate change. There is far too little relevant information available on bats to be able to assess the impacts of climate change. In Europe, a migratory atlas of bats is being prepared under the auspices of the CMS Eurobats Agreement, but there is an urgent need to improve the infrastructure to support bat migration studies, to put it on a par with bird ringing.

3. Session 2: Functional Aspects of Climate Change

Discussion 2.1: Physiology

Convener: Prof. Franz Bairlein (Vogelwarte Helgoland, Germany)

Understanding the impacts of climate on physiological processes, and the variability in an individual's response (phenotypic plasticity), is important for understanding the ability of migratory species to adapt to changing climatic conditions. For example, is there sufficient variation in the population (more likely in larger populations) and will physiological constraints 'allow' biological adaptation? A consideration of physiological processes will also help in understanding the mechanisms behind a species' response to climate change, enabling better predictions of impacts and better targeting of adaptation measures.

Ambient temperature could affect individuals of migratory species in many ways, for example, reducing the energetic cost of wintering at higher latitudes (leading to shortened migration routes), affecting the growth and development of ectotherms (e.g. reptiles, fish) and altering the timing (and duration) of events, e.g. pregnancy in bats and moult in birds. More generally, it will also affect the distribution of prey (whose ranges are often temperature dependent, as everything else) and prey quality, as growth schedules (of the prey) will be altered. This can influence both the intake rates of animals, but also their migratory schedules, as has been shown for warblers (Sylviidae) migrating through Africa.

Increased levels of carbon dioxide (CO_2), as well as rising ambient temperature will affect physiological processes directly, for example, by affecting the oxygen transport capacities in aquatic species. Ambient CO_2 concentration also influences the quantity of secondary compounds in plant leaves (which can be toxic to herbivores), altering prey quality, which may lead to reduced survival (because of reduced nutrient intake) or increased movements (to locate better forage).

Migration dynamics may also be affected by changing patterns of precipitation, both because of altered energetic considerations (such as a decreased ability to thermoregulate) and difficulties in orientation, particularly if a sun-compass or geographical cues to determine location are used. Similarly, changed wind regimes may alter the location of migratory routes or result in increased energetic costs in trying to maintain a traditional route. Such changes may also alter the initiation of migratory behaviour. Similar considerations presumably apply to aquatic species and changing oceanic currents. However, little is known about these effects, and the likely population consequences and predictions are difficult due to scale limitations in current climate models.

Discussion 2.2: Population Dynamics

Convener: Dr Stephen Baillie (British Trust for Ornithology, UK)

Climate change may have adverse impacts on the population dynamics of migratory species, as summarised in the following table

Factors	Birds	Bats	Sea Mammals	Fish	Turtles
Loss of Stopover Sites	Major	Important	--	--	--
Temperature	--	--	--	--	YES (for sex determination – but may be able to respond)
Loss of Breeding Habitat	Yes	Yes	Yes	Yes	Yes
Longer Migratory Pathways	Yes	Yes??	Yes (need to go to Poles)	??	--
Mismatch in Timing	Yes	??	??	Yes	--
Changes in prey availability	Yes	Yes	Yes	Yes	Yes
Inter-specific Competition	Debated	?Roosting sites	??	??	No
Non-breeding habitat/ wintering sites	Yes	Yes	?	?	Important

Key potential adaptation measures might thus be: provision of stopover habitats (primarily for birds and bats); creation of habitat (e.g. haul-out sites for seals) and protection of existing habitat, particularly reducing site degradation and planning protected areas in relation to future climate scenarios and not just present conditions. A further key measure for adapting to climate change is protection of prey resources through ecosystem management.

A full understanding of the effects of climate change on population dynamics, and hence on a species status, are hampered by a lack of knowledge, particularly with regard to marine taxa and bats, as summarised below:

Climate Change Factors	Birds	Bats	Sea Mammals	Fish	Turtles
Migration Patterns	***	*	**	*	*
Abundance & Distributions	***	**	**	**	**
Habitat use of each species to allow future modelling	***	**	*	*	*

* = poor knowledge; ** = moderate knowledge; *** = better knowledge
Note for marine animals it is not enough to have distributional information, because habitat is not known at various locations, and attributes of a given location may change over time

The use of simple 'correlational' models between numbers, habitat/prey availability and climate may be a useful starting point, but they still need to be developed for most species and their limitations need to be recognised. In particular, they are usually descriptive and may or may not be successful at predicting changes; they may also often use simple, easily measured environmental parameters as proxies for key demographic parameters – relationships that may change over time.

