BTO Research Report 495

Indicators of the impact of Climate Change on Migratory Species

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EXECUTIVE SUMMARY

1. Migratory species, by travelling large distances, often between discrete sites, are particularly likely to be affected by anthropogenically-induced climate change at some point in their life cycles. The UK Government is a signatory to a number of international treaties and agreements that seek to promote and maintain the conservation status of migratory species of wildlife, and the Department for Environment, Food and Rural Affairs (Defra) takes a lead role for the Government in these areas. The primary instrument in this area is the Bonn Convention on the Conservation of Migratory Species of Wild Animals (CMS). Recently, the CMS adopted a Resolution (UNEP/CMS/8.13) recognising the impacts of climate change on migratory species and calling on parties and range states to undertake more research to improve our understanding of these impacts and to implement adaptation measures to help reduce foreseeable adverse effects addressing this.

2. Given the great range and diversity of taxa affected by climate change it is impossible to monitor all species and all impacts of climate change. However, it is likely that many of the key physical and ecological processes, through which climate change may have an impact on wildlife, could be monitored using indicator species or groups of species as a proxy for wider assemblages, habitats and ecosystems. In this project, we aim to identify a suite of indicators that would represent detrimental impacts of climate change on a representative range of migratory wildlife.

3. At the start of this project, we reviewed previous research to identity those habitats where climate change impacts are likely to be most extreme, the species likely to be most influenced by climate change, and the key ecological and physical processes (e.g. ice retreat, increasing temperature) acting on species populations. To help refine indicator methodology, to review the objectives of project, to critically examine a provisional draft suite of indicators and to identify any important gaps in monitoring, a workshop of international experts and relevant stakeholders was organised by the BTO and held at the University of East Anglia, Norwich on the 13th and 14th December 2007 (see Annex 1). As part of this project, we also review potential mechanisms for generating biodiversity alerts as a means of assessing the extent of the impacts of climate changes on migratory taxa, and the success of any management measures implemented.

4. Importantly, the climate change literature has a bias towards birds and, to some degree, marine mammals, fish and turtles. These are species groups for which there is generally better monitoring data and for which the relationships with climate change are best understood. Whilst we have attempted to obtain representative taxonomic coverage, completely representative coverage has not been possible, because of knowledge gaps for certain taxonomic groups and geographic regions of the world. Following the December 2007 workshop, a suite containing 18 indicators was proposed, including four indicators for birds (1) Relative abundance of Trans-Saharan migrant birds, (2) Relative abundance of Penguins, (3) Productivity of seabirds, and (4) Productivity of Arctic Shorebirds; four indicators for marine mammals (5) Polar bear body condition, (6) Fur seal pup production in the Antarctic, (7) Southern Right Whale calf output in the Antarctic, (8) Ice-breeding seal pup survival; one indicator for fish, (9) Juvenile survival of Salmon; two indicators for turtles (10) Loss of suitable sea turtle nesting habitat through sea level rise, (11) Skewed sex ratios in sea turtles; four indicators for land mammals (12) Caribou / Reindeer calf production and survival, (13) Population size and range of large African herbivorous mammals, (14) Population size and movements of Wildebeest, (15) Population size of Saiga antelope; and three indicators for bats, (16) Abundance of bat aggregations at ‘underground’ hibernation sites, (17) Populations of straw-coloured fruit bat in Africa, and (18) Populations of Mexican Free-tailed Bats.

5. The scope of the project, which is global and considers migratory wildlife as potentially providing an indicator of climate change, was extremely ambitious. When choosing indicators, there will always be a level of judgement required, and the choice of indicators selected may be, to some degree, a reflection of the knowledge of the experts present and certainly driven by our current understanding of climate change impacts. In terms of gaps in coverage, freshwater and montane habitats are currently poorly represented and there are few indicators covering species in Asia, South America and Australia. In general, it is recommended that further expert opinion is obtained when developing individual indicators. This would help to strengthen support from the scientific community and improve global awareness of the need for indicators of climate change impacts on migratory species, which would in turn help stimulate monitoring and possibly provide a lever to obtain funding in areas that are currently poorly or not monitored by existing schemes. This process may also identify further gaps, which could be filled and would help refine the priorities for further data collection.

6. Whilst we have endeavoured to select indicators that present the clearest signal of climate change impacts, it is likely that these indicators will still be subject to strong influences other than climate change. Therefore, where possible, indicators should be complemented by analyses to identify the contribution of climate change, over and above other influences. It is also important that, where there is additional information that provides support for an indicator, this is presented alongside the indicator. This may include distributional changes or phenological indicators which are thought to reflect climate change, but where the precise nature of the impact is currently unclear. In addition, remote sensing information provides an extremely powerful resource for putting an indicator in context. This has the potential for improving our understanding of climate change processes and, more generally, for explaining the processes to a wider audience.

7. For a small number of the indicators presented here, such as the population changes of Trans-Saharan migrants birds, or Polar body condition and survival, their implementation would be relatively straightforward, given support from the appropriate data providers. However, most indicators here require additional data collation using standardised protocols and, and in many cases, would require some methodological development, e.g. to quantify trends. In the development of all indicators, it is important to consider how the approach taken would fit more generally into an alerts system, and how it would relate to objectives from a management perspective.

1. INTRODUCTION

Anthropogenically-induced climate change, is one of the major factors likely to affect the Earth's ecosystems in the coming years and centuries (IPCC 2007, Stern 2007). The role of human activities in the observed changes is now clearer than ever. The IPCC Fourth Assessment Report concludes that most of the observed increase in global temperatures since the mid-20th century is very likely (i.e. more than 90% chance) due to the human-induced increase in greenhouse gas levels in the atmosphere. The increase in global temperature in the 20th century was greater than in 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 Fourth Assessment Report (2007) gives a range of warming of between 1.1 and 6.4 degrees above 1990 levels by the end of the Century, depending on climate model and emissions scenario. 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 (Hansen *et al*. 2006). There is already compelling evidence that a wide range of animals and plants have been affected by recent climate change (e.g. Parmesan & Yohe 2003, Root *et al.* 2003, Crick 2004, Thomas *et al.* 2004, Robinson *et al.* 2005, Menzel *et al.* 2006). In this report, we define *climate change* according to Article 1 of the Framework Convention on Climate Change (UNFCCC) as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. Thus we also make a distinction between climate change attributed to human activities altering the atmospheric composition, and *climate variability* attributable to natural causes. These effects have already been demonstrated on migratory species and include earlier breeding (e.g. Crick *et al*. 1997, Crick & Sparks 1999, Weishampel *et al.* 2004); changes in timing of migration (e.g. Sims *et al.* 2001, Lehikoinen *et al.* 2004); changes in breeding performance (e.g. Thompson & Ollason 2001, Pierce & Boyle 2003, Whitehead 1997, Green & Pershing 2004); changes in population sizes (e.g. Crick 1999, Pierce & Boyle 2003); changes in population distributions (e.g. Berry *et al.* 2001, Zheng *et al.* 2002, Austin & Rehfisch 2005, MacLeod *et al.* 2005, Sparks *et al.* 2007); changes in selection differentials between components of a population (Visser *et al*. 1998, Buse *et al.* 1999, Bradshaw & Holzapfel 2006); and even extinction (Pounds *et al.* 2006).

Migratory species, by travelling large distances, often between discrete sites, are likely to be affected by climate change at some point in their life cycles (Robinson *et al.* 2005, Frisch *et al.* 2006). Birds comprise the best-studied group of migratory species, but the effects of climate change have been documented among species of migratory marine mammals, fish, turtles, squid, bats, terrestrial mammals and insects (Robinson *et al.* 2005). Although many effects are species-specific, some parallels can be discerned across taxa, including: changes in prey availability and timing of prey life-cycles, changes in the distribution and quality of important habitats and changes in the environmental and ecological conditions encountered while on migration.

The UK Government is a signatory to a number of international treaties and agreements that seek to promote and maintain the conservation status of migratory species of wildlife, and Defra takes a lead role for the Government in these areas. The primary instrument in this area is the Bonn Convention on the Conservation of Migratory Species of Wild Animals (CMS, 1979, www.cms.int), which is particularly concerned with the conservation of species listed as endangered (CMS Appendix I) or as having unfavourable conservation status (CMS Appendix II). The CMS also has a number of associated agreements focussing on particular groups of taxa, such as waterbirds (AEWA), cetaceans in the Baltic and North Seas (ASCOBANS) and Mediterranean/Black Seas (ACCOBAMS), and European bats (EUROBATS). Other key international legal and policy instruments for nature conservation that cover migrant species include the Ramsar "The Convention on Wetlands of International Importance especially as Waterfowl Habitat" (1971, www.ramsar.org) and the EC "Birds" (1979/409/EEC) and "Habitats" (1992/42/EEC) Directives. Recently, the CMS adopted a Resolution (UNEP/CMS/8.13) recognising the impacts of climate change on migratory species and calling on parties and range states to undertake more research to improve our understanding of these impacts and to implement adaptation measures to help reduce foreseeable adverse effects addressing this. In order to achieve this successfully, monitoring of the impacts is required, both to quantify the extent of the problem, but also to assess the success of any implemented measures.

Clearly, given the great range and diversity of taxa affected by climate change it is impossible to monitor all species and all effects of climate change. However, it is likely that many of the key physical and ecological processes through which climate change may impact wildlife could be monitored using indicator species or groups of species as a proxy for wider assemblages, habitats and ecosystems (Furness & Greenwood 1993, BirdLife International 2004).

Before we go any further, it is important to provide a clear definition of what we mean here by an "effect" or "impact". We define an "effect" here as a measurable response to climate change. This includes phenological change, for example earlier egg-laying in birds with warmer spring temperature or changes in distribution. An "impact" however is defined as an "effect" at the level of interest, which in this case is the conservation status of the population or community of interest. For example, phenological change or changes in distribution would not necessarily be classed as "impacts", because there is little evidence in most cases that these would impact on the conservation status of the species or communities of interest as a whole, although it is appreciated that these effects can have important management implications at a regional level. Impacts may be positive or negative on the conservation status of species.

In this project, we have concentrated on identifying a suite of indicators that will reveal the negative "impacts" of climate change on migratory species for the CMS. This has a very specific focus, with the aim of informing parties to the CMS of detrimental impacts of climate change that may require policy action.

Indicators quantify and simplify phenomena and provide insight into complex realities. An indicator should be easy and/or cheap to measure but co-vary with changes in the system we wish to know about, which is more complex, difficult and/or expensive to measure. For example, an indicator of the state of bird populations co-developed by the British Trust for Ornithology (BTO) and Royal Society for the Protection of Birds (RSPB) has been adopted as one of the UK Government Sustainable Development Framework Indicators (Defra 2007). This carefully formulated indicator highlights the unfavourable conservation status of farmland birds in the UK, and has stimulated action to address this by altering agri-environment scheme designs (Gregory *et al.* 2004). A similar approach has recently been adopted to monitor the state of wildbird populations across Europe (Gregory *et al.* 2005). In the marine environment, fisheries management in the European Union has broadened from the traditional, narrow focus on single-species management to a wider ecosystem-based approaches. A broad array of indicators have been developed to describe the threat status of individual species; the average size of fish, and the sustainability of fisheries. These indicators are used in 'state of the seas' (e.g. MCCIP 2007) and 'state of the environment' (Harrison 2006) reporting and are being developed to measure progress toward regional policy goals (Common Fisheries Policy) and international treaty targets such as the World Summit on Sustainable Development targets, *e.g.* to achieve a significant reduction in the current rate of loss of biological diversity by 2010.

The greatest efficiency and cost-effectiveness in developing a suite of indicators for monitoring the effects of climate change on migratory wildlife would be achieved by utilising appropriate information from pre-existing long-term monitoring schemes. In addition for many indicators physical/abiotic information including the use of remote sensing data may provide important supportive information or to help with interpretation. In some cases, although potentially suitable protocols and data already exist, they require compilation and harmonisation to be effective at the scale required. Such standardised protocols can then serve as templates for establishing monitoring of similar species in other areas.

A second key aspect to the development of monitoring schemes is to implement a system of "alerts" whereby thresholds for action are established at pre-determined levels of change in an indicator. This is an approach widely adopted in fisheries management, whereby estimated fish stock abundance is compared to a biological limit reference point and management responses are triggered if stock abundance levels below this limit reference point. The BTO have led the development of statistically-based alerts both for national bird population declines and also for changes in site condition (Baillie & Rehfisch, 2006), and these will form the basis for the development of alerts here. Although developed specifically for UK bird monitoring schemes, such approaches are readily applicable at a broader scale and to other taxa. Similar reference points and reference directions have been developed at CEFAS for a range of marine species (e.g. Jennings & Dulvy 2004, Dulvy *et al.* 2006).

1.1 Aims and methods

The aim of this project is to identify a set of indicator species, which can provide information on climate change impacts on the global status of migratory species. Here we defined migratory species according to the CMS, as 'species that cyclically and predictably cross one or more national jurisdictional boundaries'.

To achieve this aim, we have built on previous Defra-funded research (CR0302 – Robinson *et al.* 2005), the results of which were presented to the CMS 8th Conference of Parties (UNEP/CMS/Conf 8.22) and literature published since this time to identify key habitats, ecological and physical processes (e.g. range change, phenological mismatch) and species that are likely to be affected by climate change. To examine the suitability of potential indicators, we collated information on the extent, nature and reliability of existing data collection and monitoring schemes and identified a set of desirable criteria against which to evaluate indicators.

To help refine indicator methods and objectives, critically examine the first ideas for indicators and identify any important gaps in monitoring, a workshop of international experts and relevant stakeholders was organised by the BTO and held at the University of East Anglia, Norwich on the 13th and 14th December 2007 (see Annex 1).

Finally, a review was carried out of the potential mechanisms for generating biodiversity alerts as a means of assessing the extent of the impacts of climate changes on migratory taxa, and the success of any management measures implemented.

In this document we refer to indicators considered for the final suite as belonging to one of three broad categories i) *Time-series available* ii) *Empirical observation*, and iii) *Concept-only*.

- *Time-series available* is where the underlying data are collected according to a standardised monitoring protocol and constructing an indicator from these data would be feasible in collaboration with the data-holders.
- *Empirical observation* is where data are collected according to a standardised monitoring protocol, but there are currently significant gaps in coverage at the species or geographical level. In addition, it is likely that some development work would be needed to construct an appropriate indicator.
- *Concept-only* is where there is a good theoretical basis for nature of the climate impact, but the data are not currently being collected according to a standardised monitoring protocol, there are perhaps gaps in coverage, and it is likely that significant development work would be needed to produce the indicator.

2. CHOOSING AND EVALUATING INDICATORS

2.1 Introduction

Indicators can have a number of uses but are typically used to communicate the *state* of a species or habitat, the human *pressures* on the environment in which they occur and the *response* of management to prevent or mitigate these pressures. Indicators are increasingly used as a decision-support tool within management frameworks of complex systems. The recent move toward developing ecosystem-based approaches to environmental management and evaluating the progress of international treaties has led to a concerted effort to develop appropriate indicators of environmental or ecological state and of the natural and human pressures influencing state.

A key problem associated with developing a suite of indicators is that there are potentially many hundreds of plausible candidates. Consequently much recent research has been less focussed on indicator development, but rather has concentrated on developing evaluation frameworks for selection suites of appropriate indicators (Rice & Rochet 2005). The high diversity of potential indicators means that indicators need to be evaluated for the degree to which they are 'fit-for-purpose' as a decision support tool. For the purposes of this project at least eleven desirable properties of indicators were identified (2.2). Amongst the most important characteristics are:

- **specificity** of an indicator to a single pressure (climate change) rather than to a suite of other pressures (exploitation, invasive species etc);
- **responsiveness** or degree to which the indicator lags behind the pressure; and
- **sensitivity** or magnitude of the change in indicator to the pressure, relative to background variation, or noise (Rice 2003, Rice & Rochet 2005).

The properties of even widely-used indicators have rarely been fully evaluated in a quantitative manner; Those indicators that have often appear to be less useful than initially hoped for. A number of limitations have been identified: (1) indicators are less specific and respond to a range of environmental factors rather than a single specific pressure (Blanchard *et al.* 2005); (2) they exhibit considerably lagged changes and therefore low responsiveness (Jennings *et al.* 2002); (3) even the most data-intensive indicators may have very low responsiveness; consequently 5-15 years may elapse before the change in index is deemed significant enough statistically to warrant a change in management (Jennings & Dulvy 2005); and finally (4) setting reference points or thresholds for triggering 'alerts' or a change in management can be challenging because of poor theoretical understanding of the ecological complexity of the system (Jennings & Dulvy 2005).

While weighting and scoring algorithms have been developed for specific situations (MSC 2004), we feel here that such scoring would give a false sense of precision to a subjective exercise, weighting is also a major barrier to the transparent communication of the basis for any indicator. In addition, the intended purpose for which the indicator will be used is likely to differ to some degree between different indicator users. In this project, desirable criteria for evaluating and choosing indicators were first defined and agreed upon by the project group. These criteria were then used as a guide by the project group to propose indicators for consideration at the 2007 workshop; The key aim being that an indicator should be fit for purpose, such that the choice of indicator depends on the user's aims and objectives.

During the workshop it was important to ensure that participants (experts and stakeholders) had a common understanding of these desirable criteria. For this reason, at the beginning of the 2007 workshop, the criteria were clearly defined and we asked participants within expert taxonomic break-out groups to score indicators (1-3) according to consensus and using a simplification of the criteria below, the results of which we present in Chapter 4. See also Appendix 3 for more detailed indicator-specific recommended protocols and actions for data collection and collation, and a costing and practicality assessment for application of data collection protocols in developing countries where relevant.

The CMS, and its associated agreements, provide the primary instrument for the protection of migratory species, and this provides a starting point for the list of species to be considered as indicators. For many reasons, CMS appendices I and II do not include all migratory species, notable exceptions include species such as the barn swallow *Hirundo rustica* and European eel *Anguilla anguilla*. Consequently, it has been necessary to identify those species not covered explicitly by the CMS, but which may prove useful as indicators of particular systems, areas or taxa; or be particularly suitable because of existing monitoring activities. The CMS listings are continually updated and we have endeavoured to identify and evaluate any species that are currently being considered for inclusion on CMS appendices.

2.2 Criteria for evaluating indicators

In this project, desirable criteria for evaluating and choosing indicators were first defined and agreed upon by the project group. These criteria were guided by the literature, others experiences of developing indicators and the views of the project group.

2.2.1 Impact, policy relevance, public perception and communication

Net impact: *To what degree does the indicator measure net impact (positive or negative) of climate change on populations either regionally or globally?*

Where possible the indicator should relate to a net impact of climate change on the population status of species or a group of species of interest. At the December 2007 workshop, a number of indicators were presented which exhibit a strong link to climate, but for which there was little evidence for a net impact of climate change. Examples include phenological indicators for wild birds (e.g. advanced egg-laying, earlier arrival on breeding grounds), changes in shorebird distribution and range shifts in fish and marine mammals. These represent changes to populations, but for which there is little or no evidence to suggest there will be a negative or positive net impact directly or indirectly on abundance.

With respect to the direction of the impact, there was some discussion at the workshop as to whether an indicator should reflect a positive impact of climate change. For example, it is predicted that, into the near future at least, geese populations will benefit from climate change. However, it was considered that for the CMS, indicators that reflect negative impacts of climate change on migratory species would be of most interest although it was acknowledged that when presented they should be interpreted in a balanced way.

Easy to understand: *To what degree is the indicator easy to communicate to, and easily to non-scientists and those who will decide on their use?*

Whilst not important from a scientific viewpoint, the indicator should be easy to understand by non-scientists and decision-makers who do not have detailed technical expertise. Thus calculation should be simple and method transparent. This is important to ensure that take up of the information provided by the indicators by e.g. policy makers is as high as possible.

Policy relevance: *What is the degree of policy-relevance to the Convention of Migratory Species, i.e. are the species listed on the CMS appendices, those of its daughter agreements or other legislation or agreements (national, regional or international), e.g. species or habitats listed in the habitats directive?*

Ideally, the indicator should include species of particular interest to the CMS (listed on CMS Appendices I or II). However, these Appendices are regularly updated and there are additional species that are candidates or potential candidates for listing. Thus, although the immediate focus is on species listed on the CMS appendices, other important or representative species have also been considered. Species listed as being of concern or interest through other legislation or agreements would also be of greater interest than those that are not listed.

Public profile: *How high would the public profile of the indicator be?*

Whilst a high public awareness of the existence or conservation status of a species may be irrelevant to the scientist, public awareness of a taxon can be an extremely valuable consideration for decision-makers in engaging a general audience and, ultimately for driving policy change. For example Barn Swallows, *Hirundo rustica* currently have a higher public profile at least in Western Europe than Olrog's Gull *Larus atlanticus*, and an indicator reflecting change in penguin populations "a Happy Footsie Index" would obtain high public interest (building on the popularity of *Happy Feet,* a very successful animated feature film about penguins).

2.2.2 Statistical properties of the indicator

Specificity: *To what degree is the indicator specific to climate change as a single pressure or affected by a number of other pressures (exploitation, pollution, invasive species etc.)?*

Most indicators presented in section 3 are likely to be influenced by pressures other than climate change to a greater or lesser degree. The aim here is to focus on indicators that are principally impacted by climate change. To illustrate this, when the workshop considered an indicator based on the population change of Antarctic seabirds, it was felt that it would be too difficult to distinguish the impact of long-line fishing on albatross species (Family: Diomedeidae) from impacts of climate change. For this reason, it was proposed that an indicator for penguins would best reflect impacts on seabirds (at least krill-eating seabirds) of the Antarctic.

Using abundance as an indicator is often unfeasible due to the lack of reliable estimates of absolute population rather than an index, but also in some cases to the low specificity of 'population size' to the impacts of climate change. Population dynamics are influenced by a wide range of environmental, biological and anthropogenic factors. The responses of component demographic parameters that are more closely related to biological functions, such as reproductive rate or adult survival, may, in some cases, be more specific to driving factors, be more easily measured and provide the most useful information on population level effects with the additional benefit of providing a better understanding of the causal mechanisms through which climate change might be affecting populations.

Sensitivity: *To what degree is the indicator sensitive to climate change, i.e. is the slope of the relationship between a measure of climate change versus indicator response shallow or steep?*

It is important that the indicator is sensitive enough to detect important long-term changes, but not so sensitive that such signals are made chaotic by natural variability. Rapid, and sometimes dramatic, responses of marine species to the short-term sea surface temperature (SST) changes accompanying El Niño events, for example, indicate that these taxa will respond sensitively to ocean warming. Paradoxically, the strong sensitivity to climate of some of the species considered renders them unsuitable as indicators of global climate change since it would be difficult to detect the signal of long-term climate change from the high background environmental variability. These include the El Niño Southern Oscillation (ENSO) driven sardine-anchovy regime shifts of the Pacific (Lluch-Cota & Lluch-Cota 1997, Chavez *et al.* 2003) and its consequence on pup production and survival in South American species of otarid seals along the Peruvian and Chilean coasts (Limberger 1990, Soto *et al.* 2004, Soto *et al.* 2006), two of which are listed on CMS appendices. Another example is the abundance of Goldcrest *Regulus regulus,* which fluctuates widely in response to changes in winter weather. However, due to high breeding productivity (number of chicks fledged per breeding attempt) these changes in abundance are generally short-term and any underlying trend in abundance in relation to climate change would be difficult to discern statistically. Hence, changes in abundance of such a species would not be the best indicator of long-term climate change for the purposes of this project. Having said this, it is normally necessary to have a long-time series of data to start to discern a climate change signal as distinct from natural variability. For this reason, we consider indicators here, which have been shown to respond to short-term change in climate, if we believe that these imply likely future impacts in the longer term in response to climate change.

Responsiveness: *Is there a lag in indicator responsiveness after a change in pressure (climate change), if so how long is the lag (years, decades)?*

Some characteristics of species may only show a response to climate change after a certain time period (lag). For many long-lived species, such as marine mammals, population size may not be very responsive to climate change due to long generation times, which means that it may take many years for effects on factors such as breeding success to become translated into changes in population size. This is another reason why component demographic parameters, such as reproductive success, may, for some species, be better indicators than population size, since these are more likely to respond rapidly to climate change. Through discussions at the workshop, it was felt that indicators should present a response to climate change pressure within 3–5 years, although this should be flexible depending on the perceived importance of the indicator.

Representativeness: *To what degree is the indicator representative of spatial, regional and global scale beyond the local site, and representative of other species, assemblages, habitats or ecosystems?*

It is important that the indicator is representative of a broad geographic area or range of species. Such representativeness will generally need to be assessed by expert opinion, based on knowledge of the sampling of the data used to create an index, and knowledge of the ecological characteristics of other species, habitats and ecosystems. However it is also important that the indicator should not resort to using poor quality data simply to achieve this representativeness.

Theoretical basis: *What is the strength of theoretical basis underlying the indicator, i.e. is the indicator based on an existing body of theory, empirical or time series of data that allow a realistic setting of objectives?*

Ideally, the properties of a well-developed candidate indicator will have been evaluated prior to its selection and implementation. However, few indicators will be as well developed as this, and even widely-used indicators have yet to be evaluated, e.g. Farmland Bird Index and Marine Trophic Index. For some candidate indicators, there will be published evidence to show that changes in an ecological process are related to climate change. At the least, there should be a body of scientific evidence to support its use as an indicator, perhaps based on *a priori* reasoning.

Ideally, to develop adequate indicators, long-term time series of data should be used. These are and have been essential to distinguish the signal of climate change from the noise of natural variability, (e.g. work carried out using the Continuous Plankton Recorder, CPR). Multi-decadal time series are rare and for many species there are as yet insufficient long time-series of data. For long-lived species, for example, the time-series may be restricted to one or two generation times. Cause-effect links are often hypothesised based on an observed correlation between two short time-series. It is possible that once longer time-series become available, the correlation may not hold, since links are often complicated and short time-series might not reflect them adequately (Solow 1995, Myers 1998).

2.2.3 Data requirements

Data availability: *How available are the data? Are data to support the indicator readily available or available at a reasonable cost / benefit ratio?*

Whilst few indicators have already been compiled, and are effectively ready-to-go, the data should be readily available in a defined format so the indicator could be produced without a large additional cost.

Data quality: *What is the quality of the data? Are the data collected (or have the potential to be collected) through a well-designed monitoring program and / or likely to be of high quality?*

Particularly from a scientific viewpoint, it is important that the data contributing to an indicator are of high quality and, ideally, known accuracy and precision. Preferably, the monitoring programme should be based on stratified random sampling to ensure that biases that might compromise the representativeness of the indicator are minimised. However, alternatively these should be explicitly quantified.

2.2.4 Applicability of data collection methods

Applicability: *How widely-applicable are the data collections methods? Are the data collection methods readily applicable and a monitoring scheme feasible in less developed countries?*

The importance of this point depends on the existing degree of geographical and taxonomic representativeness. If current monitoring is representative now and likely to be in the future, this point is of less importance. In some cases, the methods used to collect suitable data can vary between regions, so long as the ultimate measures are comparable. Thus, for example, information on bird abundance can be gathered along transect lines, point counts, intensive territory mapping or timed counts; some of which may be more applicable or practical in less developed countries or very remote areas. However, the ultimate measure produced by the different methods will be similar (e.g. changes in relative abundance) and these can be readily combined or compared.

Continuity of the data collection scheme: *What is the long-term continuity of the data collection scheme?*

It is difficult to maintain funding for long-term monitoring schemes. Where possible however, indicators should be based on data originating from a scheme for which there is likely to be long-term funding security. This is especially important for monitoring indicators of climate change due to the long time series needed to detect a climate change signal (at least 30 years worth of data). When a scheme starts to contribute to one of the indicators proposed in this report, if adopted by the CMS, this may contribute to its perceived value by funding bodies, thereby contributing to its funding security.

3. CONSIDERING KEY PHYSICAL AND ECOLOGICAL PROCESSES ACROSS TAXA, HABITATS AND REGIONS – SETTING THE SCENE FOR THE INDICATOR SUITE

In this chapter we briefly review the currently better understood key physical and ecological processes through which climate change may affect each broad group of migratory species (birds, marine mammals, fish and squid, turtles, terrestrial large herbivore mammals and bats). This process allowed the identification of key impacts that may be appropriate or desirable as the basis of a suite of climate change indicators. Previous Defra-funded research (Robinson *et al*. 2005) had identified changes in processes such as phenology, survival, distributional range, as well as influences on arctic, upland, temperate dryland and wetland habitats as being of particular concern. Similarly, particular species groups, such as the longer-distance migrants (*e.g.* many shorebirds), or those whose migratory routes bring them into conflict with human activities (*e.g.* large African ungulates, many cetaceans) are likely to be affected to a greater extent than other species. We reviewed the information in the Robinson *et al.* (2005) report, together with new information published in the intervening period, to identify the key processes, habitats and species for which potential indicators should be sought.

3.1 Birds

For many bird species, the geographical distribution and 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. For many temperate species, the impacts of climate change may be beneficial, but for high Arctic and montane species the impacts may be severe as the area of suitable habitat is likely to reduce markedly.

Changes in the timing of migration and of breeding among many species have occurred in response to increases in spring temperatures. An earlier commencement to the breeding season may have beneficial effects if it allows access to enhanced food supplies, reductions in energy requirements of individuals, or more breeding attempts. However, differential changes in timing with respect to food supplies may also lead to asynchrony with prey populations, with potentially 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.

The survival of many bird species is linked to climatic conditions, in particular weather in the non-breeding season. 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 shorebirds. Trans-equatorial migrants, particularly those that winter in Africa south of the Sahara might be expected to see a decline in survival rate, if precipitation declines as predicted. The increased desertification of the Sahel, a key sub-Saharan “refuelling area” 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 (i.e. number of chicks fledged per breeding attempt) in relation to changing climate. However, these changes vary between species groups. Amongst many terrestrial bird 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 a positive density dependent response to population declines may also be a factor. In the marine environment, increased sea surface temperatures are causing shifts in plankton and marine fish communities, which are having adverse impacts on seabird productivity. Some ground-nesting species may be adversely impacted by increased precipitation, but the timing of precipitation will be critical.

Overall, there are many studies showing that changes in climate 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 change and density-dependence 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. Whilst climate-induced changes in habitat area, phenology and demography are likely to affect all bird species in the future, irrespective of their migratory status, there are three key concerns that apply particularly to migratory birds:

- Increased drought frequency and desertification in the Sahel (the transitional zone of several hundred kilometres between semiarid deserts in northern Africa and the open woodland savannah to the south) affecting the survival and condition of passerine species migrating north to breed in Europe (many species listed on CMS Appendix II).
- Climate-induced change in prey availability in the marine environment, resulting in a decline in productivity and ultimately abundance of migratory seabird populations (several species listed on CMS Appendix I and II).
- Loss of polar habitats (including tundra) that are a key breeding habitat for shorebirds and wildfowl. Most of the species breeding in these location/habitats are migratory, and many are listed on the CMS Appendices.

In total four key indicators for wild birds were selected here for the suite. These were: 1) Relative abundance of Trans-Saharan migrant birds; 2) Relative abundance of Antarctic Penguins; 3) Reproductive output of fish-eating seabirds; and 4) Reproductive output of Arctic shorebirds. A number of other indicators were considered, but not chosen for the suite (see Chapter 5).

3.2 Marine mammals, fish, cephalopods, crustaceans and plankton

Information on the potential impacts of climate change on many aspects of the biology and ecology of marine species has increased markedly in recent years. For example, more than 100 papers were published on the subject in 2007 alone. Nevertheless, identifying indicators to illustrate, understand and monitor the impact that climate change is having on marine species around the globe is a challenge. Many marine migratory species are difficult to study; there are few monitoring schemes in place and few long time-series of data on which to base an indicator. Most importantly, there are very few established links between climate change and changes in marine species life-history parameters or distribution. Given these limitations, one is left with a small collection of potential indicators to choose from. These correspond to some better studied species for which correlations have been shown, across taxa and regions, between the spatio-temporal dynamics of ice and of sea surface temperature (SST) and body condition, reproductive success and young animal survival. The most plausible explanations for these correlations relate to changes in prey availability and habitat loss as a result of climate change.

Species that depend on ice for feeding or breeding will be the first to reflect the impacts of climate change. In the case of the polar bear, *Ursus maritimus,* those populations that are on the edge of range depend on the presence and duration of sea-ice to acquire and store body fat during good seal hunting periods and then use these stores in periods of low prey availability. Polar bears feed on ice-breeding seals, primarily ringed seals (*Phoca hispida*). It is hypothesised that the poorer condition and reduced cub survival seen in recent years is caused by the earlier sea-ice break-up, since the bears have less time to feed. Reduced foraging opportunities for adult females as a result of the earlier break-up appear to result in poorer survival of cubs (Stirling *et al.* 1999, Derocher *et al* 2004; Rode *et al.* 2007, Regehr *et al.* 2006, Regehr *et al.* 2007). The polar bear has become a flagship species of the impacts of climate change. It could be one of the first species to show marked changes in their ecology and to show significant population declines as a result of a warm Arctic. The IPCC Fourth Assessment Report suggests that polar bears will be at risk of extinction if temperatures rise by between 2.5-3 C^o; something which is highly likely in the absence of strong mitigation measures.

The responses of some other marine mammal species will depend on the signal of climate travelling up the food chain, and affecting their prey (Learmonth *et al*. 2006). The southwest Atlantic population of southern right whales (*Eubalaena australis*) and most Antarctic fur seals (*Arctocephalus gazella*) feed in the waters off South Georgia. Variations in the reproductive success of these two migratory mammal species (calving rate and pup production respectively) have been shown to be closely related to variations in regional SST, which in turn seems to be influenced by the ENSO (El Niño Southern Oscillation). Both species showed lowered reproductive success following years of warmer SST in the region. The possible explanation for these relationships is that warmer oceanographic conditions lower the abundance and availability of krill (*Euphausia superba*) (Trathan & Murphy 2002, Trathan *et al.* 2003), the whales' and seals' primary prey off South Georgia (Reid & Arnold 1996, Tormosov *et al.* 1998). A reduction in the energetic balance of mature females prior to conception or during pregnancy will affect their reproductive success.

The links between ENSO and climate change are not clear, as there is debate on whether the frequency or strength of El Niño events will change (Timmermann 1999, Moy *et al.* 2002). However, there is some evidence to suggest that the severity of El Niño is exacerbated by present climate change trends. Reciprocally, there is also some evidence that El Niño events might have contributed to the warming observed in the last decades. Nevertheless, whatever direction these type of natural oscillations in climate will take, if we are to measure and detect the response of species and populations to climate change, it will be important to understand and monitor how they respond to natural long term environmental variability such as ENSO and the North Atlantic Oscillation (NAO) (Reid & Croxall 2001, McMahon & Burton 2005). Having said this, in this project, we have tried to restrict our choice of indicators, to those where there is underlying evidence of climate change.

Habitat loss represents another key aspect of how climate change may directly affect species. The reduction in habitat available for breeding, growing and escaping from predators has been shown to impact on the survival of fish and marine mammal offspring. For example, female ice-breeding seals give birth and raise their young in lairs situated under the snow, which offer protection from adverse weather and predators (Smith & Stirling 1975, Lyndersen & Kovacs 1999). Early sea-ice break-up and snow melts are known to have a detrimental effect on, for example, ringed seal recruitment (Ferguson *et al.* 2005, Härkönen *et al.*, 1998). Juvenile Chinnock Salmon *Oncorhynchus tshawytscha* on the other hand are dependent on river temperature and flow conditions for growth and predator escape; warmer temperatures and lowered flow can affect their survival (Crozier & Zabel 2006).

Reductions in ocean global productivity together with changes in its distribution have been observed during the recent post-1999 warming period; these provide insight on how future climate change can alter marine food webs (Behrenfeld *et al.* 2006). Changes in the distribution and timing of migration of marine migratory species have also been observed in what seems to be a response to increased SST, but neither the mechanistic links, nor the net population effects are well understood. These changes might be related to the direct effect of temperature on species that adapt their movements to remain within preferred ranges of temperature (e.g. many fish species, Stenseth *et al.* 2004), or to indirect effects through changes in the availability of their preferred prey species.

Five key marine / freshwater indicators were selected here for the suite, as those for which there was the best trade-off between the evaluation criteria in Chapter 2. These were: 1) Polar bear adult body condition and cub survival; 2) Southern right whale calving output; 3) Antarctic fur seal pup production; 4) Pup survival in ice-breeding seals; and 5) juvenile survival in salmon. Other potential indicators, serving the main purpose of monitoring the changes in primary and secondary productivity and biogeographic shifts taking place in the marine environment were also suggested. These include indicators of changes in the range and distribution of several migratory species, indicators of primary productivity (global and associated with the Arctic ice-edge) and indicators of prey availability (krill, fish and squid).

3.3 Terrestrial land mammals

Migratory terrestrial mammals (except bats) fall mainly under the herbivorous mammal (ungulate) category. These animals migrate to benefit from the emergence of plant forage in spring (e.g. Caribou *Rangifer tarandus*, Post & Forchhammer 2007), or to follow seasonal changes in rainfall affecting the spatial distribution of new vegetation growth (several ungulate mammal species in Africa, e.g. Boone *et al.* 2006). Other benefits include the avoidance of areas of dense snow, which could affect foraging (e.g. Saiga antelope *Saiga tatarica*, Bekenov *et al.* 1998) and the need to follow watering places and escape predators. Large scale climatic variability (e.g. NAO) and local climate influence all these migratory motivations and ultimately have an impact on reproduction, survival, growth and population dynamics. Population sizes have indeed been found to display variability closely associated with rainfall and snow cover patterns (Ogutu & Owen-Smith 2003, Miller-Gulland 1994, Pascual & Hilborn 1995, Aanes *et al.* 2000). In addition, the timings of migration, routes and seasonal geographic ranges occupied depend also on regional and local climate through its influence on forage resources (Boone *et al.* 2006).

The better understood key processes through which climate change may affect migratory ungulates are mostly related to the influence of climate on the availability of their food resources; the processes include: the effect of increasing temperatures on the timing, abundance and quality of plant forage; and the effect of changes in rainfall patterns on the timing, abundance, spatial distribution and quality of plant forage; the effect of changing snow conditions on the access to vegetation. A lowered availability of food resources will have impacts on the survival of adults and calves and on reproductive success. The survival of both adults and calves in particular, responds rapidly to periods of low food resources and mass mortalities following periods of drought or harsh winters are widespread in ungulate populations.

The theoretical basis of some of the indicators considered was perceived to be weak. This was either due to a lack of data or the lack of large-scale analyses of existing data. For ungulates in northern hemisphere high latitudes, climate data is available and predictions can be made with some certainty as to how climate change will affect regional climate patterns. The retrospective analyses of some existing datasets might allow for stronger theoretical basis of potential indicators and even model possible responses. For regions of Africa and Central Asia, although long-term data on population size exist for some ungulate populations, in most cases no concurrent climatic data series exist, so it is difficult to build a strong theoretical basis to most of the indicators considered in these areas.

The widespread sensitivity of migratory ungulates to climatic variation does not necessarily translate into an easier process of choosing indicators of the effects of climate change and several challenges exist. Most terrestrial mammals listed on CMS appendices (e.g. mountain gorilla *Gorilla gorilla*, elephants *Loxodonta africana*, Sahel Saharan antelopes, and several other species of ungulates) do not seem to be good candidates due to the small population sizes and the endangered status of many of these species. Climate change is only one of many other anthropogenic pressures faced by their populations (Bolger *et al.* 2008). Over-hunting (and poaching) affects many of these species. In addition, human occupation has transformed and reduced the connectivity between terrestrial habitats, creating barriers to the natural seasonal movements of migratory mammals. Habitat loss and fragmentation have therefore restricted species distribution and access to resources. The flexibility of terrestrial migratory mammals to respond to future climate change by adapting their movement patterns and ranges, tracking seasonal changes in resources might therefore be much constrained (Bolger *et al.* 2008).

Even though the effects of climate change might exacerbate those of other pressures, it may be difficult to distinguish the signal of different potential pressures on population demographic parameters and size. One possible way around this problem could be to develop indicators that combine indices across different species or populations of a same species. This type of indicator would be able to illustrate the effects of climate change in a more robust way, since synchrony in fluctuations in population size, reproductive parameters or movements between different populations would more likely reflect a global driver such as climate (Post & Forchhammer 2002, Grøtan *et al.* 2005). Still, careful choice of species or populations would be needed, since it is possible that climate change will be expressed differently depending on the region and so populations from two separate regions might show different responses (e.g. Forchhammer *et al.* 2002). For many of these endangered species, however, a better use of an indicator framework may be to develop "response" measures in order to assess the success of ongoing or new conservation measures in the face of all existing pressures (overexploitation, habitat loss and fragmentation, climate change) and not an indicator of the effects of climate change alone.

Four potential indicators are suggested here: 1) Caribou/reindeer calf production and survival; 2) African herbivorous mammals population sizes (and ranges as supportive information); 3) Wildebeest population size (and movements as support); 4) Saiga antelope population size. Potentially, all of these could be linked to the management of hunting and of the networks of conservation areas (e.g. national parks in Africa).

3.4 Bats

There has been relatively little published on bats and climate change, but the review by Robinson *et al.* (2005) suggested that the most significant impacts are likely to be indirect, through influences on their food supply or roost sites. As populations move northwards with climate change, they may be constrained by the lack of suitable roosting locations such as caves. Warmer winter weather may interfere with hibernation to their detriment, and earlier emergence may not be well timed to their food supplies. Declines in the occurrence of humid or wet habitats used on migration, as well as changes in landuse in response to climate change may be detrimental to bats on migration. For species inhabiting tropical islands, increased occurrence of storms may destroy important habitat and sea-level rise may reduce the availability of sea-caves.

Although there are some good long-term data sets available, there has been little attempt to assess how these might reflect or will indicate the impact of climate change. In many areas where climate change may have impacts on bats, there is neither the long–term historical data (which may not be essential) nor currently the infrastructure to obtain the data required for the future. However, there is sufficient basic knowledge to understand where there is, or could be in the future, the capability to separate climate change influences from other influences with some confidence. In some cases, indicators could use existing mechanisms of data collection (such as colony monitoring), although in many cases better co-ordination and centralising of data or some modification of techniques may be required. Others would require the development of new networks and data gathering protocols. Encouragingly, there is a rapidly growing interest in developing the monitoring that could be used to assess the impacts of climate change on bats.

Three bat indicators are currently considered for the indicator suite, for which there is the best historical data and infrastructure to carry them forward: 1) Abundance of bats at ‘underground’ hibernation sites in Europe; 2) Populations of the Straw-coloured fruit bat in Africa; and 3) Populations of Mexican Free-tailed Bats. Acceptably further research is needed to examine the feasibility of producing these indicators, and their applicability to the CMS. We also present here other considered indicators for which there is currently a lack of available long-term monitoring data and a lack of infrastructure to consider these further at the present time.

For information on CMS activities with respect to bats see CMS/ScC12/Doc.12, CMS/ScC12/Doc.13, and the report for CoP8, Nairobi 2005. For information on the operation and activities of the *Agreement on the Conservation of Populations of European Bats* (EUROBATS) see www.eurobats.org. IUCN is currently compiling data on distribution, status, ecology and conservation of all bats as part of its Global Mammals Assessment programme, the results of which should be available in 2008.

4. INDICATORS SELECTED FOR SUITE

Note: for more information on data collection and collation protocols, an assessment of cost and practicality for extending coverage to include developing countries where relevant, and recommended actions to develop each indicator see Appendix 3.

4.1 Relative abundance of Trans-Saharan migrant birds (Arid-dry habitat / terrestrial) Time-series available

Brief description and methods: Change in relative abundance of trans-Saharan migrants on their breeding grounds.
Methods: A composite multispecies indicator of population change for Trans-Saharan migrants, similar to the Farmland Bird Index, could be produced according to methods in Gregory *et al*. (2005). In brief, national species' indices would be calculated and then combined into supranational indices for species, weighted by estimates of national population sizes (obtained from BirdLife International 2004). Weighting by national population size would allow for the fact that different countries hold different proportions of each species' European population. Species trends in abundance would then be combined across species through calculating the geometric mean of index values across species for each year in the time series (Gregory *et al*. 2005). The focus here is on the Trans-Saharan migrants and does not consider long-distance migrants of the Americas, because it has been very difficult to differentiate the climate change signal from other effects in these species.