Mechanistic models of population dynamics are the best way both to understand the impacts of climate change and to make robust predictions. However, these require a good understanding of the link between prey availability and demography (reproduction/survival). These relationships are likely to be dependent on the density of both prey and the animal in question. Developing such models is likely to be time-consuming, thus efforts may be best concentrated on a small number of species that are representative of a range of taxa. Where possible these should build on existing datasets and knowledge:

- Turtles: a limited number of stage-based demography models have been developed to estimate some basic parameters, though there is a lack of time series data on resource availability to go with this.
- Fish: spatially explicit modelling was thought necessary to fully understand population dynamics, but there is not yet enough information to understand how spatial factors influence demographic parameters.
- Marine Mammals: a number of data-sets are available, some of which show density-dependence in demographic parameters, however, most are not from the species thought to be most sensitive to climate change and there is little in the way of resource availability data.
- Birds: a small number of detailed models are available, many of migratory species, e.g. Oystercatcher *Haematopus ostralegus*, Red Knot *Calidris canutus* and several species of geese.
- Bats: very little is known.

Discussion 2.3: Community & Multi-trophic Issues

Convener: Prof. Brian Huntley (University of Durham, UK)
Rapporteur: Dr Tim Sparks (Centre for Ecology and Hydrology, UK)

Much remains unknown. Key gaps in knowledge were identified as:

- Changes in prey quality (i.e. nutritional value) and abundance, which might affect growth schedules or change migration patterns.
- Synchrony with prey populations, particularly in terms of timing of reproductive schedules. We need to know how widespread are the impacts on distributions and abundance and whether migrants, particularly long-distance migrants, are more affected.
- Spread of diseases and parasites, as might happen in response to increased temperatures. A further question is whether migratory species might help spread these, and whether there is likely to be transfer into populations of resident species, which may have evolved far from the parasite population.
- With shifting ranges, competitive pressures within communities are likely to change. A key area where little is known is whether changed wintering areas of migratory species (e.g. because of shorter migratory distances) will affect populations of resident species in their new wintering areas.

Discussion 2.4: Socio-economic interactions

Convener: Dr Jennifer Gill (University of East Anglia, UK)

The key interaction between climate change and land management issues will involve changed agricultural practices. Perhaps the biggest impacts will arise from conversion of wetland and marginal habitats. These are habitat types frequently used by migratory birds, either as staging areas or as migratory corridors. Widespread impacts are also likely from increased water abstraction, which is likely to be greatest in the driest areas, where wetland resources provide the greatest benefits to migratory species, particularly in terms of staging areas before or after major ecological barriers (i.e. deserts). Other habitats important for wildlife, which may be threatened with agricultural conversion as a result of a changing climate, include tundra, steppe and chalk grassland and tropical forest.

In Europe, priority conservation action should focus in three particular areas. Firstly, creation of habitat corridors at a range of scales. At small scales, planting of hedgerows and creating networks of small woodlands will benefit 'broad-front' migrants, whose migratory routes are relatively diffuse. This might be best achieved by using carefully tailored agri-environment schemes to encourage broad participation amongst farmers, for example as seems possible with the UK's Entry Level Scheme. At larger scales, initiatives such as the Meso-American Corridor should help facilitate migratory journeys, but may be more appropriate in landscapes with a higher proportion of 'pristine' habitat. Secondly, integrated management, including the use of buffer zones, of wetland sites is required, many of which are critical stopping-off areas for migratory species. More generally, there is a need to ensure a coherent provision of a network of stopover sites to ensure migratory routes can be maintained under future climate scenarios.

In Africa, although the same actions may be beneficial, more fundamental measures are likely to be required. Tackling issues of poverty and education are, in some ways, more pressing issues, however, these are unlikely to be solved without reference to environmental management and the impacts of climate change. Education in land and soil management issues and the development of drought tolerant crops may be particularly useful. Rather than designating new protected areas, there is a need to enforce the designations already in place.

More generally, adaptation to the effects of climate change is likely to require a multi-benefit ecosystem approach. Thus, it is much more likely that conservation goals will be achieved if they are part of ecosystem management with wider aims such as floodplain management, coastal protection or reducing deforestation. The ecosystem management approach of the Convention on Biological Diversity provides many of the mechanisms for these, but they will require the education and empowerment of local people.