Evidence for link with climate change: There is evidence that reduced precipitation and increasing temperature is leading to loss of stop-over and wintering habitat for Trans-Saharan migrants (e.g. Sanderson *et al.* 2006), with resulting impacts on demography (e.g. increased mortality) and subsequent declines in abundance. Differential changes in the timing of arrival and breeding with respect to food supplies may be important too, leading to reductions in productivity and abundance.

Population impact, policy relevance, public perception and communication: There is good evidence that this indicator would represent a negative impact of climate change on the population status of trans-Saharan migrants. The indicator would be easy to understand by non-scientists, would include a number of species of high public profile and would include several species listed on the CMS Appendices.

Properties of the indicator:
Specificity: Medium. It would be difficult to differentiate purely climate -related effects from increased desertification and the impact of overgrazing on habitat quality in Africa. Land-use changes on European breeding grounds may also be a factor.
Sensitivity: High. We speculate that the indicator would be buffered up to a point by density-dependent regulation, (for example, higher survival where fewer individual competing for resources), although pronounced climate change impacts should be detectable.
Responsiveness: High. The indicator is likely to respond to climate change pressure within 1-3 years.
Representativeness: Medium. This indicator would provide little information on rare or highly-localised species. Currently, there are also some gaps in monitoring in the south and east of Europe, the Middle East and for some species further east.
Theoretical basis: High. The indicator is based on an existing and well understood time series of data and research that would allow for a realistic setting of objectives.

Data requirements:
Protocol for data collation and collection: The European Bird Census Council (EBCC) Pan-European Common Bird Monitoring Scheme (PECBMS) funded by the EU currently collates single-species trends in relative abundance from annual monitoring data (counts of individuals or territories) recorded by volunteers using recommended survey methodology (line transects, point counts or territory mapping) for common and widespread Trans-Saharan migrants in 20 European Countries (Ireland, UK, Netherlands, Denmark, Sweden, Norway, Finland, Estonia, Latvia, Poland, Czech Republic, Hungary, Austria, Germany, Switzerland, Belgium, France, Spain, Portugal, Italy). Whilst the absolute counts may not be comparable because different survey methods are employed, the same survey methods are employed at each site, such that it is possible to combine these data to examine the relative changes in abundance. It is envisaged that the EBCC would play the major role in coordinating the production of this indicator.
Practicality of applying data collection protocols in developing countries: Trans-Saharan migrants breed principally in developed European countries, for which monitoring is already well established. However, there are some gaps in coverage notably in parts of south and east Europe, and for some Trans-Saharan migrants into the Middle East and Asia. It is expected that the number of European countries at least contributing data and number of sites monitored within countries will increase over time, through the efforts of the EBCC which will improve spatial and likely species coverage (for example data for Cyprus will shortly be available from 2004). Improving coverage further for the purposes of this indicator would be difficult because the volunteer infrastructure is likely to limited and if professional fieldworkers were employed this is likely to be extremely expensive.
Recommended actions: It is necessary to get support for this indicator from the EBCC council and its data providers across Europe and to determine the cost of producing this indicator.
Costing: The exact costing to produce the indicator and update it on an annual basis would need to be determined through the EBCC, although because the logistics are already in place covering much of Europe, set up costs are expected to be in a lower costing band of less than £50,000.

Supportive (context) indices: A relationship between rainfall in Africa and adult survival has been found in a number of trans-Saharan migrants (e.g. Peach *et al*. 1991, Szép, T., 1995, Cowley & Siriwardena, 2005, Robinson *et al*., in prep.). Temperature increases on the wintering grounds and at stop-over sites are also resulting in earlier arrival (Lehikoinen *et al*. 2004) and advanced egg-laying of trans-Saharan migrants (Crick *et al*. 1997, Crick & Sparks 1999, Both *et al*. 2004). Whilst the importance of these changes at the population level are uncertain for many species, for Pied Flycatcher *Ficedula hypoleuca* at least, there is evidence that arrival dates are becoming out of synchrony with timing of food availability, with consequent declines in productivity and relative abundance (Both *et al.* 2004, Both & Visser 2001). Remote sensing data (annual change in rainfall, temperature or vegetation) may provide information to support this indicator (see Appendix 1).

4.2 **Populations of Antarctic Penguins** (Antarctic / marine)

Empirical observation

Brief description and methods: Change in the number of breeding pairs of Antarctic penguins. Methods: We focus here on population size of penguin populations (specifically number of breeding pairs), which unlike many other seabirds of the Antarctic are not influenced by long-line fishing activities, but are likely to be influenced by climate change induced change in krill availability. A composite multispecies indicator of population change for Antarctic penguins could be produced according to methods in Gregory *et al.* (2005).
Evidence for link with climate change: Changes in nutrient availability as a result of climate change are thought to have important consequences for some penguin species and other species inhabiting Antarctica and sub-Antarctic islands, which cannot move their breeding sites as conditions change. Climate change is also thought likely to affect species that are extensively and / or seasonally dependent on ice of the Antarctic continent and the Marginal Ice Zone, and for penguins through impact on krill reducing penguin productivity and survival (e.g. Croxall *et al*. 2002, Reid *et al*. 2005, Wilson *et al*. 2001).
Population impact, policy relevance, public perception and communication: There is evidence that this indicator would represent a negative impact of climate change on the population status of penguins in parts of Antarctic. The indicator would be easy to understand by non-scientists, and would have an extremely high public profile (one could imagine publicity surrounding a 'Happy Footsie' index – Stuart Butchart pers comm.). However, currently no penguin species are listed on Appendices 1 or 2 of the CMS, although they are migratory and likely to be good indicators of climate change for other krill-eating CMS species such as Southern Right Whales.
Properties of the indicator: Specificity: Medium. It may be difficult to differentiate purely climate-related effects from those of the krill-fishing industry, although research through a Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) Ecosystem Monitoring and Management Programme (EMM) is being carried out to try and determine the contribution of these. Sensitivity: Low. Penguins are long-lived such that reductions in reproductive output will have little immediate influence on population size. However, there is evidence that a large impact on productivity or continuous years of low reproductive output can drive population change (Croxall *et al.* 1997). In addition, if there is an impact on survival, this will have an immediate impact on population size. Responsiveness: Medium. The indicator should start responding within 3-5 years, time it takes for young birds to recruit into the population, although survival impacts may be more immediate. Representativeness: Medium. This indicator would be representative of krill-eating species in the Antarctic, although it is not representative of seabirds in Antarctica as a whole. Theoretical basis: Medium. The indicator is based on an existing time series of data and long-term research that would readily allow for a realistic setting of objectives.
Data requirements: Protocol for data collation and collection: The CCAMLR Ecosystem Monitoring and Management Programme (EMM) is likely to be the best source of data. Established in response to the development of a krill fishery in the Southern Ocean, the objectives are to (i) detect and record significant changes in critical components of the ecosystem to serve as a basis for the conservation of Antarctic marine living resources, and (ii) to distinguish between changes due to the harvesting of commercial species and change due to environmental variability, both physical and biological. The Adélie, Chinstrap, Gentoo and Macaroni Penguins are already EMM indicator species, where standard recording of population size (number of breeding pairs) and other data relating to reproductive performance and diet are collected across a network of sites in Antarctica, and for which there is now a long-term and reliable time series of data. Practicality of applying data collection protocols in developing countries: Coverage of the principal penguin colonies of four in the Antarctic is good and carried out by professionals. Improving coverage further is likely to be prohibitively expensive and not necessary to produce a representative indicator. Recommended actions: It is recommended that the CCAMLR Working Group and other specialist organisations (e.g. British Antarctic Survey and the Scientific Committee on Antarctic Research (SCAR) are consulted in the first instance to assess feasibility and to produce a costing assessment for producing a multi-species indicator for penguin populations (number of breeding pairs) of the Antarctic. One concern with this indicator is that penguin population size is likely to be relatively insensitive to changes in krill abundance (Reid *et al.* 2005). Through consultation with the above organisations, a decision needs to be made as to whether an alternative measure such as mass of offspring just before independence, which is likely to be suitable proxy for the sum of foraging decisions made by a parent, should be should be considered in preference to breeding population size. It is envisaged that the above organisations would be best to make this decision and to coordinate the production of this indicator. Costing: A detailed costing and feasibility assessment is needed. However it is expected that research and set up costs for producing this indicator would be in a low costing band of <£50,000.
Supportive (context) indices: Remote sensing data highlighting temporal changes in ice-cover (see Appendix 1 of this report), an indicator showing the relative change in krill abundance over time and links to other indicators for other taxa that are likely to be influenced by changes in krill abundance would provide useful background support for this indicator.

4.3 Reproductive output of fish-eating seabirds (Temperate / marine)
Empirical observation

Brief description and methods: Change in reproductive output (chicks fledged per breeding attempt) of fish-eating seabird populations.
Methods: A multi-species indicator of productivity for fish-eating seabirds could be produced according to similar methods in Gregory *et al*. (2005).

Evidence for link with climate change: There is good evidence for a relationship between climate change, prey populations and reproductive output of seabird populations in the North-East Atlantic, Arctic and North Seas (e.g. Harris & Wanless 1990, Frederiksen *et al*. 2007). The reason for considering fish-eating seabirds only is that it was felt that it would be too difficult to distinguish the impact of long-line fishing on albatross and related species from impacts of climate change.

Population impact, policy relevance, public perception and communication: There is good evidence that this indicator would represent a negative impact of climate change on the population status of seabird populations. The indicator would be easy to understand by non-scientists, include a number of species of high public profile and include some species listed on the CMS Appendices.

Properties of the indicator:
Specificity: Medium. It may be difficult to differentiate purely climate-related effects from over-fishing. Some of the response could be due to redistribution from southerly to northern populations, so it is essential to obtain comprehensive geographical coverage for any species included in this indicator.
Sensitivity: High. The indicator would be buffered up to a point by density dependent regulation (for example higher chick survival where fewer individuals are competing for resources), although pronounced climate change impacts should be detectable.
Responsiveness: High. The indicator should respond within the same season as the climate change pressure.
Representativeness: Medium. This indicator would be representative of seabirds in the northeast Atlantic, Arctic and North Seas, where the relationship between climate change and reproductive output is perhaps best understood.
Theoretical basis: High. The indicator is based on an existing time series of data collected according to standardised data collection protocols and research that would allow for a realistic setting of objectives.

Data requirements:
Protocol for data collation and collection: There are currently plans within the OSPAR Ecological Quality Objective (EcoQO). framework to use seabird population trends as an indicator of seabird community health in the OSPAR area (North-East Atlantic, Arctic and North Seas). This framework could also be used to collate a standard measure of productivity (chicks fledged per breeding attempt).
Recommended actions: Coordinators of the OSPAR EcoQO framework are in the best position to collate and produce an indicator of productivity for seabirds, using the same network of data providers as currently planned for producing indicators of change in seabird numbers. It is recommended that coordinators of the OSPAR EcoQO framework be consulted to produce a detailed costing and feasibility assessment in the first instance, in collaboration with other expert groups such as the Conservation of Arctic Flora and Fauna (CAFF) Seabird Expert Group (CBIRD – circumpolar seabird group - http://arcticportal.org/en/caff/cbird), which is involved in a number of research projects, including monitoring population effects from climate change on seabirds in the Arctic. At present this indicator focuses on the North Atlantic, Arctic and North Seas, where the relationship between climate change and seabird reproductive output is arguably best understood. However, it is considered that climate change is likely to impact seabird populations outside this area. For this reason, it is recommended that the geographical scope of this indicator be reviewed.
Practicality of applying data collection protocols in developing countries: At present it is recommended that this indicator should in the first instance be restricted to the North-East Atlantic, Arctic and North Seas where our understanding of climate change impacts is perhaps best understood and the logistics for collating monitoring data are largely in place. However, this decision should be reviewed over time as our understanding of these relationships within other regions improves.
Costing: Because the logistics are already largely in place, it is expected that set up costs for producing such an indicator for a limited suite of species for the OSPAR region would be in a medium costing band of £50,000-100,000. However, increasing geographical coverage and species inclusion if recommended may increase the cost considerably, for which the feasibility and costing assessment recommended above would inform.

Supportive (context) indices: Information on temporal change in sea surface temperature, plankton (see Appendix 1 of this report) and fish populations would provide useful information to support this indicator.

4.4 Reproductive output of Arctic shorebirds (Arctic / Marine)
Empirical observation

Brief description and methods: Change in reproductive output of Arctic shorebirds. Methods: Although many species breeding in the Arctic are widely dispersed and remain difficult to survey accurately throughout the year, tundra-breeding shorebirds are often concentrated into large, and more easily accessible, flocks around the lower latitude coasts of temperate and tropical regions during the winter. Consequently, it may be possible to access demographic parameters relating to Arctic breeding populations using data collected during the winter, particularly as the development of cannon-netting techniques have allowed large samples of wintering shorebirds to be captured and ringed since the 1970s. Immature shorebirds of many species can be identified accurately throughout the winter period, making it possible to assess annual variability in productivity through estimation of juvenile: adult ratios in flocks (e.g. Schekkerman *et al.* 1998, Beale *et al.* 2006). The methodology for producing this indicator would follow the recommendations of Clark *et al.* (2004).
Evidence for link with climate change: There is evidence that climate-driven timing of snow-melt and insect emergence has changed the availability of shorebird prey in recent years. Warmer summers are likely to increase productivity through both increased invertebrate abundance and reduced mortality from chilling (e.g. Schekkerman *et al*. 1998). However, in years of highest temperatures, declines in productivity have been observed (Beale *et al*. 2006). Whilst the mechanism underlying this decline is not known, it is predicted that further rises in temperature will reduce productivity in the long-term. For example, as habitats become restricted with warming and habitat succession, this might affect productivity through decreased breeding success and proportion of birds breeding. A potential confounding factor is that a redistribution of adults and juveniles could change ratios without real changes in productivity. Increasing temperature could lead to increased precipitation leading to later snow melt, which could decrease the time that land is available for nesting. Climate change may also affect predator populations with resulting impacts on nest success (Zöckler & Lysenko 2000).
Population impact, policy relevance, public perception and communication: It is predicted that productivity will decline in the long-term with resulting impact on abundance. The indicator would not be as easy to understand by non-scientists as several other indicators here. This indicator would include several species listed on the CMS Appendices, and several other pre-existing legal and international agreements, although shorebirds generally have a low public profile.
Properties of the indicator: Specificity: High. In terms of a relationship with climate, it should be possible to identify climate-related impacts. Sensitivity: Medium. The indicator would be buffered up to a point by density dependent regulation, although pronounced climate change impacts should be detectable. Responsiveness: High. The indicator should respond in the same year as the climate change pressure. Representativeness: High. This indicator is likely to be restricted to the most widespread shorebird species, which would need to be assumed to be representative of Arctic shorebirds as a whole. Theoretical basis: Medium. The indicator is based on an existing time series of data and research that should allow for a realistic setting of objectives in the future.
Data requirements: Protocol for data collation and collection: The British Trust for Ornithology has already developed methods for producing an indicator of reproductive output for Arctic shorebirds and through its wader connections is best placed to collate the data across studies and to produce this indicator for the northern hemisphere. Practicality of applying data collection protocols in developing countries: A large proportion of Arctic breeding shorebirds winter in developed countries. Although mist-netting and cannon-netting techniques to assess adult / immature ratios are not used in all these countries, individuals wintering at single sites are likely to have originated from across a large geographic breeding area. Mist-netting and to greater degree cannon-netting are highly skilled techniques, which is not readily transferable to other countries, although volunteer or professional expeditions to these countries could be used to improve geographical coverage where this is believed to be important. Recommended actions: It is recommended that the British Trust for Ornithology carry out a detailed costing and feasibility assessment for producing this indicator. This should examine the likely geographical coverage of breeding areas through winter mist-netting and cannon-netting and where important, recommendations for improving geographical coverage made Costing: Data gathering is already in place, but logistics for collating these data and for producing the indicator are needed. It is expected that set up costs for producing such an indicator would be in a medium costing band of £50,000-100,000.
Supportive (context) indices: Remote sensing data showing timing of ice-melting and extent of tundra may provide useful information to support this indicator (see Appendix 1 of this report). Information on the relative change in abundance of shorebird species produced through the IWC would provide useful supporting information.

4.5 **Polar Bear body condition and cub survival** (Arctic / Marine)
Time-series available

Brief description and methods: Annual trends in body condition of polar bears and in cub survival in the Western Hudson Bay (WHB) and Southern Beaufort Sea (SBS)(Derocher *et al*. 2004). For two of the 19 known polar bear subpopulations, which are best studied, these measures have been correlated with the duration of sea-ice, which is related to climatic variations and climate change (Stirling *et al.* 1999, Rode *et al.* 2007, Regehr *et al*. 2008). Polar Bear index of body condition (weight/length^2) and cub survival (number survived in autumn/total number produced in spring) are compiled indicators (Stirling *et al*. 1999, Rode *et al*. 2007). The purpose of this indicator would be three-fold: 1. It would illustrate one mechanism through which climate change is impacting the Arctic ecosystem; 2. it would raise public awareness of climate change; 3. it could also trigger more conservative measures in the management of the polar bear harvest. Reference points could potentially be developed, for example, less than sufficient adult body condition would trigger a management action.

Evidence for link with climate change: Observed correlation between declining body condition and cub survival in WHB and SBS with warmer spring temperatures and earlier sea ice break-up over the past 15-20 years (Stirling *et al.* 1999, Rode *et al*. 2007). It is hypothesised that earlier ice break-up results in poorer condition of polar bears because they have less time to feed on ice-breeding seals, their primary prey. Reduced foraging opportunities for adult females as a result of the earlier ice break-up results in poorer survival of cubs (Stirling *et al*. 1999, Rode *et al.* 2007, Regehr *et al*. 2006, Regehr *et al.* 2007).

Population impact, policy relevance, public perception and communication: Lowered cub survival will result in population declines in the long-term, and the parameter can be used as a metric of population dynamics. While it is more difficult to link body condition to population vital rates, this parameter reflects one of the mechanisms through which climate change may affect polar bear populations and is a surrogate of adult and cub survival. A continuation of the observed trends could, in the short term, result in the local extinction of the species. This migratory species is not on either of the CMS Appendices but it is a charismatic, keystone species of climate change, with high public perception and profile. It has an IUCN status of "vulnerable to extinction" and its conservation is addressed in the Agreement on Conservation of Polar Bears, bilateral and national agreements and in the Conservation of Arctic Flora and Fauna (CAFF).

Properties of the indicator (specificity, sensitivity, responsiveness, representativeness, theoretical basis):
Specificity: Medium. Other factors may contribute to lowered adult condition and cub survival (e.g. contaminants, harvesting, industrial activities), but it is likely that the effects of a reduction in the time polar bears have to feed on the sea-ice will have the most immediate consequence on these two parameters.
Sensitivity: High. Sensitivity and responsiveness have been demonstrated for cub survival in WHB. In 1990, the sea-ice break-up occurred a month earlier than the average and cub survival was 10-20% lower than average (Regehr *et al.* 2008).
Responsiveness: see above
Representativeness: Medium. These two sub-populations, the WHB and the SBS, represent two Arctic ecoregions (Amstrup *et al.* 2007). As these sub-populations occur near the southern limit of the species' range, where changes in sea-ice dynamics will be most noticeable, they are likely to be among the first to show population-level effects of climatic change (Lunn *et al.* 2002). These may provide early warning signs of the effects of climate change on more northerly sub-populations if projected widespread losses of sea-ice occur. If, as predicted in some models, summer sea-ice disappears completely, all 19 sub-populations will be affected. Although differing in the mechanisms of impact, this indicator would be representative of climate change impacts on other ice-obligate species.
Theoretical basis: Medium. Assumptions underlying this indicator are based on correlations rather than direct evidence of a causal link between the timing of sea-ice break-up and the parameters proposed for the indicator. Another limitation is that the time-series of data used to identify these correlations (~20 years) falls close to one polar bear generation.

Data requirements:
Protocol for data collation and collection: Long-term, high quality datasets exist on body condition (weight/length^2) and cub survival (number survived in autumn / total number produced in spring) for these two subpopulations, together with relevant data on sea-ice dynamics. Monitoring is on-going through the "The Polar Bear Population project" (www.polarbearsinternational.org/pbi-supported-research/population-project), including aerial surveys and condition monitoring. Data on the SBS populations are held partially by Canadian Federal Government (Environment Canada) and the US Geological Survey in the USA, other data is held by Universities. The Polar Bear Population Project would be the best framework through which to collate these data and produce the indicator.
Practicality of applying data collection protocols in developing countries: This indicator focuses on two well-studied subpopulations. Expanding this indicator to include other subpopulations may be possible, although this would require considerable financial input and would need to be carried out by professionals in this field.
Recommended actions: The Canadian Federal Government (Environment Canada) and the US Geological Survey through the Polar Bear Population Project are perhaps in the best position to collate and produce an indicator for Polar Bear populations. It is recommended that relevant parties are consulted to produce a detailed costing assessment in the first instance, and the cost for improving coverage of other subpopulations also considered here.
Costing: Because the logistics are already largely in place, it is expected that set up costs for producing this indicator covering the two subpopulations above would be in a lower costing band of <£50,000.

Supportive (context) indices: Timing of break-up of sea-ice can be obtained from satellite imagery (see Appendix 1 of this report). Other sea-ice indices (e.g. extent) would also be useful. Population size estimates would be useful to make a distinction between climate change effects and other effects, as well as to monitor the lags between the indicator parameters and the population-level effects.