4. Session 3: Policy directions

Discussion 3.1: Tackling underlying issues

Convener: Eric Blencowe (Defra, UK)

Three broad areas were identified as being critical to migratory birds:

- Changes in water resources, particularly wetland quality and site maintenance
- Desertification, particularly when this increases the width of ecological barriers and impacts on staging sites either side
- Habitat extinction, particularly of tundra, cloud forest, sea ice and low-lying coastal areas, especially in Small Island Developing States

The discussions focussed largely on terrestrial ecosystems, where adaptation is likely to be possible; in marine systems mitigation of emissions may be the only approach to yield substantial benefits. In general, actions were thought possible within existing frameworks, though increased linkages between instruments was likely to be required.

Priorities for action were identified as:

- Strengthening legislation for marine mammals and turtles.
- A research focus on intra-tropical migrants, about which little is known.
- Technology transfer to support establishment of site networks.
- Mapping and identifying stopover sites to reduce fragmentation and help develop a coherent network of sites.
- Developing multi-functional ecosystem approaches.
- Recognise the need for flexible site management policies to enable adaptation to climate-induced changes in habitat.
- Encourage the use agri-environment schemes on a global scale. In many areas farming represents the predominant land-use so even relatively small modifications over such an extensive area can have a potentially large cumulative effect.

Discussion 3.2: Assessing Priorities for Action and Monitoring

Convener: David Webb (Defra, UK)

Priority Action on Species

- There is a need in many areas for basic inventories of migratory species, for example in the UKOTs.
- Need to identify vulnerable species and consider how important are the threats due to climate change in the context of other factors; whether long-distance migrants are intrinsically more vulnerable than short-distance migrants; and how vulnerable are habitat specialists, especially in the light of habitat fragmentation.
- Need to identify indicator species, including those that might indicate site condition and the condition of migration routes.

Priority Action for Monitoring?

- Provide consistent support to existing monitoring efforts, especially long-term schemes such as the Continuous Plankton Recorder, to monitor abundance, distributions (both spatial and temporal) and condition of individuals– which may provide an early warning of impacts and help to inform on the mechanisms of those impacts.
- Develop standardised protocols for monitoring populations and their dynamics, for example, the guidelines on monitoring survival and reproduction in migratory shorebirds, Robinson *et al.* (2005) *Wader Study Group Bulletin* 106:17-29.
- Develop thresholds for assessing the success of environmental management programs.
- Facilitate monitoring of sites and habitats and identification of site networks used by migratory species.
- Ensure the release and security of long-term historical datasets.

Priority Action for Knowledge Transfer

- Improve awareness and use of existing databases such as the Global Register of Migratory Species (GROMS, www.groms.de) and the Global Biodiversity Information Facility (GBIF, www.gbif.org).
- Facilitate exchange of knowledge from countries where monitoring techniques are already highly developed.
- Facilitate integration of existing data between countries, for example of the databank of the European Bird Ringing Union (EURING, www.euring.org) shows how multi-national data exchange protocols and cost efficiencies can be developed.

Discussion 3.3: Addressing Uncertainty

Convener: Dr Mike Harley (English Nature, UK)

"… as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns, the ones we don't know we don't know … it is the latter category that tend to be the difficult ones." D. Rumsfeld, U.S. Dept of Defense briefing (2002)

One response to climate change that is certain is that species will try to shift their ranges, as ample palaeontological evidence suggests. However, it is uncertain how much habitat fragmentation will slow, or prevent, these range shifts. In general, we have a reasonable idea of many of the likely responses to climate change. Although there is a perception that the predictions of ecological models are less certain than those of other disciplines, e.g. climate modelling, the conclusions are probably no less robust. This might stem from the very clear statements of uncertainty that (for example) climate modellers give. Developing a probabilistic framework to model outputs may help in this regard, as well as allowing the costs of different options to be evaluated.

An overall goal would be to adapt the management of existing sites (and new sites, possibly identified on the basis of geographic or edaphic characteristics) to provide an ecologically functional and resilient landscape allowing connectivity and permeability of species through it.

5. Workshop Programme

Day 1: Biological issues:

09:30 Arrival

Introduction
09:45 Introduction and welcome: aims of workshop
Eric Blencowe (Defra)
10:00 Climate change and the CMS
Humphrey Crick (BTO)

Climate Impacts on Migratory Species
10:15 Birds
Rob Robinson (BTO)
10:35 Bats
Tony Hutson (IUCN/SSC Chiroptera Specialist Group)
10:55 Terrestrial mammals
Graham Pierce. (University of Aberdeen)
11:05 Terrestrial invertebrates
Tim Sparks (Centre for Ecology & Hydrology)

11:20 Coffee

11:40 Marine mammals (cetaceans & seals)
Jennifer Learmonth. (University of Aberdeen)
12:00 Marine poikilotherms (turtles, fish, cephalopods)
Graham Pierce (University of Aberdeen)
12:20 General Discussion
Mark Rehfisch (BTO)