4.6 Antarctic Fur Seal pup production (Antarctic / Marine)

Time-series available

Brief description and methods: The population of Antarctic fur seals (*Arctocephalus gazella*) on Bird Island, South Georgia has shown extreme reductions in pup production the year after extreme positive austral summer sea surface temperature (SST) anomalies. These are potentially driven by a period of persistent global high Sea Surface Temperature (SST, Forcada *et al.* 2005). The population of Antarctic Fur Seals on Bird Island is only a small proportion of the total population, but there is no reason to expect that this population is not representative of the population as a whole. This is a compiled indicator using beach total counts of newborns during the pupping season. The purpose of the indicator would be to illustrate the effects of climate change on the Southern Ocean ecosystem and would be an early warning sign of population-level consequences.
Evidence for link with climate change: Pup production has been closely linked to maternal condition in many otarid seal species, indirectly reflecting prey availability to females (Guinet *et al.* 1994, Soto *et al*. 2004, Forcada 2005, Lea *et al*. 2006). A 10-year period of persistent high SST, driven by global climatic variability (El Niño Southern Oscillation, ENSO), over and above what has occurred in the past and subsequent positive SST anomalies in South Georgia could explain the reductions in fur seal pup production. A potential causal mechanism for this is the effect of warmer oceanographic conditions on krill availability, fur seals' primary prey (Trathan 2003, Reid & Arnold 1996, Murphy *et al*. 2007). Female fur seals are central place foragers during lactation and rearing of their young, with little time to forage between bouts of nursing. Nursing females are almost totally dependent on krill availability for food (Reid & Arnold 1996), and years of low krill have repercussions on their breeding success the following year. The link between these climatic and oceanographic indices and climate change is not clear. Nevertheless, correlations suggest that this indicator would be sensitive to persistent SST warming.
Population impact, policy relevance, public perception and communication: Pup production is likely to decline if high SST becomes persistent, either caused by more and/or stronger El Niño events in response to climate change (Timmerman *et al.* 1999) or as result of the warming of parts of the Southern Ocean (SO). Continued lowered Antarctic fur seal pup production will very likely be reflected in a reduction in population size. The conservation of Antarctic seals is covered by the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR). The Antarctic fur seal is not on CMS appendices, unlike other otarids, such as some species of south American fur seals and sea lions. Even though these species are very likely to be influenced by global climatic changes, through the impacts on prey availability (Soto *et al*. 2004), the high sensitivity to natural climatic variability reduces their potential as long-term trend indicators. The purpose of the indicator would be to illustrate the effects of climate change on the SO ecosystem and would be an early warning sign of seal population-level consequences. Seals in general have a high public profile and the number of pups produced each year is an easy to communicate parameter.
Properties of the indicator (specificity, sensitivity, responsiveness, representativeness, theoretical basis): <u>Specificity</u>: Medium. Other factors will influence pup production (top-down processes such as density dependence, competition from other krill predators, including fisheries). However, the widespread correlations between SST and reproductive parameters across species and regions suggest that the effects of climate variability are driving the observed patterns. <u>Sensitivity</u>: High, but only for positive SST anomalies higher than 1.6ºC. The response of pup production to SST anomalies is highly non-linear. An increase in the temperature anomaly from 1.6ºC to 1.8ºC results in a reduction of 100 in the offspring produced. <u>Responsiveness</u>: High, a one year lag was observed from the South Georgia SST anomaly. This in turn is lagged 2.5 years from the ENSO related anomaly in the South Pacific. <u>Representativeness</u>: Medium. The animals in Bird Island represent only a small fraction of the South Georgia population, but the latter consists of more than 90% of the species. Indicator would be representative of other pinniped species, eared seals (fur seals and sea lions) in particular, which feed on prey strongly affected by climatic variability. Similar relationships have been found between SST anomalies and reproductive success in other krill-eating species around South Georgia, supporting the correlations found for the fur seal. Therefore, this indicator would probably represent similar mechanism in large whale calf production and penguin productivity and survival. <u>Theoretical basis</u>: Strong. Over 20 years of data exist for the Bird Island population, corresponding approximately to 5 generations (Boyd *et al*. 1995).
Data requirements: <u>Protocol for data collation and collection:</u> Long-term monitoring of Antarctic Fur Seals has been carried out by the British Antarctic Survey on Bird Island, South Georgia including the recording of the number newborns during the pupping season for more than 20 years, and would form the basis of this indicator. The British Antarctic Survey is therefore in the best position to produce this indicator. <u>Practicality of apply data collection protocols in developing countries:</u> This indicator focuses on the best studied and well understood subpopulation of Antarctic fur-seals. Expanding this indicator to include other subpopulations or other species of eared seals may be possible but would probably require considerable resources. <u>Recommended actions:</u> It is recommended that support is obtained from the British Antarctic Survey and that a detailed costing and feasibility assessment is carried out. This assessment should also assess the feasibility of improved coverage of other subpopulations or further work to assess the representativeness of the subpopulation at Bird Island. <u>Costing:</u> The logistics are already in place, and for this reason it is expected that set up costs for producing such an indicator would be in a lower costing band of <£50,000.
Supportive (context) indices: South Georgia SST anomaly index seems to be an indicator of larger-scale physical processes driving the availability of krill. An index of krill biomass and availability for the region would provide the link between the indicator and the climatic signals.

4.7 **Southern Right Whale calf production in the Antarctic** (Antarctic / Marine)
Time series available (SW Atlantic)/Empirical observation (other oceans)

Brief description and methods: An annual index of calving success was compiled from data on the observed calving histories of individual females (distinguished and catalogued using photo-identification) belonging to the SW Atlantic southern right whale population *Eubalaena australis* (Cooke *et al.* 2003). This index of calf output, which varies between -1 and 1 is negatively correlated with the sea surface temperature (SST) anomaly in the summer feeding grounds (South Georgia) for the previous year and positively correlated with the El Niño SST anomalies. Therefore, it reflects both regional and global climatic variation (Leaper *et al*. 2006). This is a compiled indicator for that specific population. Some potential exists to develop an indicator that would combine this index for different populations (e.g. Argentina, Australia); even though the response to climate change may differ between populations. The purpose of the indicator would be to illustrate the effects of climate change on the SO ecosystem and would be an early warning sign of population-level consequences to right whales.
Evidence for link with climate change: Correlations have been found between southern right whale calving output index and SST anomalies both in the feeding grounds and in the El Niño regions of the Pacific. The possible explanation for this relationship is that krill availability in the summer feeding grounds (also affected by global and regional climatic variations, Trathan *et al.* 2003, Trathan & Murphy 2006), before conception of whale calves, affects the reproductive success during the following winter. The link between these climatic and oceanographic indices and climate change is not clear, as there is debate on whether the frequency or strength of ENSO events will change with climate change (Timmerman *et al.* 1999, Moy *et al.* 2002. Nevertheless, the correlations found suggest that this indicator would be sensitive to any potential regional changes in SST caused by climate change. A correlation has also been shown between the calving rate of the northern right whale, the abundance of their prey and the NAO (Greene & Pershing 2004).
Population impact, policy relevance, public perception and communication: Current population numbers are a minor fraction of pre-exploitation levels, and the SW Atlantic population has been growing at a steady 7% rate (Baker & Clapham 2004). Calf output can be used as a metric of population dynamics, with continued lowered calving output resulting in a decline in population numbers. However, due to the uncertainty surrounding predictions of the effects of climate change on oceanographic conditions in the Southern Ocean (SO), and the possibility that those will be reflected in different ways throughout the region, it is difficult to predict the direction of population response. Right whales are the most threatened of the baleen whales, they are red-listed as threatened by the World Conservation Union (IUCN), and are listed on the CMS appendices. Of the three species, the southern right whale is the one with sufficient population size to be viable to use as indicator. Right whales have a high profile and the indicator would be easy to communicate to policy makers and the wider public. The purpose of the indicator would be to illustrate the effects of climate change on the SO ecosystem and would be an early warning sign of population-level consequences to right whales.
Properties of the indicator (specificity, sensitivity, responsiveness, representativeness, theoretical basis): Specificity: Medium. There are no major identified threats to southern right whale populations. The effects of climatic variability will probably have major influence on the indicator. However, competition from other krill predators, including fisheries, will be a confounding factor Sensitivity: High. The indicator seems to be sensitive to global climatic fluctuations in a linear fashion, with an increase of less than 1ºC in the SST of the feeding grounds resulting in a 60% decline from expected calf output of the following year (Leaper *et al*. 2006). Responsiveness: High. The response of calf production to regional SST anomalies on the feeding grounds was observed to be short-lagged, around 15 months, i.e. time between the summer feeding before conception takes place and calving. Representativeness: Medium. Most baleen whales calve in warm sub-tropical waters during winter, and migrate to feed in the highly productive cold temperate and subpolar waters in spring and summer. Although the effect of climate change on most species of cetacean remains speculative, the mechanism implicated in this potential indicator (the changes to prey availability impacting on reproductive success), may mean that similar effects occur in other baleen whale species. Similarly, this indicator may also be representative of other krill-feeding species in the Antarctic, such as the Antarctic fur seal and penguin species. Theoretical basis: Medium. Similar relationships have been found between SST anomalies and reproductive success in other krill-eating species in the Antarctic supporting the correlations found for the SW Atlantic right whale. Although over 20 years of data exist for the SW Atlantic population, this time series only spans approximately one generation.
Data requirements: Protocol for data collation and collection: Some long-term datasets on right whale calf output exist and there is ongoing monitoring by both governmental and voluntary organisations in several parts of the world (e.g. Argentina, Australia, South Africa, Brazil). The most detailed database comes from the population that uses the bays of Peninsula Valdés, Argentina as nursery grounds. Over the past 30 years, and on an annual basis, the Ocean Alliance & Whale Conservation Institute have carried out photo-identification combined with an automated database comparison, allowing the study of individuals and the modelling of calving output. NGO dependent funding, not secured. Practicality of applying data collection protocols in developing countries: A standardised international data gathering protocol, based on the SW Atlantic experience, could potentially be agreed between the different organisations to collate data across much of the range of this species, although the feasibility and cost of doing so would need to be determined. Recommended actions: In the first instance the Ocean Alliance & Whale Conservation Institute should be consulted, in collaboration with other expert groups, involved in right whale research to examine the feasibility and costs involved in developing this indicator. Costing: The logistics of this indicator are only partly in place (for the SW Atlantic) and as such, it is expected that set up costs for producing such an indicator would be in the medium to high costing band £50,000->£100,000.
Supportive (context) indices: South Georgia SST anomaly index (Trathan & Murphy 2002) seems to be an indicator of larger-scale physical processes driving the availability of krill (Trathan *et al.* 2003). An index of krill biomass and availability for the region would provide the link between the indicator and the climatic signals.

4.8 Pup survival in ice-breeding Seals (Arctic & enclosed seas, marine/ freshwater lakes) Concept-only

Brief description and method: Pup survival in ringed seals (*Phoca hispida*) in the Arctic and Baltic Sea, and potentially in Caspian seals (*Phoca caspica*), is dependent on the existence and stability of sea-ice and snow cover since females give birth and raise their young in lairs situated under the snow (for ringed seals) or on the sea-ice (for Caspian seals), which offer protection from the weather and predators and prevents the pups from prematurely entering the cold waters (Smith & Stirling 1975, Lyndersen & Kovacs 1999). Early sea-ice break-up and snow melts are known to have a detrimental effect on ringed seal recruitment in western Hudson Bay (WHB) and the Baltic Sea (Ferguson *et al.* 2005, Härkönen *et al*., 1998). This indicator could potentially combine indices of pup survival of ice-breeding seals from the three regions. The purpose of this would be to illustrate the effects of climate change on migratory species that depend on ice. Triggers could be developed that would link in with the harvesting and with conservation measures.
Evidence for link with climate change: Climate change is expected to cause major reduction in sea-ice and snow cover in all three regions. Early sea-ice break-up or snow melts is likely to reduce the extent of the seals' breeding habitat. In the absence of good ice/snow conditions, pups become more vulnerable to adverse weather conditions, starvation and predation, resulting in high mortality (Smith & Harwood 2001, Ferguson 2005). Populations of ringed seals in some areas are showing downward trends in reproductive rates and survival of young. These are thought to be linked to changes in sea-ice conditions and other major ecosystem shifts, pathways which are poorly understood (Stirling 2005). In WHB, a significant reduction in ringed seal recruitment during the period 1990–2001 was attributed to climate warming (Ferguson *et al.*, 2005). In the southern Baltic Sea, a series of nearly ice-free winters from 1989–1995 led to high pup mortalities (Härkönen *et al*., 1998).
Population impact, policy relevance, public perception and communication: Seal recruitment into the population has a clear impact on population dynamics, particularly for small populations. A reduction in pup survival could potentially lead to a decline in population, particularly those in the Baltic and Caspian, which have been more abundant in the past. Neither of these seals is listed on CMS appendices. Baltic seals conservation falls under the HELCOM agreement on seals in the Baltic Sea. An international agreement on Caspian seal conservation is being pursued. Land locked ice-breeding seals are now being proposed as indicators of the impacts of climate change in other contexts. Seals in general have a high public profile and the number of pups produced each year is an easy to communicate parameter.
Properties of the indicator (specificity, sensitivity, responsiveness, representativeness, theoretical basis): <u>Specificity</u>: Medium. Other factors may contribute to a reduction in pup survival (e.g. contaminants, harvesting, industrial activities, prey depletion), but it is likely that the effects of earlier sea-ice break-up and reduction in snow cover would have immediate response in this indicator. However, mass mortalities caused by disease (e.g. Caspian Sea), and density-dependent factors (particularly in the Arctic) could be confounding factors. <u>Sensitivity</u>: High. Sensitivity and responsiveness to climate change and variability have been demonstrated for ringed seal pup survival. For example, in the southern Baltic Sea, a series of nearly ice-free winters from 1989–1995 led to very high pup mortalities in those years (Härkönen *et al*. 1998). For Caspian Seals this is unknown. <u>Responsiveness</u>: see above. <u>Representativeness</u>: High. Since the ringed seal is the most abundant seal species in the Arctic, primary prey to several top predators, it could be considered an indicator species of the Arctic. This indicator would also be representative of other migratory ice-breeding seal species of the Arctic (e.g. Harp seal), and the walrus as well as non-migratory land-locked ice-breeding seals (Ladoga and Baikal seals). <u>Theoretical basis</u>: Weak. Assumptions are based on correlations rather than direct evidence of a causal link between the timing of sea-ice break-up, snow cover patterns and pup survival. There are no available long time-series for the Caspian Sea.
Data requirements: <u>Protocol for data collation and collection:</u> In the Beaufort Sea, ringed seals are monitored by US and Canadian governments in collaboration with Inuit communities and NGOs (www.beaufortseals.com), and in the Baltic, by the Swedish Natural History Museum. In the Caspian, this is carried out by the Caspian Seal Project (www.caspianseal.org). Funding seems secured at least in the short-term. In the Beaufort Sea, pup survival is calculated using harvested animals. Data gathering protocols are standard across the Baltic and Caspian regions, as seals are monitored annually using aerial surveys (Härkönen and Heide-Jörgensen, 1990). However in the Baltic there are no estimates of pup survival, just counts of moulting seals. Coordination and considerable analytical work would be needed to bring these data sets together, if possible, and produce the indicator. The organisation that would be best placed to assess the appropriateness and feasibility of producing this indicator would need to be decided upon, through consultation with the above organisations. <u>Practicality of applying data collection protocols in developing countries:</u> The Caspian seal project is a good example of applying data collection methods in developing countries. <u>Recommended actions:</u> It is recommended that relevant parties be consulted to produce a detailed costing and feasibility assessment in the first instance. Consideration should be given at the time to the usefulness and feasibility of expanding this indicator to include species of the Antarctic. <u>Costing:</u> The logistics for collating data across geographic areas and for producing this indicator would need to be determined before this indicator could be produced. For this reason, it is expected that the costs for producing this indicator would be in a medium to high costing band £50,000 - >£100,000.
Supportive (context) indices: The extent of sea-ice and snow, the timing of break-up, and the number of annual sea-ice days can be obtained from satellite imagery. These would be indices of available breeding habitat during the breeding season, and could be used as alternative indicators to pup survival since the latter is difficult to monitor, particularly for the Baltic.

4.9 **Juvenile survival in Salmon** (Temperate / freshwater)

Concept-only

Brief description and methods: Juvenile survival of several populations of the threatened spring-summer Chinook salmon, *Oncorhynchus tshawytscha,* seems to be affected by warmer river temperatures and lower flow in the Salmon River basin (Crozier & Zabel 2006). Climate change is likely to result in higher summer temperatures and changing hydrological regimes in the region, which might negatively impact on juvenile survival. Juvenile survival is estimated using mark-recapture techniques associated with transponder tags (Crozier & Zabel 2006). The purpose of this indicator would be to illustrate the effects of climate change on riverine habitats and anadromous species in general and it could have a clear management link. The relationship between juvenile survival and two physical parameters (water temperature and flow) that can be manipulated in the field could be turned into a system of triggers of action.

Evidence for link with climate change: Catches of different salmon species, timing in migration of returning salmon, and both juvenile and adult survival have shown to be related to climate change in several parts of the world (Crozier & Zabel 2006, Hare & Francis 1994, Mantua *et al.* 1997, Mueter *et al.* 2002, Hyatt *et al.* 2003, Beaugrand & Reid 2003, Hodgson *et al*. 2006). Juvenile survival of spring-summer Chinook salmon has shown a particularly clear negative correlation with water temperature in wide and warm streams and a positive correlation with stream flow in narrow cool streams, in the Salmon River basin, Idaho, US (Crozier & Zabel 2006). Stream temperatures in the Salmon River basin already routinely exceed the 13ºC maximum daily temperature thresholds for salmonids (Donato 2002). Annual air temperatures have also been increasing steadily since 1992 (Crozier & Zabel 2006).

Population impact, policy relevance, public perception and communication: Reduced survival as a result of warmer summer temperatures and decreased flow will have a negative impact on the salmon populations. Salmon are able to adapt to rapidly changing habitats (such as the shift from freshwater to estuarine and marine), but it is not known whether this capacity might enable salmon populations to adapt their behaviours concurrently with the rate of climate change. Salmon is a high-profile species in many countries. Salmonids are not listed on CMS appendices. Nevertheless, the effects of climate change on juvenile survival of salmon populations are likely to be broadly representative of the effects on other anadromous species, such as sturgeons, which are listed on the appendices. The impact of warmer temperatures and reduced flow on the survival of juvenile salmon would be an easy parameter to communicate.

Properties of the indicator (specificity, sensitivity, responsiveness, representativeness, theoretical basis):

<u>Specificity:</u> Other factors exert great pressure on juvenile survival (e.g. low productivity, habitat loss, disease and density). In addition, dams may alter hydrological regimes and stream temperature, and could also affect juvenile survival (Schaller & Petrosky 2007). Nevertheless, the fact that the effects of climate change through change in temperature and hydrographic regime are detected in eighteen different populations in a broad area, adds strength to the specificity of this indicator, when combining data from different populations.

<u>Sensitivity and responsiveness:</u> This indicator showed sensitivity and responsiveness for the 10-year period studied in the Salmon River basin. In some areas, a 1ºC increase in mean summer stream temperature in the year of tagging could result in 20% decrease in survival of juveniles the same year. In addition, the halving in the minimum autumn flow could reduce survival by 30% in the same year (Crozier & Zabel 2006).

<u>Representativeness:</u> The survival of juvenile salmon would be representative of the impact of climate change on freshwaters ecosystems and on other anadromous species such as the sturgeon. Salmon are often considered indicator species of the health of freshwater, estuarine and marine environments and they play a major role in transferring marine nutrients to otherwise nutrient-poor environments, providing a primary food resource for many vertebrates (Willson & Halupka 1995). It would also represent, for example, the effects of warmer temperatures on reduced viability of eggs and adults of other species of salmon and sturgeons.

<u>Theoretical basis:</u> There is only approximately one decade of data for this indicator, but the fact that relationships with climatic parameters are shown by 18 different populations of the Salmon River basin gives support to the indicator.

Data requirements:

<u>Potential for data collation and collection:</u> For the Salmon River basin, there are detailed juvenile survival data for 18 populations of Chinook salmon over 11 years and corresponding climatological data. These data are owned by the US National Marine Fisheries Service. Mark-recapture studies using tags to estimate juvenile survival are common in several areas, particularly in order to assess the impact of dams on this parameter. A standardised international data gathering protocol, based on the Salmon River basin long-term study, could potentially be applicable to other parts of the world in order to identify the most important environmental driving factors relating to climate change for a particular population and implement a monitoring system that would feed into the indicator.

<u>Practicality of applying data collection protocols in developing countries:</u> Chinook Salmon range widely, and the same protocol could potentially be used in countries such as Russia provided support. International initiatives such as www.stateofthesalmon.org could be a good starting point in considering an indicator encompassing populations of wild Pacific salmon from different areas.

<u>Recommended actions:</u> It is recommended that support be obtained from the US National Marine Fisheries Service. This organisation is perhaps in the best position to collate and produce this indicator. A detailed costing and feasibility assessment should be carried out, and the potential for improving geographic coverage wider than the Salmon River basin explored.

<u>Costing:</u> The logistics are currently in place to produce an indicator for Chinook Salmon. For this reason, the cost of setting up and producing this indicator is likely to be relative low <50,000, although would increase considerably if this indicator was extended to include other Salmon populations across the world.

Supportive (context) indices: Local mean summer stream temperatures and minimum autumn stream flow in the year of tagging. Other local context indices could include mean summer air temperature in the year of tagging, and spring snow pack and winter precipitation (previous to tagging) but these have been found correlated with the former (Crozier & Zabel 2006).

4.10 Loss of sea turtle nesting habitat through sea level rise (Caribbean, Pacific / marine) Concept-only

Brief description and methods: Sea turtles will be affected by an increase in sea levels through the loss of egg laying beaches. 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. Alternatively, at other less developed sites, the dynamic nature of beaches may simply lead to these gradually moving inland. However, in the Pacific and Indian Ocean and Caribbean Sea where nesting frequently takes place on low lying coralline islands, the situation may be far worse for sea turtles with complete loss of suitable nesting habitat. The challenge here is to empirically measure changes in suitable habitat and to make realistic predictions of how this may affect the viability of sea turtle nesting sites. This requires the identification of a number for key sites that encompass different geographic regions and types (e.g. coastal continental or coralline island), level of coastal defence, species requirements and predicted extent of sea level rise. Once these indicator sites have been established it will be possible to remotely assess the loss of nesting beaches using satellite images provided by the US Geological Survey Archive (TerraLook). The purpose of the indicator is to provide an early warning mechanism that will enable remedial action to be taken prior to population collapse (i.e. assessment of nearby alternative sites, removal of coastal defences, construction of new nesting beaches and transplantation of threatened clutches).
Evidence for link with climate change: 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 – whilst several Pacific States are currently threatened with total disappearance and two uninhabited islands in the Kiribati chain have already disappeared through sea level rise (IPCC 2001).
Population impact, policy relevance, public perception and communication: Sea level rise will affect sea turtles through direct loss of nesting habitat and rising water tables which will increase hatch failure. The combined impact of these factors at a population level is not easy to predict as it is reliant on the following factors: (1) the extent of local sea level rise; (2) topography of the beach and current position of water table; (3) the occurrence of storm events in the region increasing beach erosion; (4) the type of nesting site needed (i.e. deep sand or scrub at back of beach); (5) the level of coastal development or armament. Additionally, two sea turtle species (Kemp's Ridley and Flatback) display relatively small nesting ranges and are therefore more susceptible as a whole to localised raises in sea level than more widely dispersed species. Although not exclusive to sea turtles such threats are well documented and receive substantial attention in the international media, whilst from a policy perspective the loss of critical nesting habitat is of direct relevance to: CMS (Appendix I & II), the MoU for Marine Turtles of the Atlantic Coast of Africa, CITES (Appendix I), the Bern Convention (Appendix II), the EC Habitats Directive (Annex II & IV) and Schedule 5 of the Wildlife and Countryside Act 1981 and UK Conservation Regulations 1994.
Properties of the indicator: Specificity: Medium. This indicator is likely to be impacted by climate induced sea-level rise, although loss of nesting habitat will also be caused as a result of human developments. Sensitivity and Responsiveness: Medium. The nesting beaches are considered highly sensitive and responsive to climate change. However, predicting the extent of sea level rise in particular regions is a difficult variable to model with statistical certainty and deleterious effects may not become apparent for 1-3 years. Representativeness: Medium. This indicator is likely to be representative of all sea turtles, but not of other CMS taxa in terms of critical habitat loss. Theoretical basis: High. The predicted effects of sea-level rise are well documented although estimates of rate processes are varied and subject to substantial debate. However, a recent study in Bonaire suggested that under a predicted sea level rise of 0.5m, up to 32% of the beaches could be lost via coastal squeeze, with significant consequent reductions in the area of nesting habitat available to sea turtles (Fish *et al.* 2005).
Data requirements: Protocol for data collation and collection: At present there is no index or collated empirical data to support this indicator. Suitable satellite imagery to assess the loss of sea turtle nesting habitat are available via the US Geological Survey's 'TerraLook' programme at no cost to the user. TerraLook was developed to provide both ASTER and Landsat datasets as simulated natural-colour JPEG images (using a standardised international data gathering protocol). TerraLook aims to serve user communities who have a need for images of the Earth but do not have technical remote sensing expertise or access to expensive and specialised scientific image processing software (thus directly transferable to less developed countries). Users who have a need to perform digital analysis can also acquire the source data. Practicality of applying data collection protocols in developing countries: Following the recommended research above, coverage would effectively be complete, although on-the-ground validation for a sample of sites may be required Recommended actions: In the first instance it would be necessary to identify who would be best to develop this indicator and for a detailed feasibility and costing assessment carried out by this person or organisation. Secondly, initial research would be needed to identify the key nesting sites for Turtles. Costing: Initial research to identify key nesting sites for Turtles, which is expected to be in the low to medium costing band <£50,000 – £100,000, although following this work, the indicator could be updated on an annual basis at low cost, although the exact costing would need to be determined.

4.11 Skewed sex ratios in sea turtles (Caribbean, Pacific / marine)
Empirical observation

Brief description and methods: For sea turtles, a 50:50 sex ratio is produced within clutches at a 'pivotal temperature' (~29°C) above which the ratio is skewed towards female production. Subsequently, there is concern that climate induced warming at nesting beaches may lead to the production of only female hatchlings and eventually to extinction. Making direct measurements of hatchling sex ratio is not easy to do, however, as identifiable secondary sexual characteristics are not evident during early life history stages. This problem can easily be overcome using sand temperature as a direct proxy given its established link to sex ratio. Such an indicator would be readily developed as temperature data loggers are regularly deployed at nesting sites around the world. Furthermore, since direct measurements of sand temperature have only been collected for a number of years, less direct proxies of sex ratio such as air temperature, precipitation and incubation duration might also be used. The key purpose of this indicator is therefore to identify a threshold where sex ratios have surpassed a critical threshold for population viability so that informed decisions regarding mitigation can be made (e.g. artificial manipulation of incubation conditions to increase male production).

Evidence for link with climate change: Quantitative genetic analyses and behavioural data suggest that populations with temperature dependent sex determination (TSD) may be unable to evolve rapidly enough to counteract the negative fitness consequences of rapid global temperature change. Indeed, pivotal temperatures for sea turtles are a conservative trait always being close to 29°C for different species and populations. Consequently, shifts in sand temperature do not need to be large for sex ratio shifts to manifest themselves at a population level. Such increased sand temperatures have already been reported for important nesting sites such as Ascension Island and North Carolina and that already female skewed populations are likely to become ultra-biased with as little as 1°C warming (they will experience extreme mortality if warming exceeds 3°C).

Population impact, policy relevance, public perception and communication: The population impact of skewed hatchling sex ratios will be determined by the severity of the skew. If we consider the possibility of an entirely female skew then the immediate effects for a population may be difficult to discern given that the numbers of nesting females may appear to increase over the first few decades. However, as no new males would be produced the chances of successful mating events will decrease over time leading to increased rates of clutch infertility. Females may therefore continue to nest for many decades until only unfertilised clutches are produced and thus to population extinction. This scenario has direct policy relevance to CMS with sea turtles listed in Appendices I and II. Atlantic leatherbacks are also covered under the CMS *MoU for Marine Turtles of the Atlantic Coast of Africa*. All species are listed on Appendix I of CITES 1975, Appendix II of the Bern Convention 1979, and Annex IV of the EC Habitats Directive. The loggerhead is also listed as a priority species on Annex II of the EC Habitats Directive. All five species are protected under Schedule 5 of the Wildlife and Countryside Act 1981 and the UK Conservation Regulations 1994. Sea turtles are a keystone species used to highlight global conservation concerns to the public although the particular threats posed by increased temperatures are not well publicised beyond the realms of peer reviewed journals.

Properties of the indicator (specificity, sensitivity, responsiveness, representativeness, theoretical basis).
Specificity: High. This indicator is highly specific to climate change, although other factors such as clearance or growth of shade trees on nesting beaches may alter the direct influence of warming of sand.
Sensitivity and Responsiveness: High. As explained above, the population impacts of changes in sex ratio are likely to occur only after a long time lag, but the sex ratios of hatchlings will be highly responsive to changes in ambient temperatures during development. Although recent evidence suggests that a genetic predisposition for producing a particular sex may operate in the background, the ratio of a particular clutch is almost entirely a result of its immediate incubation environment. Consequently, for species with TSD, climatically driven shifts in ambient air temperature and rainfall will manifest themselves immediately through changes in incubation conditions and the subsequent sex ratio produced within clutches.
Representativeness: Medium. Given the widespread occurrence of TSD amongst reptiles, such taxa as a whole may act as suitable bellwethers for the impending disruption of biological systems posed by global temperature change. Representative taxa include other species within the Order Testudinae, in addition to Orders Crocodilia and Squamata.
Theoretical basis: High. The effects of climate change on sea turtle sex ratios are well documented as clearly highlighted in: Godfrey *et al*. (1996), Hays *et al.* (2003), Hawkes *et al*. (2007), Houghton *et al.* (2007).

Data requirements:
Protocol for data collation and collection: Temperature data loggers have been deployed at most major sea turtles nesting sites around the world. This information is readily comparable between sites. Acquiring unpublished data will require cooperation of relevant principal investigators at each site. Internationally standardised meteorological data for most sites are also publicly available via the Comprehensive Ocean Atmosphere Dataset making large-scale assessments of climatically driven changes in incubation conditions possible.
Practicality of applying data collection protocols in developing countries: Because temperature loggers are already deployed at most major sea turtle nesting sites, extending coverage further is not relevant here.
Recommended actions: It is recommended that a feasibility and costing assessment is carried out by an expert in this field.
Costing: The logistics are not already in place for collating data across studies. For this reason, the set up costs are expected to be in the medium costing band of £50,000-100,000, although ongoing costs are likely to be relatively low cost thereafter.

4.12 Caribou / Reindeer calf production and survival (Arctic / Terrestrial)
Empirical observation

Brief description and methods: The calf production and survival of caribou and wild reindeer (both *Rangifer tarandus*) in West Greenland have shown reductions associated with an increase in mean spring temperatures of foraging sites. One likely explanation is the consequent mismatch between the timing of peak calving and the earlier emergence of their plant forage, essential for the newborn calves (Post & Forchhammer 2007). This indicator would consist of calf production (ratio of calves to mature females) and, as supportive indices, survival parameters and an index of trophic mismatch (percentage of forage species emergent on the date at which 50% of births have occurred, Post & Forchhammer 2007). This indicator could potentially be applied to the several populations of this species occurring in Scandinavia, Russia, Alaska, Canada and Greenland, and a combined populations' indicator generated. The purpose of the indicator would be to illustrate the effects of climate change on several ecosystems (high Arctic islands, boreal forest and tundra) within the range of caribou/reindeer populations. Reference points could potentially be developed and harvest management changed accordingly.
Evidence for link with climate change: Caribou migrate between seasonal ranges and their migration to calving areas coincides with the timing of emergence of their plant forage, essential for the newborn calves. Calf production and survival may therefore provide good indicators of the effect of temperature increases, since they appear correlated to a mismatch between the peak in calf production and the peak in forage availability (Post & Forchhammer 2007). This mismatch probably results in lowered foraging success of the lactating females with negative impacts on newborn calves. Other relationships have been observed in several caribou populations between reproductive success parameters (fecundity, survival of calves), the timing of life-history events, and winter and summer climate, spring temperatures, the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO) (e.g. Post & Klein 1999, Post & Stenseth 1999, Aanes *et al.* 2000, Post *et a1.* 2001, Forchhammer *et al.* 2002, Chan *et al.* 2005, Post & Forchhammer 2007).
Population impact, policy relevance, public perception and communication: In large herbivores, the calf stage may be the critical component of population dynamics, except perhaps in populations where adult mortality is high (Gaillard *et al* 2001). The importance of the juvenile/calf stage for population growth rate may also increase with environmental harshness. Reduced survival as a result of warmer spring temperatures might therefore have a negative impact on populations, particularly those with none or regulated hunting. This species not listed on the CMS appendices. However, they have a high profile and the indicator would be easy to communicate to policy makers and the wider public. The status of caribou populations is also very important for Arctic and subarctic ecosystem functioning and of socio-economic value.
Properties of the indicator: <u>Specificity</u>: Medium. There are other strong drivers of caribou reproductive success (such as density dependence, harvesting) and of calf mortality (e.g. predation). <u>Sensitivity</u>: Unknown. It is difficult, based on the very short time-series that supports the observed correlation between calf production/mortality and the trophic mismatch index, to assess whether the response of the potential indicator is sensitive to climate. More research and a longer time-series of data are necessary to corroborate the evidence available. <u>Responsiveness</u>: High. If the hypothesised link with climate is proven, it is possible that calf mortality could respond very fast to a shortage of food for lactating females in the calves' first spring. <u>Representativeness</u>: Medium. It could be representative of the response of reproductive success of many other high latitude Arctic and subarctic hoofed mammal populations (e.g. Musk Ox *Ovibos moschatus*) to climate change. <u>Theoretical basis:</u> Weak. The time-series used in the study that supports the potential indicator are of short-duration; hence the theoretical basis is weak.
Data requirements: <u>Protocol for data collation and collection:</u> Data could potentially be available through the CircumArctic Rangifer Monitoring and Assessment network (CARMA). This is an international monitoring programme that aims to manage the caribou harvest in a sustainable way and assess the resilience of the caribou harvesting regime to future changes in climate. There are future plans to compile databases, monitor in a standardised way, across different countries, several parameters of caribou populations and to retrospectively analyse existing data series on population and individual animals with relation to climate and productivity. Currently, the analysis that supports this indicator was carried out on one population and a short time series of six summers (Post & Forchhammer 2007), with funding only secured in the short-term. <u>Practicality of applying data collection protocols in developing countries:</u> There are already plans through CARMA for professionals to collate standard measures of calf production (ratio of calves to mature females), across the main populations of this species. <u>Recommended actions:</u> It is recommended that a feasibility and costing assessment is carried out for producing this indicator. CARMA is perhaps best placed to carry out this work. Whilst there are already plans to introduce standardised monitoring across countries, this would need to be evaluated in relation to this indicator. <u>Costing:</u> The logistics for producing this indicator are in place through CARMA, however, considerable collation and development work would be needed. For this reason, it is expected that the cost would be in a medium costing band of £50,000 to £100,000.
Supportive (context) indices: Mean spring temperatures of foraging sites and AO/NAO could be used as context indices. An index of trophic mismatch (see above) would provide more information on a possible causal link between mean spring temperatures and calf production and survival (Post & Forchhammer 2007).

4.13 **Populations of large African herbivorous mammals** (Africa / Arid-dry habitat) Concept-only

Brief description and methods: Large African mammal population sizes and ranges are likely to respond to changing patterns in precipitation and aridity as a result of climate change, since food availability and species interactions are influenced by climate. This indicator would consist of population size estimate of several species of large mammals (e.g. wildebeest, elephant, giraffe) and to support the indicator a spatial indicator (map-based and quantifiable) that would show animals' geographical centre of distribution within their ranges and range extent (e.g. area) and how these change over time in response to changes in precipitation patterns and aridity. One of the purposes of the indicator would be to illustrate the effects of climate change on migratory large mammals in Africa. The main purpose, however, would be to monitor the expected shifts in the geographic ranges of migratory mammals, and employ adaptation measures and policies as appropriate. Monitoring and predicting range shifts and how these may move out of protected areas (main conservation tool in Africa) will be essential to conserve migratory mammals as highlighted in several recent papers (e.g. Hannah *et al*. 2002). Reference points could potentially be developed and harvesting and conservation strategies changed accordingly.
Evidence for link with climate change: Declines in several species of large mammals have been related to lowered precipitation, which could be related to climate change (Ogutu & Owen-Smith 2003, Owen-Smith *et al.* 2005, Ogutu & Owen-Smith 2003). Lowered precipitation reduces growth of forage plants and may increase predation risk. The extent to which large migratory herbivorous mammals in Africa will adapt to the effects of climate change on their habitats will greatly depend on their ability to change their distribution and movement patterns to match changes in the available resources. However, due to intense land transformation, the connectivity between migratory species natural seasonal ranges has been very much reduced. There is currently little evidence that mammals' ranges in Africa have been changing in response to climate change. However, the effects of climate change on regional climate in Africa are not well documented. There is also uncertainty regarding the prediction of future African climate with global climate change. Nevertheless, modelling studies indicate substantial range shifts are likely to occur with climate change (Erasmus *et al.* 2002, Thuiller *et al.* 2006), and these could lead to species declines or even extinctions.
Population impact, policy relevance, public perception and communication: Part of this indicator would measure net population impact. Drought changes food resources and causes mass mortality with immediate effect on population size. Range shifts on the other hand, cannot be clearly linked to population dynamics. However, a reduction in the habitat available (caused by land-transformation and climate change) is predicted to lead to local extinctions (Erasmus *et al.* 2002, Thuiller *et al.* 2006). Species that could be used to develop this indicator are either listed on CMS appendices (e.g. African Elephant) or would be representative of large mammals in general but with sufficient population sizes to allow an indicator to be developed (e.g. wildebeest, Thompson's gazelle). In addition they are of major economic and ecological importance with a major public profile throughout the world.
Properties of the indicator: Specificity: Medium. Land-transformation and poaching is also a major factor influencing large herbivorous mammal population sizes and range in Africa. Other pressures exist, such as species interactions and density dependent effects. Sensitivity: High. Adult survival of some species is highly sensitive to drought. The sensitivity and responsiveness of species ranges are not so clear; however species distribution models predict that a mean temperature increase of 2ºC could cause 75% of species to contract their ranges (Erasmus *et al.* 2002) and that 10-20% of species could become critically endangered or extinct by 2080 (Thuiller *et al.* 2006). Responsiveness: High. Mortality follows periods of drought. For range see above. Representativeness: Medium. The indicator would potentially be representative of changes in African savannah ecosystems. Theoretical basis: Weak. The effects of climate change on regional climate in Africa are not well documented.
Data requirements: Protocol for data collation and collection: Long time-series of data on population sizes and species distribution are held by several museums, universities, government departments and national park surveying programmes in Africa. Data availability, quality, applicability and security will vary and these will have to, in part, inform the choice of the species to use in the indicator. As such there is currently no standard protocol for data collection. Practicality of applying data collection protocols in developing countries: Monitoring is already carried out by volunteers or professionals in many African countries, although standard data collection methods are needed. Recommended actions: It is recommended that a detailed feasibility and costing assessment be carried out to evaluate what monitoring data is available and collected on an annual basis and if such indicator would be feasible. This should also identify gaps and recommend ways forward for the standardisation of monitoring methods. A good first point of contact would be the IUCN/SSC African Elephant Specialist Group (see IUCN African Elephant Status Report 2007 (www.iucn.org/themes/ssc/sgs/afesg/aed/pdfs/aesr2007.pdf)). Costing: The logistics for producing this indicator and monitoring protocol are not already in place. For this reason, it is expected that the cost of setting up this indicator would be in a higher band of >100,000.
Supportive (context) indices: Indices of temperature and precipitation are available for several regions. Landsat time-series of land-use would also be useful context indices. The "Human Footprint" dataset could be used (Sanderson *et al.* 2002).

4.14 Population size (and movements) of Wildebeest (Africa /Arid-dry habitat) Concept-only

Brief description and methods: Climate change, and in particular the increase in droughts (and consequent lack of plant forage) could lead to a decline in the populations of wildebeest (*Connochnetes taurinus*) in Africa. In addition, geographic changes in migratory routes and seasonal ranges could take the animals outside protected areas, making them more vulnerable to land transformation, poaching, and species interactions. In addition to population size figures, this indicator would be supported with a measure of change in movement patterns, such as home-ranges, which could be map-based and quantifiable (area).

The purpose of the indicator would be to illustrate the effects of climate change on migratory hoofed mammals in Africa. Reference points could potentially be developed and harvesting and conservation strategies changed accordingly. Land transformation (and protected areas) can potentially be adapted to changes in species migration patterns that may be induced by climate change.

Evidence for link with climate change: The wildebeest population is regulated partly by the amount of green grass available during the dry season, which in turn depends on rainfall and the number of wildebeest (Mduma 1999). Mass mortality caused by under-nutrition has followed periods of drought (e.g. 1993-94). In addition, the amount of rainfall determines wildebeest movement patterns (as a consequence of changes in the distribution of green grass) and the susceptibility of wildebeest to predators (Musiega & Kazadi 2004). The IPCC is uncertain whether the climate in Africa will become wetter or drier. Nevertheless, temperatures are set to increase and this may exacerbate the impacts of droughts.

Population impact, policy relevance, public perception and communication: Part of this indicator would measure net population impact. If more droughts were to occur it is very likely that a population impact caused by mass mortality would be evident. Movements cannot be clearly linked to population dynamics. However, a reduction in the habitat available (caused by land-transformation) and consequent changes in movements has led to a 75% decline in a population of wildebeest (Homewood *et al.* 2001). The wildebeest is not listed on CMS appendices, however it has a very high public profile and it is a symbol of the Serengeti-Mara ecosystem.

Properties of the indicator:

Specificity: Medium. In addition to climate, there are other factors that drive the population dynamics of wildebeest, such as disease, predation, poaching, species interactions and density-dependent effects. Nevertheless, food availability in the dry season is the primary factor driving population dynamics under density dependency, and this is greatly influenced by climate (Mduma *et al.* 1999). Land-transformation has the potential to greatly exacerbate the effects of climate change through barriers to migration and range shift adaptations, but it can also confound those effects. For example, a 75% decline in the Mara wildebeest has been attributed to agricultural intensification (Homewood *et al.* 2001). By monitoring the movements and habitat availability, the combined effects of climate change and land-use could potentially be better understood.

Sensitivity: High. High sensitivity to the frequency of droughts if these increase with climate change. The sensitivity and responsiveness of wildebeest movement are not so clear.

Responsiveness: High. The drought of 1993 produced the lowest rainfall yet recorded and extended the dry season by several months, resulting in extremely low food availability and causing mass mortality that season. See above for movements. It is likely that mortality will be highly responsive to drought conditions.

Representativeness: Medium. The indicator would potentially be representative of changes in the frequency and intensity of extreme events affecting large terrestrial mammals in general. The Serengeti-Mara Ecosystem is defined by the movements of the wildebeest (Thirgood *et al.* 2004), so this indicator would be representative of that whole ecosystem and also of the effects of climate change on other migratory hoofed mammals dependent on precipitation patterns in semi-arid areas.

Theoretical basis: The theoretical basis is weak since the effects of climate change on regional climate in Africa are not well documented.

Data requirements:

Protocol for data collation and collection: Long-term (since the 1960s) aerial survey data exists (recording number of individuals), together with some tag data, mostly from the Serengeti National Park but also from other national parks in South Africa. Monitoring is secured by the Serengeti Ecological Monitoring Programme. For other national parks monitoring is uncertain. Data availability for the purposes of producing this indicator is not known.

Practicality of applying data collection protocols in developing countries: Monitoring of the main wildebeest populations is secured in the Serengeti National Park. However, ongoing data availability and the standardisation of data recorded needs to be assessed. Outside this national park, monitoring is probably not secured.

Recommended actions: It is recommended that in the first instance a detailed feasibility and costing assessment be carried out to determine ongoing data availability and to determine the current level of standardisation in monitoring protocols. The Serengeti National Park would be the logical first point of contact.

Costing: The logistics for producing this indicator is in place in the Serengeti but not in other areas and for this reason it is expected that the initial set up costs are likely to be high >£100,000. However, the feasibility and costing assessment recommended above should provide a better idea of ongoing costs.

Supportive (context) indices: Temperature and precipitation data are available in some parts of the wildebeest range. Landsat time-series of land-use would also be useful context indices.