13:15 Lunch

Discussion Sessions
14:00 Introduction to discussions
14:15 Review of impacts on species, particularly those on CMS
  i) Birds
  ii) Marine poikilotherms
  iii) Marine mammals
  iv) Non-marine mammals

16:00 Tea

16:30 Gaps in knowledge and action priorities –
  i) Physiology
  ii) Demography & population dynamics
  iii) Community/multi-trophic issues
  iv) Interactions with socio-economic factors

18:30 Reception

19:15 Dinner

Day 2: Policy Issues

Reporting Session
09:00 Reports from the convenors and discussion of species review.
09:45 Reports from the convenors and discussion of gaps review.

Policy Reviews
10:30 Climate change and the Convention on Biological Diversity
Glenys Parry (Biodiversity Convention and Darwin Initiative, Defra)
10:45 Climate change, the IPCC and wildlife
David Webb (European Wildlife Division, Defra)
11:00 The Convention on Migratory Species
Eric Blencowe (Global Wildlife Division, Defra)

11:30 Coffee

Discussion Session
12:00 Policy issues
  i) Policy development – how to tackle the underlying issues
  ii) Assessing priorities for action & monitoring (species & areas) – can it be done?
  iii) Uncertainty of impacts in climate change – how best can policy address this?

13:30 Lunch

14:15 Reports from the convenors and discussion of policy review.

15:30 Conclusion and next steps
David Stroud (JNCC)

15:45 Close of meeting

6. Workshop Attendees

Stephen Baillie	British Trust for Ornithology	Thetford	UK
Dawn Balmer	British Trust for Ornithology	Thetford	UK
Prof. Franz Bairlein	Vogelwarte Helgoland Germany	Wilhelmshaven	
Marco Barbieri	CMS Secretariat Germany	Bonn	
Keith Bensusan	Gibraltar O&NH Soc.		Gibraltar
Pam Berry	Environment Change Institute	Oxford	UK
Eric Blencowe	Defra	Bristol	UK
Frances Buckel	UKOT Conservation Forum	Peterborough	UK
Colin Catto	Bat Conservation Trust	London	UK
Jacquie Clark	British Trust for Ornithology	Thetford	UK
Nigel Clark	British Trust for Ornithology	Thetford	UK
John Cortes	Gibraltar O&NH Soc.		Gibraltar
Humphrey Crick	British Trust for Ornithology	Thetford	UK
Noranne Ellis	Scottish Natural Heritage	Edinburgh	UK
Mads Forchhammer	University of Copenhagen Denmark	Copenhagen	
Charles Francis	Canadian Wildlife Service	Ottawa	Canada
Jennifer Gill	University of East Anglia	Norwich	UK
Brendan Godley	Marine Turtle Research Group	Penryn	UK
Mike Harley	English Nature	Peterborough	UK
Graeme Hays	University of Wales	Swansea	UK
Brian Huntley	University of Durham	Durham	UK
Tony Hutson	IUCN-SSC Chiroptera Specialist Group	UK	
Martin Konvicka Rep.	Czech Academy of Sciences	Ceske Budejovice	Czech
Jennifer Learmonth	University of Aberdeen	Aberdeen	UK
Esa Lehikoinen	University of Turku	Turku	Finland
Ilya MacLean	British Trust for Ornithology	Thetford	UK
Julian Metcalfe	CEFAS	Lowestoft	UK
John O'Sullivan	Royal Soc. Protection of Birds	Sandy	UK
Glenys Parry	Defra	London	UK
Charles Perez	Gibraltar O&NH Soc.		Gibraltar
Graham Pierce	University of Aberdeen	Aberdeen	UK
Paul Racey	University of Aberdeen	Aberdeen	UK
Mark Rehfisch	British Trust for Ornithology	Thetford	UK
Rob Robinson	British Trust for Ornithology	Thetford	UK
David Sims	Marine Biological Association	Plymouth	UK
David Stroud	Joint Nature Conservation Comm.	Peterborough	UK
Tim Sparks	Centre for Ecology & Hydrology	Abbot's Ripton	UK
Chris Thomas	University of York	York	UK
Marcel Visser	Netherlands Inst. for Ecology Netherlands	Heteren	
Clive Walmsley	Countryside Council for Wales	Bangor	UK
David Webb	Defra	Bristol	UK
Andy Williams	Defra	Bristol	UK
Ian Woiwod	Inst. for Arable Crop Research	Rothamsted	UK