4.15 **Population size of Saiga Antelope** (Asia / Terrestrial)

Concept-only

Brief description and methods*:* The Saiga antelope *Saiga tatarica* which inhabits the plains of Kazakhstan, Mongolia, Russia, Turkmenistan and Uzbekistan suffers occasional episodes of very high mortality and low reproductive success due to climatic conditions (drought and harsh winters) but its populations can also increase rapidly. Any indices of population size used would need to take into account harvest pressure and density dependence, in order to distinguish those from the effects of climate change. The purpose of the indicator would be to illustrate the effects of climate change on migratory hoofed mammals in central Asia. Reference points could potentially be developed and harvest management changed accordingly.
Evidence for link with climate change: The modelling of the Saiga antelope population dynamics is sensitive to assumptions about the probability of a drought or harsh winter occurring, highlighting the importance of taking climate into account in any harvest strategy adopted (Miller-Gulland 1994). Droughts and harsh winters have caused mass mortality in saiga populations, due to animals being unable to obtain sufficient forage. However, more research is needed to establish a link between population dynamics and climate change. The region in central Asia inhabited by the Saiga is mostly semi-arid and arid (IPCC 1996), with all areas experiencing wide fluctuations in rainfall. Their native plants and animals are adapted to coping with sequences of extreme climatic conditions. Central Asia climate is likely to become drier and hotter (IPCC 2007).
Population impact, policy relevance, public perception and communication: Climate-induced mortality is negated somewhat by migration and a high reproductive rate. Nevertheless, if more droughts were to occur it is very likely that a population impact caused by mass mortality would be evident. The saiga antelope is listed on CMS appendix II, but it generally has a low public profile outside of central Asia. An indicator that would include the modelling of the population size incorporating harvest and density-dependence effects could be potentially difficult to communicate.
Properties of the indicator: Specificity: Low. Many other driving factors (poaching, hunting) of saiga population dynamics besides of climate variability/change. Sensitivity: High. Populations can fall by up to 50% after a year of drought or harsh winter. Responsiveness: High. Mass mortality follows periods of harsh winters and drought. Representativeness: Medium. The indicator would potentially be representative of changes in the frequency and intensity of extreme events affecting terrestrial mammals in general and hoofed mammals in central Asia in particular. Theoretical basis: Weak, since the effects of climate change on regional climate in central Asia are not well documented and forecasts highly uncertain (IPCC 2007). There are, nevertheless, well-developed population models that are used to manage populations of this species. These would need further development to better understand the potential impacts of climate change.
Data requirements: Protocol for data collation and collection: Long-term counts of individuals from aerial surveys exist for part of the species range and a continued monitoring programme is kept by the Saiga Conservation Alliance (http://www.saiga-conservation.com/) in some areas. The aerial surveys in Kazakhstan for example, which give an annual population estimate, are government-funded and they are secure for the next few years. No security for other monitoring programmes, although there is now a 3-4 year dataset from Kalmykia on year-round observations of saigas. Saiga movement and distribution are very variable, both seasonally and inter-annually, which makes surveying fallible and population size estimates have associated uncertainties that are difficult to quantify. Considerable research effort would be needed to gain further evidence of the likely effects of climate change on this species and to build a long term time series of data. Practicality of applying data collection protocols in developing countries: The most cost-effective method for carrying out large-scale surveys of this species is through aerial surveys (line transects) over suitable habitat. Whilst this species is relatively easy to monitor using this approach, it is expensive, and at present aerial surveys are only carried out in Kazakhstan for which funding is only secured for the next few years. Recommended actions: It is recommended that a detailed feasibility and costing assessment is carried out to assess what data are currently collected on an annual basis and the current standardisation of monitoring and data collection protocols used. In addition costs for surveying populations in Uzbekistan, Russia and continued surveying in Kazakhstan, which together support >90% of this species population should be evaluated and options for securing funding explored. Costing: The logistics for producing this indicator are not already in place and initial work is needed to determine the feasibility of producing this indicator. For this reason, it is expected that the initial set up costs are likely to be in a high costing band >£100,000, although the feasibility and costing assessment recommended above should provide a better assessment of this and ongoing costs.
Supportive (context) indices: Temperature and precipitation data are available in some parts of the saiga range and could be used as context indicators.

4.16 Abundance of bats at 'underground' hibernation sites in Europe (Europe / Terrestrial) Concept-only

Brief description and methods: Changes in relative abundance (counts of individuals) and, as support indices: 1) bat species ratios indicating changes in distribution, populations; 2) reliance on hibernation assessed through counts of bat species and their numbers observed in hibernation sites over a broad geographical range. The purpose of this indicator will be to identify population and community changes that will impact productivity and long-term survival, including possible conflicts though changes in species communities.
Evidence for link with climate change: Hibernation is a crucial strategy for almost all northern temperate bats to survive periods of insect shortage, even where there is migration between summer and winter quarters. Changes in air temperature in and around hibernation sites will affect suitability of sites for different species. Higher temperature and other climate changes will affect hibernation behaviour and may have effects on migration and over-wintering survival. While the requirements for hibernation can be very precise, temperature and humidity are almost exclusively the natural factors controlling hibernation. Changes of temperature are expected to correlate with changes in regional species composition and impact on hibernation behaviour affecting productivity and survival (Robinson *et al* 2006).
Population impact, policy relevance, public perception and communication: Apart from demonstrating changes in distribution and populations, the indicator would demonstrate changes in species 'communities' and may indicate problems relating to changes in hibernation patterns that include effects on the energetic constraints imposed by hibernation (e.g. Humphries *et al.* 2002), on time of dispersal from hibernation sites (which may affect foraging opportunity at a crucial time), on the onset of pregnancy and hence parturition dates and their synchrony. All European bat species are included in EUROBATS and in CMS Appendix II (see Annex to EUROBATS Agreement for a full list). All European species are protected under the EU Habitats and Species Directive (including 14 species on Annex II), and Bern Convention, etc. Bats obtain a mixed public perception, but there is a lot of public support for and interest in their conservation, demonstrated for instance through the Europe wide activities of an annual European Bat Night. CMS proposes a Year of the Bat for 2011.
Properties of the indicator (specificity, sensitivity, responsiveness, representativeness, theoretical basis): <u>Specificity</u>: Low. It may be difficult to disentangle purely climate-related effects from other (including human-induced) impacts on bat populations for individual species, but this may be clearer by considering multi-species aggregations over a broad geographical range. <u>Sensitivity & Responsiveness</u>:. The sensitivity of the indicator is likely to be good and its responsiveness it expected to operate at the scale of 3-5 years <u>Representativeness</u>: The indicator is likely to be representative of other European bat species that do not hibernate in underground roosts and to temperate insectivorous bats elsewhere. <u>Theoretical basis</u>: there is a significant body of data acquired over a long period (over 50 years in some cases) to suggest that bats will respond to climate change by altering their hibernation behaviour, with a resulting impact on abundance. Thus there is a basis for the setting of realistic objectives for the indicator, once developed.
Data requirements: <u>Protocol for data collation and collection:</u> This indicator could use the co-ordination and centralisation of existing long-term data gathering through a collaborative project in development. Currently, data are collected nationally by most European countries, and providing the most consistent and long-term data sets associated with bats. However, there has been little analysis of such data, (e.g., Daan *et al*. 1980, Horacek *et al.* 2005, Walsh *et al.* 2001) little international compilation and little examination of the data in relation to climate change. National species indices could be calculated and then combined into supranational indices for species, weighted by estimates of national population sizes (obtained from National Reports presented to each EUROBATS Meeting of the Parties), as undertaken by Gregory *et al.* (2005). Species trends would then be combined across species for periods in the time series. Initial data on key sites have been compiled by EUROBATS, which is also developing guidelines for consistent monitoring throughout Europe. All Parties (currently 32 range states) plus some non-party range states have agreed to develop monitoring programmes and 15 countries have contributed towards the development of a Pan-European programme for the monitoring of bats in underground habitats. It is envisaged that once the programme is established it will be maintained following the establishment of a partnership of NGOs (BatLife Europe). This programme will also be collating data from underground sites used for maternity colonies and as stop-off sites for migratory species. The data have been assessed as good for population monitoring and should be applicable to this project without modification. Collection of data from a broad geographical range of sites will allow assessment of impact of temperature and other climate variables (and associated influence on vegetation, etc) on changes in species population and productivity. <u>Practicality of applying data collection protocols in developing countries:</u> It is recommended that this indicator should focus on European populations only at the current time. These are some of the best-studied bat populations in the world, yet even for these our understanding of climate change impacts are little understood. <u>Recommended actions:</u> It is recommended that support is obtained from EUROBATS for producing this indicator and that a detailed feasibility and costing assessment is carried out. The framework of EUROBATS may be best placed to carry out this work and to produce the indicator. <u>Costing:</u> The logistics and exact nature of this indicator requires development and a detailed feasibility and costing assessment as recommended above is needed. For these reason, it is expected that the set up costs will be in a high costing band of >£100,000.
Supportive (context) indices: Remote sensing data (annual change in rainfall, temperature or vegetation) may provide further information to support this indicator (see Appendix 1 of this report). Changes in temperature and humidity within hibernation sites should be monitored to relate to impacts of climate change (including change of use of sites, e.g. from winter hibernation to summer maternity). It is also likely that changes in vegetation around the site should be monitored as this may also influence site use by bats.

4.17 Populations of the Straw-coloured fruit bat in Africa (Africa / terrestrial)
Concept-only

Brief description and methods: Single species indicator of impacts of climate-induced vegetational changes that modify foraging opportunities, with impacts on breeding performance and survival, assessed through the monitoring of populations of this fruit bat in its colonies and to support the indicator changes in seasonal use of the colony sites.

Evidence for link with climate change: This large fruit bat relies on a succession of flowering and fruiting food plants, partly acquired through the migratory or nomadic behaviour of the bat (see UNEP/CMS/Conf.8.16).
Changes in temperature and rainfall patterns will correlate with foraging behaviour (including migratory behaviour) and is likely to affect colony structure and formation, with consequent effects on productivity and juvenile survival.
There is some existing evidence of changes in distribution and behaviour in similar species of fruit bat within Australia (Hughes, 2003), and also evidence of stress and mortality induced by excessive temperatures is suggested to become a likely impact of climate change (Welbergen *et al*., 2008). Bumrungsri (2002) has related effects of extreme weather events to the breeding success of fruit bats in South-east Asia. The purpose of the indicator is to identify how changes in fruiting and flowering regimens (arising from changes in temperature and rainfall patterns) affect seasonal use of traditional roost sites, productivity at breeding roosts, and post-weaning survival.

Population impact, policy relevance, public perception and communication: Changes in seasonal flowering and fruiting of food trees is likely to cause changes in colony structure and seasonal movements, which are likely to affect productivity and long-term survival and may increase competition with other fruit bats. The indicator will identify changes in populations and behaviour that can be used to assess longer term impacts on the species.
The species is included in CMS Appendix II.
Most known major colonies are in centres of human population, where they are highly visible, have a high profile (positive and negative) for both residents and visitors.

Properties of the indicator (specificity, sensitivity, responsiveness, representativeness, theoretical basis):
Specificity: Unknown, until further data analysis is undertaken. Exert opinion suggests that it will be practical to separate climate change impacts from other impacts over a broad geographical scale.
Sensitivity & Responsiveness: would be expected to be medium to high, while the responsiveness would be expected to be medium to low (i.e. changes identifiable over some years).
Representativeness: The indicator is likely to be representative of other fruit bats in the region, and probably of larger flying foxes elsewhere.
Theoretical basis: Monitoring of this species is largely untested (but see below under Data requirements), but there is every reason to believe that the monitoring is feasible based on the limited existing work on this species and work on the larger colonial fruit bats elsewhere. Thus the theoretical basis for this species is currently low, but considered quite practicable.

Data requirements:
Protocol for data collation and collection: This African fruit bat forms very large seasonal colonies (possibly up to one million), many of which are in centres of human population (or national parks). Some of these colonies, mostly in woodland patches in urban centres, have a fairly well-documented history. From these colony sites the bats migrate up to 1000km or more following the fruiting and flowering of food plant trees and may set up temporary aggregations en route. These migrations are not well-studied and the bats may to some extent be nomadic depending on the food availability. Changes in land temperature and rainfall patterns affecting seasonal flowering and fruiting of food trees are likely to modify foraging opportunity through vegetational changes.
Practicality of applying data collection protocols in developing countries: A trans-African network of colonies is readily accessible for monitoring by city universities or interest groups. A standardised international monitoring protocol would need to be established (perhaps based on one in current use, e.g. at Kampala) and tested. This would allow the comparison of roost occupation data (seasonal and population) with vegetation changes over a broad geographical range.
Seasonal data should be of good quality and readily applicable to identifying changes; colony count data for such species will not be highly accurate, but should be sufficient for significant changes to be identifiable over a period of years (analysis of available data from Kampala, which goes back 40 years, may be enough to enable the level of reliability of the count data over a given period of years to be estimated.
Identification of the links between the seasonal use and population size of these colonies with climate change will need to be examined further.
Recommended actions: It is recommended that a detailed feasibility and costing assessment be carried out.
Costing: The logistics for collecting data using a standardised protocol and producing this indicator need development. For these reasons, it is expected that the set up costs for this indicator are likely to be in a higher band of >£100,000.

Supportive (context) indices: Remote sensing data (annual change in rainfall, temperature or changes to vegetation) may provide further information to support this indicator (see Appendix 1 of this report).

4.18 Populations of Mexican Free-tailed Bats (South America / Terrestrial) Concept-only

Brief description and methods: Single species indicator to relate impact of changes in temperature and other regional weather patterns to population size at maternity sites. Changes in distribution, productivity and location of major maternity sites could be used as supportive indicators.

Evidence for link with climate change: The large concentrations of the species rely on high densities of prey insects, including those concentrated in insect mass-movements through the region of the roost (a colony of 20 million bats eats c.125 tons of insects per night) (Wilkins, 1989; CMS/ScC12/Doc.12). Changes in temperature and rainfall patterns (plus the increased intensity of extreme weather events) are likely to affect the local vegetation and the productivity and availability of insect prey. While the vegetation and prey resources may shift, the roost sites cannot (Scheel *et al.* 1996). Mexican free-tailed bat *Tadarida brasiliensis* colonies forage over a wide area and so might be less affected by changes in the immediate vicinity of the cave roost site than species with a very limited foraging range, but the densities of colonies is an additional pressure and the colonies are likely to be severely impacted by changes in insect prey availability. Changes in warm-season (maternity) colony populations and productivity is likely to be correlated with climate change factors of temperature, rainfall and extreme weather events.

Population impact, policy relevance, public perception and communication: Changes in temperature and rainfall are likely to affect the insect prey for this species that forms huge aggregations (up to 20 million in one maternity roost cave) in the southern states of USA (and southern South America). Changes in foraging opportunity for such large concentrations of bats could cause major population declines; changes in temperature and other weather patterns may have possible significant effects on conditions in roost caves. The indicator would demonstrate impacts on populations and productivity and would identify differences between migratory and non-migratory populations of *T. brasiliensis* (which are found in adjacent areas at similar latitude). The species is included in CMS Appendix I (see CMS/ScC12/Doc.12). The indicator could be used to identify requirements for changes in conservation management of cave-dwelling (and other) bat maternity colonies and the wider impact of changes in habitat.

Properties of the indicator (specificity, sensitivity, responsiveness, representativeness, theoretical basis):
Specificity: Low. While there are many other factors that will affect the populations and behaviour (including migration), it is considered that there is sufficient basis of knowledge of the species to relate impacts due to climate change with reasonable reliance.
Sensitivity & Responsiveness: The large colonies may not be particularly sensitive to potential impacts on the microclimate within the caves (since the bats effectively create their own microclimate), but they will be very sensitive to changes in the availability of large quantities of insect prey. The rate of response is likely to be relatively low.
Representativeness: Although the size of the colonies is much greater than in most other bats, the impacts are likely to be representative of other cave-dwelling insectivorous bat species.
Theoretical basis: This is one of the best-studied bat species with long-term population data sets, and the available knowledge and monitoring strategies established (at least at the north end of the range) should provide a good basis for assessing impacts of climate change with significant confidence. The species has already shown itself to be sensitive to particular aspects of environmental change (e.g. Geluso *et al.* 1976).

Data requirements:
Protocol for data collation and collection: There is a large and long-term body of population and other data available for the species. Modern technology is improving the accuracy of population estimates (O'Shea & Bogan, 2003). A large section of the USA population migrates to Mexico. Key factors may be the foraging habitat around summer maternity sites, maintenance of required stop-over sites and southern 'winter' roosts. Evidence of impacts may be clearer in the southern end of the range (in southern South America), where the environment may be less intensely modified by man, but standard international monitoring protocols are not yet in place here, but could be adapted from those used at the northern end of the range. At the north end of the range, population monitoring of summer, winter and migratory stop-over sites is already carried out through 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). 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; this is an NGO programme, but has the support and participation of its host governments and is producing valuable results for conservation. Similar organisations are being set up in southern South America where the species is believed to be migratory, but where the migratory behaviour is as yet largely unknown and there is as yet no systematic monitoring. Other populations are largely non-migratory as far as is known, and do not form the very large colonies recorded at higher latitudes. The standardised monitoring of populations in principal roost caves and other structures can be used to relate population or roost location changes with the relevant climate change factors.
Practicality of applying data collection protocols in developing countries: Standard protocols for monitoring the number of individuals employed in the northern end of the species range could be used throughout the rest of migratory range of this species. The fieldwork is relatively straightforward and could be carried out by volunteers if the logistics were in place to coordinate and collate such data.
Recommended actions: It is recommended that a detailed feasibility and costing assessment be carried out. In addition, the potential for improving the quality of the data collection in the southern part of the species range should be assessed.
Costing: The logistics for collecting data using a standardised protocol and producing this indicator need development. For these reasons, it is expected that the set up costs for this indicator are likely to be in a higher band of >£100,000.

Supportive (context) indices: Monitoring of foraging habitat around maternity sites (e.g. by satellite). Associated monitoring of required stop-over sites and 'winter' roosts could provide supporting evidence.

5. Other indicators considered

5.1 Birds

Abundance of montane specialists

Temperature increases are likely to result in altitudinal range shifts. This is likely to have a great impact on montane species, where in many cases there is nowhere to shift significantly in range. In Northern Europe for example, this would include the Eurasian Dotterel *Charadrius morinellus*, which is listed on Appendix II of the CMS. However, the consensus at the workshop was that there are relatively few migratory montane specialists (*sensu* CMS), and for these species, monitoring data was poor or non-existent. For these reasons, it was not thought worth developing this indicator at present, although with improved monitoring this indicator could be considered in the future. If required an alternative indicator could reflect vegetation changes within this environment for which a network of observers through the *GLORIA*'s *Multi-Summit project* http://www.gloria.ac.at/ already collects and collates standardised data on alpine biodiversity and vegetation patterns on a European, and in the near future global scale. The purpose of this project is to assess risk of biodiversity losses and the vulnerability of high mountain ecosystems under climate change pressures.

Changes in distribution of wintering shorebirds

Increasing winter temperatures have resulted in a north-easterly shift in the distribution of shorebirds over the past 30 years (Maclean *et al.* submitted). An indicator could represent the shift in range, through the calculation of a multi-species geographical centre of distribution for each year of the time-series of interest. This would allow visual representation of the shift in range as well as a quantitative measure of distance. To date, analyses have focused on seven migratory European shorebird species, although species inclusion could be expanded and consideration given to improving geographical coverage. In the workshop, it was argued that this indicator whilst having high policy relevance in terms of legal status of protected sites, does not necessarily relate to a net impact on the population status of the species of interest, and therefore does not meet the objectives of this project.

Phenological indicators for Trans-Saharan migrants

There are good data to show that temperature increases on the wintering grounds and at stop-over sites have resulted in earlier arrival (Lehikoinen *et al.* 2004) and advanced egg-laying of Trans-Saharan migrants (Crick *et al.* 1997, Crick & Sparks 1999, Both *et al*. 2004). At present the importance of these changes at the population level are uncertain for many species, and to date Pied Flycatcher *Ficedula hypoleuca* is the only species for which there is evidence that arrival dates are becoming out of synchrony with timing of food availability. Thus such indicators do not at present relate clearly to negative impacts on population size.

Changes in tundra-breeding goose abundance and productivity

A number of important populations of geese breed in the arctic tundra and these are strongly influenced by climate (Zöckler & Lysenko, 2000). However, many populations are currently increasing, partly due to decreased hunting pressure, partly from changes in food supply on their wintering grounds and partly from the beneficial effects of climate warming. It is likely that an index based on these populations will not provide the CMS with a warning of detrimental impacts of climate change though, and it may be difficult to distinguish such impacts from those of other confounding factors. Thus an index based on these populations was not considered further, but may be useful in the future.

5.2 Marine mammals, fish, cephalopods, crustaceans and plankton

Although an attempt was made at covering a representative range of biogeographic regions, taxa and key processes, there are many gaps in the suggested suite of marine indicators. Many other marine species listed on the CMS appendices, such as dugongs and manatees, otters, monk seals, river dolphins and whale sharks, were considered as candidates for the development of indicators. However, in the context of this project these were not yet suitable for inclusion due to: i) lack of long time series, ii) their endangered status and the many other pressures their populations face, and iii) the fact that such small populations are very prone to the effect of demographic stochasticity (random variability in individual survival and reproductive success) and census errors on lowering the signal-to-noise ratio in population size trends (Benton 2006, Clark & Bjørnstad 2004). Below we discuss the other potential indicators that were considered.

Ratios of warm to cold water dolphins, fish and plankton in temperate waters

An indicator combining information on the relative occurrence of warm water / cold water dolphin, fish and zooplankton species in cold temperate zones was considered. Changes in ratios with latitude would reflect south to north movements of biogeographic zones (expanding warm water species / retreating cold water species) as a response to climate change. It was argued that having an indicator that would combine taxa across different trophic levels would allow for a better understanding of how ecosystems were responding and of the causal mechanisms. For example, in coastal cold temperate regions, the relative frequency of strandings and sightings of white-beaked dolphins, a cooler water species, have declined, while common dolphins, a warmer water species, have increased in the last decade (MacLeod *et al.* 2005). These observations are consistent with changes in local water temperature. Temperature is also one of the primary factors, together with food availability and suitable spawning grounds, in determining the large-scale distribution pattern of fish. Because most fish species (and stocks) tend to prefer a specific temperature range, long-term changes in temperature may lead to expansion or contraction of the distribution range of certain species (Stenseth *et al*. 2004). These changes are generally most evident near the northern or southern boundaries of the species range. For example, the distributions of both exploited species, such as Atlantic cod *Gadus morhua* and common sole *Solea solea*, and non-exploited species in the North Sea have responded markedly to recent increases in sea temperature, with distributions of nearly two-thirds of species shifting in mean latitude and / or depth over the past 25 yr (Perry *et al*. 2005). Clear evidence of pronounced trends and decadal change is also seen in zooplankton communities. Long-term trends in the abundances of the two main copepod species in the North Atlantic are opposite. *Calanus finmarchicus* shows a downward trend and *C. helgolandicus* an upward one. Zooplankton changes have major implications for the productivity of regional seas since they are the link between primary production and the prey of marine migratory species. Zooplankton indices are already used as climate change indicators (UK) and used in conjunction with migratory species indicators would allow for a better understanding of the effects of climate change on these species.

Many dolphin species are on CMS appendices, and although the fish and zooplankton are not, these would provide information that would help with interpretation of patterns of higher predator distribution. Closely related species of dolphins with similar range limitations to white-beaked dolphins and common dolphins occur throughout the world. A global network of cetacean strandings and sightings in cold temperate zones could be developed to provide an index that would show how dolphin biogeographical regions are responding to climate change. For the fish part of the indicator, data sources would come from fisheries and long-term monitoring research surveys. For the zooplankton, data sources would come from Continuous Plankton Recorders (CPR)**.** This biological monitoring programme operates on an ocean basin scale, and long-term datasets exist. Data are available from the North Atlantic, North Sea, Mediterranean and North Pacific. For fish and plankton monitoring, funds are generally secured to coordinate continued data collection and analysis using international standardised protocols.

However, the above distributional shifts would not directly meet the specifications of this project, to produce indicators that reflect an impact on the conservation status of species or communities of interest, since changes in migratory species' distribution and range will not necessarily lead to population declines. Nevertheless, those species occurring in cooler higher latitudes (e.g. belugas) will likely see their ranges contracted pole-ward if sea temperatures continue to rise. Some fish populations occurring in shallower water seas (e.g. haddock in the North Sea), for example, might be at risk if they have to track their preferred isotherm as it shifts northward and out of their continental shelf habitat. It was recognised that range and distribution changes can have major implications for management, and such an indicator could, therefore, serve to monitor species biogeographical shifts, which may allow managers to anticipate changes in human activity and species interactions. Limitations of such indicators include (1) uncertainties with regards to the process through which species would be affected (physiology / prey changes); (2) low specificity since other factors could influence the observed changes (i.e. changing patterns of resource exploitation and other anthropogenic pressures, together with density- dependence and species interaction may cause apparent changes in distribution); (3) unknown sensitivity, one cannot tell by how much the ratio of cold / warm water species would change if, for example, temperature changed by 1ºC; (4) unknown responsiveness, i.e. how long it would take for the species range change to take place, once temperature changes occurred; (5) the fact that given the short time-series currently available, it might be difficult to distinguish natural variability in distribution from longer term changes; and (6) the fact that, populations of the same species may respond differently to climatic change in different regions, owing to additional local environmental determinants, interspecific ecological interactions and dispersal capacity.

Range and distribution of top predators

There is currently little understanding as to how climate change affects top predator foraging behaviour, although it is predicted that there will be distribution range shifts in response to climate change. Tagging of migratory species will allow for the simultaneous monitoring of movements, habitat use and the oceanographic environment they experience, and allow the relationship with climate change to be explored. Basking sharks, white sharks and the leatherback turtle are all CMS species. A tagging programme of top predators in the pacific (TOPP) has been underway and could potentially be extended to other oceans. However, limitations of this indicator replicate those of the above. This would be a map-based (spatial indicator) together with the annual mean latitude to the northern limit of the ranges of tagged basking sharks, white sharks, bluefin tuna, leatherback turtles and comparison with Gulf Stream Position Index (GSPI), which measures the latitude of the north wall of the Gulf Stream. More than half of the interannual variation in the GSPI can be predicted by the NAO, and so it is a good regional indicator of climate. The Gulf Stream position influences the abundance and distribution of plankton with repercussion to upper trophic levels. The only certain way to distinguish between declining numbers of migratory species and changing distributions is to follow the animals. Tagging of migratory species will allow for the simultaneous monitoring of movements, habitat use and the oceanographic environment they experience. This will be most useful to see how the environment and its variability influence their migration paths.

Using tags, the foraging patterns of top predators has been monitored and showed differences in foraging behaviour (e.g. home range) that are related to oceanographic patterns potentially related to climate (basking sharks, Cotton *et al*. 2005; white-sharks Martin 2006; blue-fin tuna, Block *et al.* 2001; leatherback turtle, Hays 2004). Limitations to this indicator replicate the ones for the previous indicator, low specificity, unknown sensitivity and responsiveness. In addition, a large number (unknown at present) of tagged animals would be necessary to represent a population/species wide response, and this can become prohibitively expensive. Nevertheless, understanding how changes in oceanographic patterns affect top predators foraging behaviour will help in understanding the potential effects of climate change on them. In addition, if similar trends in range of individual animals were seen across taxa it would support evidence of wide scale shifts at the population level.

Basking sharks, white sharks and the leatherback turtle are all CMS species. A tagging programme of top predators in the pacific (TOPP) has been underway and could potentially be extended to other oceans. Tagging marine animals was one of the priorities identified by the Partnership for Observation of the Global Oceans. Other data sources exist, all short time-series of data (e.g. WWF "movements of Atlantic leatherback turtles", bluefin tuna and basking shark tagging programmes).

Phytoplankton abundance / biomass, distribution and phenology

Global and regional ocean productivity is likely to change beyond the boundaries of normal variability due to climate change (Reid *et al* 1998, Richardson & Schoeman 2004, Behrenfeld *et al* 2006). This is likely to have important implications for marine predator populations, which may be affected through bottom-up processes (e.g. Edwards & Richardson 2004. Phytoplankton indices are already compiled and used as climate change indicators (in the UK), and there is the potential to be produced for other parts of the world. Data could come from satellite imagery (see Appendix 1 for more information) and Continuous Plankton Recorders (CPR). This biological monitoring programme operates on an ocean basin scale, and long-term datasets exist. Long-term data series are available from the North Atlantic, North Sea, Mediterranean and North Pacific. Funds are secured to coordinate continued data collection and analysis using international standardised protocols. Whilst changes in phytoplankton abundance and distribution are widely regarded as an early warning system of the effects of climate change on the oceans (Hays *et al*. 2005), the consequences of these changes on migratory species are not currently understood, such that this does not represent a viable indicator for this project at this time. Nevertheless, improving the understanding of plankton distribution and abundance is essential to the understanding and forecasting of future climate change scenarios.

Beluga whale *Delphinapterus leucas* movements (range and timings) as an indicator of changes in Arctic ice-edge productivity

It was argued at the workshop that one of the main changes we might observe as a consequence of climate change in the Arctic might be changes in ice-edge productivity (see also Tynan *et al* 1997). Belugas' foraging ecology is strongly associated with the ice edge and cracks. Migrations of belugas closely linked to seasonal cycle of sea ice and to the spring production of ice algae and ice-edge productivity, which affect the recruitment of Arctic cod *Arctogadus glacialis* (prey of belugas). Alterations in the timing and geographical patterns of seasonal migrations might reduce genetic diversity through bringing together separate stocks and this is potentially detrimental to the population status of belugas. Beluga whales would be representative of effects on narwhals and harp seals that also feed on the ice edge and cracks. Several tag datasets exist for many regions. "Pan-Arctic Tracking of Belugas" plans to attach satellite transmitters to around 50 belugas per year over the next three years. "Circumpolar flaw lead" project – will monitor throughout this (in 2008-09), the chronology of ice edge development during spring and the primary production cascades into the life processes of migrant marine mammals. Because the relationships here are not well understood at present, this indicator was not considered further for the purposes of this project.

Availability of Antarctic Krill *Euphausia superba*

Krill forms the major part of the diet for many species in the Antarctic, of which we currently have selected three indicators for the suite – Indicators 4.2, 4.6 and 4.7. Information on the availability, abundance, distribution and size-frequency distribution of Krill would therefore provide extremely useful support information for these indicators. There is scope for producing a single indicator for the Antarctic that combines the responses of several krill predators to climate change since this may provide the most convincing indicator. Indeed, indicators have been developed for the Antarctic that could potentially be used as climate change indicators (Boyd & Murray 2001). This could include species such as the crabeater seal (*Lobodon carcinophagus*), which is probably the most abundant seal species in the world and feeds almost exclusively on krill (Southwell *et al*. 2008). Previous research has indicated that crabeater seal population parameters such as age of sexual maturity and strength of cohorts might be sensitive to environmental fluctuations through the influence these have on krill availability (Testa *et al*., 1991; Bengtson & Laws, 1985).

Recruitment of fish species (abundance and timing)

The strength of fish recruitment depends on direct effects of temperature on growth and indirect effects on the time and abundance of prey. Links between the availability of zooplankton and the distribution and recruitment of several of its fish predators have been found and modelled. During their larval stages, all fish consume zooplankton and synchrony between the peak in plankton abundance and the arrival of fish larvae in the plankton (match-mismatch) is thought to be crucial for fish recruitment hence the importance of monitoring the timing of recruitment (Edwards & Richardson 2004). The decline in cod recruitment in the North Sea has been linked to rising temperatures affecting the plankton composition and availability (Beaugrand *et al*. 2003). In the Arctic, cod larvae depend on the timing of phytoplankton bloom, driven by the break-up of sea ice (Tynan *et al.* 1997). Sand eel recruitment in the North Sea is linked to oceanographic conditions driven by the NAO through the effect on their zooplankton prey. Data sources would come from long-term egg and young fish research surveys and recruit estimates from stock assessment. Fish recruitment modelling in fisheries management already takes into account environmental variability. This indicator was not considered because it did not include species listed on CMS appendices and it was difficult to see how this indicator would be representative of fish or their predators listed on these appendices.

Recruitment of Loliginid and Ommastrephid squid

Earlier and stronger recruitment in warm years benefits some squid species and is disadvantageous to other. The life history strategy of squid makes them a good candidate for following the effects of climate change, since these animals have fast growth rates and short lives, making demographic parameters very responsive to changes in environmental variables (e.g. *Illex argentinus,* Waluda *et al*. 2001), although it would be important to distinguish climate variability from underlying climate change. Data sources would be available from fisheries and research surveys and some long-term data sets exist. Squids may be representative of short-lived marine invertebrates in temperate waters, although probably more sensitive than most. It is also indicative of food supply to squid eaters (e.g. whales, seabirds). Annual recruitment can be measured from fisheries data but can also be proxied by remotely sensed data on SST. This indicator was not considered because it did not include species listed on CMS appendices and it was difficult to see how this indicator would be representative of other migratory species of interest.

5.3 Turtles

Remigration intervals and shifts in foraging conditions

The ability of leatherback turtle (*Dermochelys coriacea*) populations to buffer dramatic by-catch in long-line fisheries may be linked to their reproductive remigration intervals. For example, in the Atlantic, remigration intervals are typically 2-3 years whilst in the Pacific animals return to their breeding grounds less frequently at around 5-6 years. Differences in foraging conditions between the two ocean basins is thought to be the principal reason for this difference with the productive waters of the temperate north Atlantic allowing turtles to acquire resources more quickly, increase their frequency of reproduction and thus produce more hatchlings per female turtle. Consequently, Atlantic leatherback populations appear more stable than their Pacific counterparts as the incidental mortality of adults is better counteracted by the production of juveniles. However, as leatherback turtles feed almost exclusively on gelatinous zooplankton there is concern that the distribution, abundance and seasonality of prey may shift in line with climate change. Should the foraging conditions in the Atlantic shift to a more Pacific scenario then remigration intervals should correspondingly increase driving overall population decreases. It is feasible to monitor such changes through: (1) saturation tagging programmes run at all major sea turtle nesting grounds; (2) Proxies of foraging success from movement / dive data although further work is required to test the sensitivity of these indicators. Unfortunately, the missing link in our current understanding is the exact response of gelatinous zooplankton to climate change preventing the adoption of remigration intervals as an indictor at this time. Moreover, empirical data on the distribution of gelatinous zooplankton is not available on a basin wide scale although concerted efforts to map species using ships, aerial surveys and shoreline surveys are currently underway in restricted areas.

5.4 Bats

Changes in migration patterns of nectivorous migrant bats of Central America

In the arid zones of northern Central America to southern USA there is an extreme mutualism between many of the plants and a suite of nectivorous bats (Fleming & Valiente-Banuet, 2002). Three species of nectivorous bats undertake migrations following the flowering of food plants that they pollinate. The extent of the migration, particularly in one or two of these species, is dependent on the flowering patterns that may be dependant on conditions of temperature and rainfall. A change in the migration behaviour of the bats may have far reaching effect on the plants. The migration is well-understood and the monitoring of changes in the extent of migration of *Choeronycteris mexicana* and

Leptonycteris curasoae and *nivalis* could link well with climate change; these species are proposed candidates for Appendix II (CMS/ScC12/Doc.12). The conservation of these migratory bats is one of the key aims of an organisation (PCMM) already established for the area. Insufficient data exist at the moment for this to be a potential indicator.

Changes in dates of maternity colony formation (and/or dispersal) and parturition dates (and occurrence of multiple births?)

Climate change factors, including changes in temperature, rainfall pattern and storm events, could all have serious influence on the breeding patterns of temperate insectivorous bats. Prolonged storms during late pregnancy and lactation have led to high levels of abortion, abandonment and death of young. Probably the main long-term impact might be changes to the parturition date and the decline of synchrony of parturition in colonies. This may also produce asynchrony with suitable insect food during the key lactation and post-weaning periods. Late weaning can affect juvenile survival and long-term reproductive capacity. The incidence of multiple births might also be affected. The least intrusive method of monitoring such changes might be from monitoring the dates of colony formation and/or dispersal, but these are unlikely to be as reliable as observations of birth dates. A great deal of such monitoring is already carried out by both governments and NGOs, both throughout Europe and North America (and elsewhere), but in many cases could be more co-ordinated and the data better centralised. In Europe, all species are included in CMS Appendix II (see Annex to EUROBATS Agreement). More research is required to determine whether and how this monitoring would detect detrimental impacts of climate change on these species.

6. THE INDICATOR SUITE

To be cost-effective and provide clear management guidance, suites of indicators should be kept as small as possible whilst still fulfilling the key needs of the main users. Specifically our aim was to identify indicators that would illustrate detrimental "impacts" of climate change on a representative range of migratory wildlife. Too large a suite of indicators is likely to overwhelm policy makers with information and may fail to provide clear information to guide policy. Currently, the proposed suite covers most of the major components of migratory wildlife likely to be stressed through climate change, and for which there is, or likely to be in the near future, adequate monitoring data.

As a guide, at the start of this project, we reviewed previous Defra-funded research (CR0302, "Climate change and migratory species" and work published in the meantime to identify those habitats where climate change impacts are likely to be most extreme, the species likely to be most influenced by climate change and the key ecological and physical processes (e.g. ice retreat, increasing temperature – see Appendix 1 of this report) acting on species populations. Importantly, the climate change literature has a bias towards birds and to some degree, marine mammals, fish and turtles. These are species groups for which there is generally better monitoring data and for which the relationships with climate change are perhaps best understood. Whilst we have attempted to obtain representative taxonomic coverage, completely representative coverage is not possible to achieve, because of gaps in scientific understanding or in studies for certain taxonomic groups and regions of the world. Following the December 2007 workshop, Table 6.1 shows our proposed indicator suite. This presently includes 18 indicators, of which there are four bird indicators, two indicators for turtles, one indicator for fish, four indicators for marine mammals, four indicators for terrestrial land mammals and three indicators for bats.

Taxonomic group	**Proposed indicator**
Birds	4.1 Relative abundance of Trans-Saharan migrants
Birds	4.2 Populations of Antarctic Penguins
Birds	4.3 Productivity of seabirds
Birds	4.4 Productivity of Arctic shorebirds
Marine mammals	4.5 Polar bear body condition and cub survival
Marine mammals	4.6 Fur seal pup production in the Antarctic
Marine mammals	4.7 Southern Right Whale calf production in the Antarctic
Marine mammals	4.8 Ice-breeding seal pup survival
Fish	4.9 Juvenile survival of Salmon
Turtles	4.10 Loss of suitable sea turtle nesting habitat through sea level rise
Turtles	4.11 Skewed sex ratios in sea turtles
Land mammals	4.12 Caribou / Reindeer calf production and survival
Land mammals	4.13 Population size and range of African large mammals
Land mammals	4.14 Population size and movements of wildebeest
Land mammals	4.15 Population size of Saiga Antelope
Bats	4.16 Abundance of bat aggregations at 'underground' hibernation sites
Bats	4.17 Populations of the straw-colored fruit bat in Africa
Bats	4.18 Populations of Mexican Free-tailed Bats

Table 6.1. The proposed indicator suite following the December 2007 Climate Change Indicators workshop.

During the 2007 workshop, participants were asked to score (1-3) the proposed indicators in Table 6.1 according to the list of desirable criteria presented in Chapter 2. This process was a function of the expertise represented by the participants present. While there was a broad spread of expertise, there were unavoidable gaps in knowledge of certain groups and certain regions. However, because all participants started with a shared definition of the evaluation criteria, we believe that this provides a fair appraisal of the strengths and weaknesses of individual indicators. The scores[1] of which are shown in Table 6.2.

Indicator	I	II	III	IV	V	VI	VII
4.1 Populations of Trans-Saharan migrant birds	3	2	3	3	3	1	3
4.2 Populations of Antarctic Penguins	3	3	1	2	2	3	2
4.3 Productivity of fish-eating seabirds	3	2	3	3	3	2	3
4.4 Productivity of Arctic shorebirds	3	3	2	3	3	3	2
4.5 Polar bear body condition and cub survival	2	2	2	3	1	1	3
4.6 Antarctic fur seal pup production	2	2	3	3	2	3	2
4.7 Antarctic Southern Right Whale calf production	2	2	3	3	2	2	2
4.8 Pup survival of ice-breeding seals	2	2	3	3	2	3	2
4.9 Juvenile survival of Salmon	2	2	3	3	2	1	2
4.10 Loss of suitable sea turtle nesting habitat	2	3	3	3	1	2	2
4.11 Skewed sex ratios in sea turtles	2	3	3	3	1	2	3
4.12 Caribou / Reindeer calf production and survival	2	2	2	3	2	1	1
4.13 Population size (and range) of large African mammals	2	2	3	3	3	3	1
4.14 Population size Wildebeest	2	2	3	3	1	1	1
4.15 Population size of Saiga Antelope	2	2	3	3	1	1	1
4.16 Abundance of bats in 'underground' hibernation sites	1	1	-	-	-	-	-
4.17 Populations of the straw-colored fruit bat in Africa	1	1	-	-	-	-	-
4.18 Populations of Mexican Free-tailed Bats	1	1	-	-	-	-	-

[1] Some scores have modified slightly since the workshop to improve standardisation across taxonomic groups

Table 6.2 Indicators scored by experts according to desirable criteria. I = Impact, II = Specificity, III = Sensitivity, IV = Response, V = Spatial, VI = Taxa, VII = Theoretical.

Table 6.2 suggests that none of the indicators in the proposed suite are ideal in every sense, and some score poorly for particular criteria. For example, most of the indicators for marine and terrestrial mammals scored poorly for specificity, because changes in the populations of these species are driven to large degree by the activities of man. However, the impact of climate change on bat population and indicators here are least understood. For this reason, it was not possible to evaluate these in relation to several of the desirable criteria here at the present time. Three bat indicators are currently included in the indictor suite, because their exclusion would represent an important gap in taxonomic and to some degree geographic coverage. However, more work would be needed to determine whether it was feasible to produce useful indicators of climate change for this taxa, based on existing data and our current knowledge of this group at this time.

6.1 Coverage of key processes and taxonomic groups

If we examine the above indicator suite according to key ecological and physical processes through which climate change might affect different taxonomic groups identified in Appendix 2, the number of indicators for birds, turtles, marine mammals and terrestrial mammals is approximately in the proportion that we would expect considering our current understanding of climate change impacts on migratory species (Figure 6.1.1). However, excluded completely from the indicator suite are plankton, crustaceans, cephalopods, amphibians and insects. These are not represented in the indicator suite because there are few species that could be considered as being migratory according to the CMS definition of migratory, that monitoring data is currently poor and likely to continue to be so for the foreseeable future or that currently the link to climate change is not well understood.

In terms of the key processes identified in Appendix 2 of this report, the indicator suite currently provides good coverage of these, although there are some gaps. This includes those ecological and physical processes that are not currently well understood, including changes in precipitation, ocean salinity, ocean stratification and upwelling, storm frequency and intensity, underlying changes in climate variability patterns, implications of increasing ocean acidity (CO_2 load), climate driven disease, incidence of harmful algal blooms, and climate change effects on interspecific competition. Nevertheless, it is accepted these may provide useful indicators in the future as our understanding of their impacts and monitoring data improves.

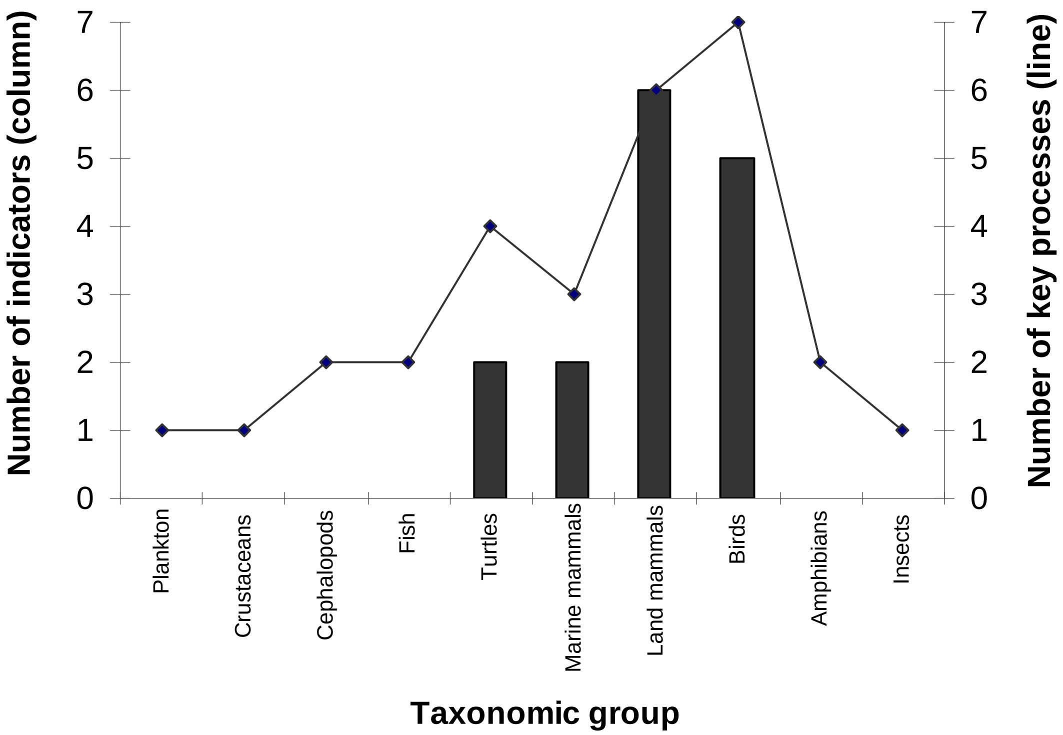

Figure 6.1.1 Indicators classified according to key processes identified in Appendix II.

6.2 Coverage of key habitats

In terms of coverage of key habitats, the literature identified five principal habitats where climate change impacts on migratory species are likely to be most pronounced. This includes (i) Marine and coastal habitat (ii) Freshwater, (iii) Tundra, (iv) Montane and (v) Arid dry habitat.

In Figure 6.2.1 we present the number of indicators according to each of these key habitats and the taxonomic groups that contribute to each habitat. Gaps include coverage of freshwater, which is currently only represented by juvenile Salmon survival and montane habitat. Montane species are currently also represented by an indicator for the cave dwelling bat Mexican Free-tailed Bat *Tadarida brasiliensis*, which cannot shift roost sites as conditions change. A montane bird indicator was also proposed, but not included in the suite. It was considered at the workshop was that there are relatively few migratory bird montane specialists, and for these species, monitoring data was poor or non-existent. For these reasons, it was not thought worth developing an indicator for montane birds at this time, although with improvement in monitoring this should not be excluded from consideration in the future.

Perhaps the main difficulty in producing indicators for freshwater habitat, is that wetland loss is driven to the largest degree by the activities of man. For this reason, it would be extremely difficult to determine the component influence of climate change. In addition, for many of the species at greatest risk, there is poor monitoring data, making this a difficult indicator to develop at this time.

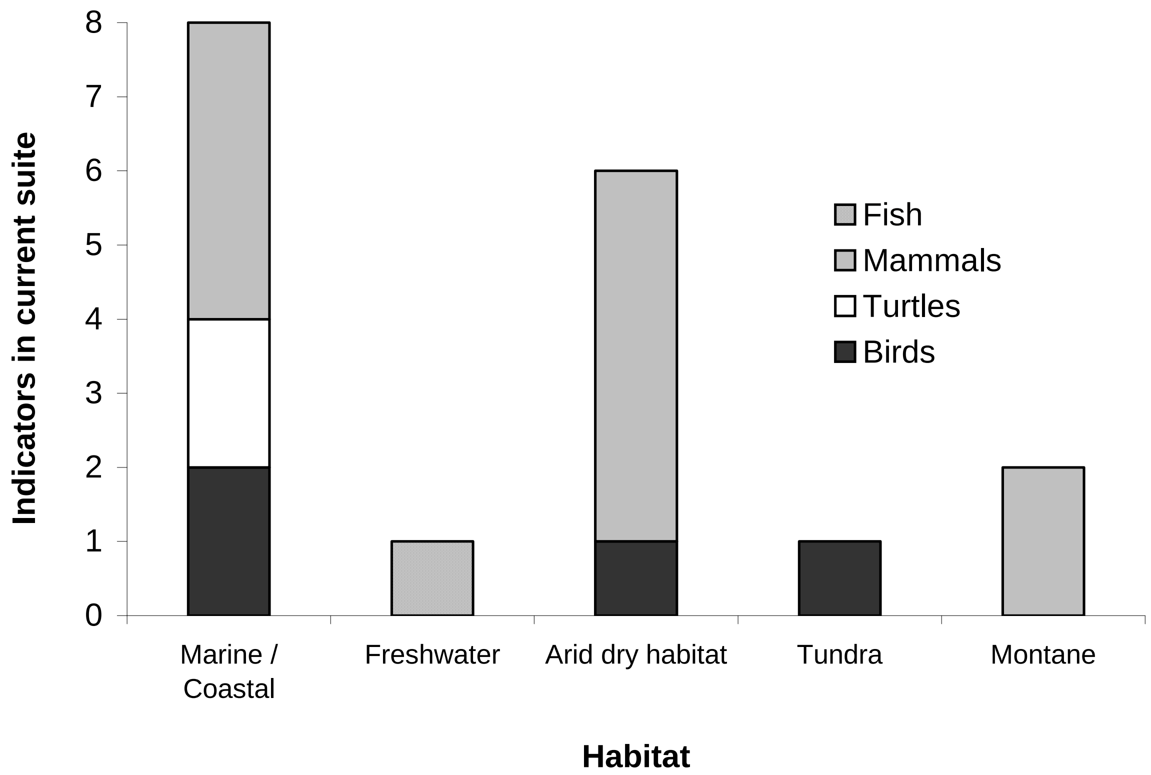

Figure 6.2.1 Number of indicators by taxonomic group within each key habitat

6.3 Geographic coverage

Finally, examining the indicator suite in terms of geographic coverage of proposed indicators, there are no major gaps that would prevent a useful indicator being produced, although the extent and quality of monitoring data is likely to vary geographically, perhaps for most indicators here. Geographic representativeness of each indicator is examined in more detail for each proposed indicator in Chapter 3. However, looking more widely than the indicator suite, Figure 6.3.1, shows how the proposed indicators breakdown by continent and in Figure 6.3.1 for marine species broken down by ocean. In both cases, an indicator can contribute to more than one continent or ocean for species that move between continents / oceans.

This highlights that the indicator suite has particularly poor coverage of Asia, South America and Australia and for marine species, the Indian Ocean which is reflected by one indicator. This may be partly driven by geographic coverage in the literature, but also that the knowledge base of experts who have contributed to discussions and proposal of indicators may be greatest for Europe and North America in particular. For this reason, it will be important for the CMS to explore the possibilities of developing further indicators in these regions or to assess whether there are datasets that can be used to create comparative parallel indicators to the ones here proposed for other parts of the World.

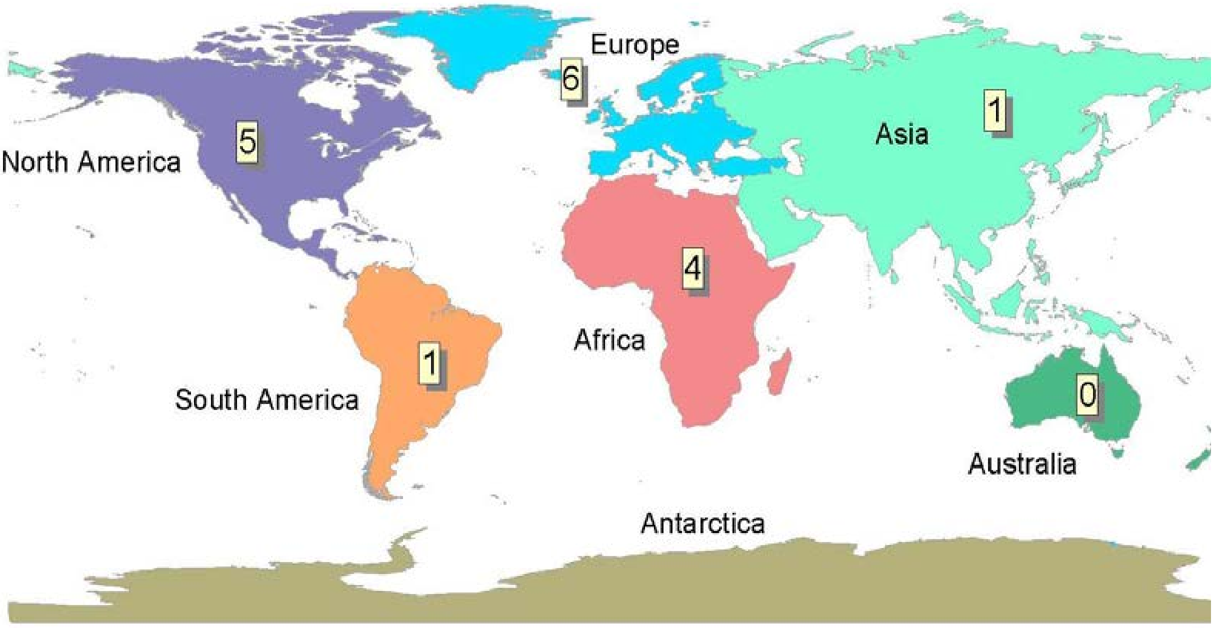

Figure 6.3.1 Breakdown of terrestrial indicators by continent. Note that some indicators span more than one continent.

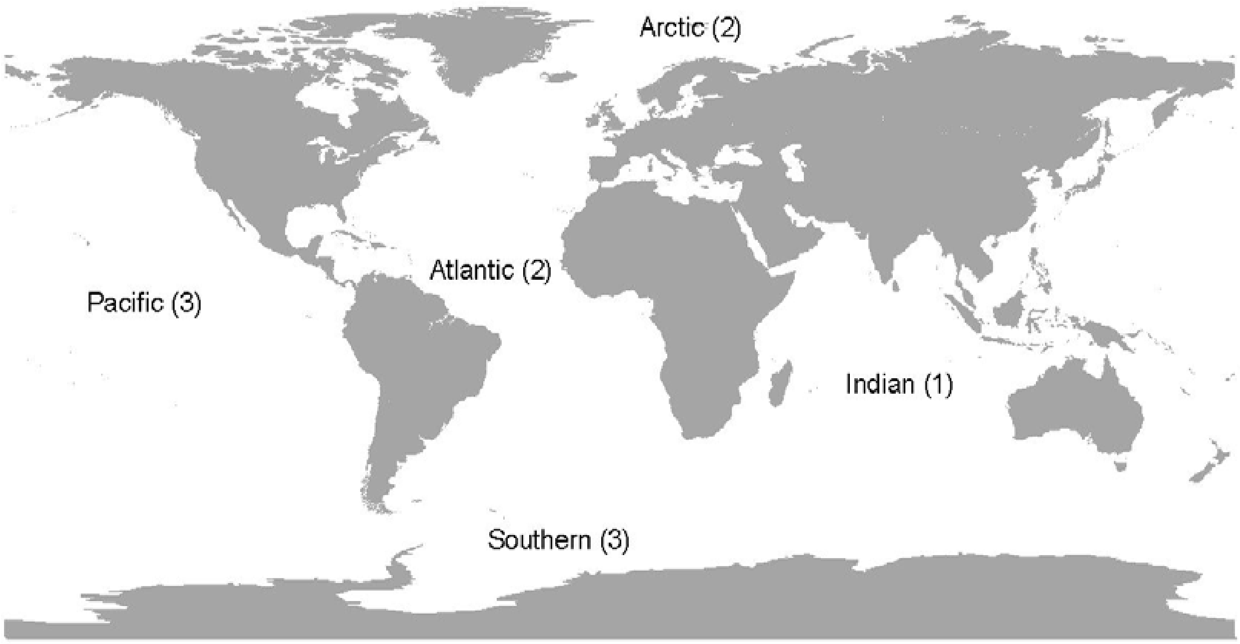

Figure 6.3.2 Breakdown of marine indicators by oceans. Note that some indicators span more than one continent.

7. SYSTEM OF ALERTS AND TRIGGERS FOR ACTION

An Alerts System (Underhill & Prys-Jones 1994, Atkinson *et al.* 2001, Atkinson *et al*. 2006, Baillie & Rehfisch 2006) was first developed for waterbird species in the UK to provide a standardised method of identifying the direction and magnitude of changes in numbers at a variety of spatial and temporal scales for a range of species for which data are available. Species that have undergone major changes in numbers can then be flagged by issuing an Alert. Alerts are intended to be advisory and, subject to interpretation, should be used as a basis on which to direct research and subsequent conservation efforts if required.

7.1 Annual indices

It is proposed that the indicators here will reflect change on an annual basis. This may be change in the absolute values of the parameter of interest, or more likely represent an index of relative change. For example an index value for a particular year may be the number expressed relative to the number in a base year, which is often arbitrarily set to 100 or 1 in the first or last year in the time series. Missing values can be accounted for using methods that allow one to impute missing observations using an iterative approach (e.g Underhill & Prys-Jones 1994).

7.2 Distinguishing natural fluctuations from longer-term trends

Natural temporary fluctuations in indicators, for example those caused by variation in the severity of conditions over the winter period, can differ in size and direction from longer-term trends, hindering their interpretation. Extreme values may trigger false Alerts due to misinterpretation of temporary, short-term declines as longer-term trends. Alternatively, long-term trends that may have led to Alerts being flagged could be obscured by short-term fluctuations. In order to avoid such misinterpretations and misidentifications when calculating Alerts, it is useful to fit smooth trend curves to indicators using for example Generalised Additive Models (GAMs). GAMs do this through a reduction in the number of degrees of freedom. As the number of degrees of freedom is decreased from (n-1)), where n is the number of years in the time series, the trend becomes increasingly smooth until ultimately with one degree of freedom the smoothed curve becomes a linear fit. Adopting a (n/3) degrees of freedom has been found to produce a level of smoothing that, while removing temporary fluctuations not likely to be representative of long-term trends, captures those aspects of the trends that may be considered to be important.

It should be noted that, because a standard degree of smoothing may be applied across all species and spatial scales, large fluctuations could trigger alerts for species showing large year-to-year fluctuations in numbers. For multi- and single species indicators, knowledge of species ecology and population dynamics of the species included in the indicator is essential for correct interpretation. This may be addressed by the use of a biological filter, which is to fine tune the general rule for triggering an Alert in a indicator-specific manner.

7.3 Triggering an Alert

Proportional changes in the smoothed GAM trend of an index over a specified short-term (e.g. 5-year), medium-term (e.g. 10-year) and long-term (e.g. 25-year) time-frames, can be calculated by subtracting the trend value at the start of the time-frame from that in the reference year.

Calculated change values are expressed as a percentage of the index at the start of the period. Larger values therefore indicate larger proportional changes in numbers, with positive values equating to relative increases in the numbers and negative values equating to relative decreases over the specified time period. These values could then categorised according to their magnitude and direction. Declines of between 25% and 50% inclusive could be flagged as Medium Alerts and declines of greater than 50% as High Alerts as used in the UK bird monitoring schemes. The level of Alert will depend on the nature of the index and of the concerns of the interested bodies.

7.4 Biological Alerts Filter

The smoothing used to produce fitted trends goes some way towards preventing alerts being triggered when decreases are due to natural fluctuations in numbers. However, when the degree of smoothing has been standardised across all species, spatial scales and locations it can be expected to achieve better results for some species than others. Rather than sustain the considerable extra processing costs that would be necessary to assess the optimal degree of smoothing for each species / spatial scale / location combination (itself is a process with a degree of subjectivity attached to it), it is recommended that a "biological filter" is applied to reduce the chance of triggering false Alerts.

Thus the aim of the Biological Filter is to attach a cautionary note to alerts being triggered when the observed decline for a given period, although exceeding the medium (-25%) or high (-50%) arithmetic threshold, might be considered well within the range of normal fluctuation for a "healthy population" of the species / indicator in question. For this, it is recommended that each indicator is assigned a Biological Filter Score (BFS) that is used to determine whether a particular class of alert (short-, medium- or long-term and medium- or high-alert) should be so cautioned for that species. The lower the BFS the more restricted will be the suite of Alerts that can be issued without caution. The biological filter would take into account a number of aspects of the population dynamics and behaviour of each species that can be expected to affect the observed level of fluctuation. The information used to assess this would be based on expert opinion and should be kept under review and may be subject to future modification should additional information on population dynamics become available.

8. CONCLUSIONS AND RECOMMENDATIONS

Following a review of the literature and a workshop bringing together international experts and stakeholders, this report identifies a suite of indicators that we believe would provide early warnings of likely climate change impacts on the conservation status of migratory species globally. Indicators can have a far-reaching impact on the policies of conservation, on socio-economic factors and on the species or ecosystems we are trying to conserve. Therefore a careful choice of indicators is needed. As suggested by Rochet & Rice (2005) in the context of ecosystem approach to fisheries management, in order to maintain a scientific basis, advance testing of individual indicator performance should ideally be undertaken before the final suite of indicators is agreed upon by the stakeholders (see also Mace & Baillie 2007).

For a project where the scope is global and potentially considers all migratory wildlife as potentially providing an indicator of climate change, this is an extremely ambitious project. When choosing indicators, there will always be a level of judgement, and the choice of indicators selected may be to some degree a reflection of the knowledge of experts present and certainly driven by our current understanding of climate change impacts. For this reason, it is recommended that peer review is obtained more widely when developing individual indicators, which would in addition add further support from the scientific community and improve global awareness of the project, which would in turn help stimulate monitoring and possibly provide a lever to obtain funding in areas that are currently poorly or not monitored by existing schemes. This process may also identify further gaps that could be filled and would help refine the priorities for further data collection.

Whilst we have endeavoured to select indicators that present the clearest signal of the impacts of climate change on migratory species, it is likely that these indicators will be subject to other strong influences. Species on the CMS appendices were particularly challenging for the development of reliable indicators. Besides the fact that many CMS species do not have good quality long-term time series of data, most are endangered, have small population sizes and are threatened by other strong human pressures, resulting in the lowered sensitivity and specificity of potential indicators. The effects of climate change on species result from the complex interaction between global climate, regional climate, local atmospheric / ocean processes, and other anthropogenic pressures such as fishing, contaminants, habitat loss. In addition, ecological mechanisms influencing the populations, such as density-dependent factors and species interactions, may act in consort with, synergistically with or in opposition to those of the climate. Both the physical, anthropogenic and ecological processes should be considered in conjunction if we are to understand the causal mechanisms that control population dynamics (Stenseth *et al.* 2002, Mori & Butterworth 2006). For any population, the interactions of all these pressures represent one state to which the population needs to adapt. If we are to have any chance of adequately conserving species / populations, then we have to consider all the pressures together. Therefore, and where possible, indicators should be complemented by analyses to identify the contribution of climate change, over and above other influences. It is also important that where there is additional information that provides support for an indicator that this is presented with the indicator. This may include distributional change or phenological indicators which reflect climate change, but where the impact is currently unclear. In addition, remote sensing information provides an extremely powerful resource for putting an indicator in context. This has the potential for improving our understanding of climate change processes and as a tool more generally for explaining what is happening to a wider audience. Summarised in Appendix I, useful remote sensing data as plankton and algal blooms, snow and sea ice extent and spatial extent of green vegetation.

For a small number of the indicators presented here, such as the bird indicator for populations of Trans-Saharan migrants and Polar Bear body condition and survival, it would be relatively straightforward to produce an indicator of the impacts of climate change given the existence of well established standardised monitoring protocols and if obtaining support from the appropriate data providers. In addition, the methods for constructing indicators from such data are already well developed for other purposes. However, most indicators proposed here require additional data collation and, and in many cases, would require data collation and some development of novel methods for producing trends and constructing indicators. In the development of all indicators, it is important to consider how any approach taken would fit more generally into an alerts system, and in relation to objectives from a management perspective.

As the next step, we make the following recommendations:

8.1 Prioritised recommendations for future action

1. It is recommended that agreement for proceeding with the development of indicators of climate change for migratory species is obtained at the next meeting of the Conference of the Parties to CMS.

2. Following agreement, the subset of indicators, which could be produced fairly quickly, classified as '*Time-series available*' in Chapter 4 should be commissioned. This includes the following indicators:

    4.1 Relative abundance of Tans-Saharan migrant birds
    4.5 Polar Bear body condition and cub survival
    4.6 Antarctic Fur Seal pup production

3. For indicators that are classified as '*Empirical observation*' in Chapter 4 and for which some development work, collation of data or addition of further data sources for improving geographical or species coverage need to be undertaken, it is recommended that the appropriate organisations or individuals are consulted to produce a feasibility and costing assessment for the production of each of these indicators (see 'Recommended actions' within the Data requirements section in Chapter 4 and Appendix 3 for further information with respect to each indicator). Depending on the findings of this work, these indicators could then be commissioned. This category includes the following indicators:

    4.2 Relative abundance of Antarctic Penguins
    4.3 Reproductive output of fish-eating seabirds
    4.4 Reproductive output of Arctic shorebirds
    4.7 Southern Right Whale calf production in the Antarctic
    4.11 Skewed sex ratios in sea turtles
    4.12 Caribou / Reindeer calf production and survival

4. For the remaining indicators classified as '*Concept-only*' for which there is good theoretical basis for the indicator, but the data are not currently being collected according to a standardised monitoring protocol, there are perhaps gaps in coverage, and it is likely that significant development work would be needed, a decision needs to be made as to whether it is cost-effective and feasible to develop a reliable and scientifically sound indicator. This decision should be informed by a detailed feasibility and costing assessment, which will include an identification of ongoing data availability and should be carried out by those organisations or individuals best placed to do so as recommended in Chapter 4 and Appendix 3. This category includes the following indicators.

    4.8 Pup survival in ice-breeding Seals
    4.9 Juvenile survival in Salmon
    4.10 Loss of sea turtle nesting habitat through sea level rise
    4.13 Populations of large African herbivorous mammals
    4.14 Population size (and movements) or Wildebeest
    4.15 Population size of Saiga Antelope
    4.16 Abundance of bats at 'underground' hibernation sites in Europe
    4.17 Populations of Straw-coloured Fruit bat in Africa
    4.18 Populations of Mexican Free-tailed Bats

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Appendix 1 Remote sensing supportive information

Earth Observation (EO) satellite sensors are designed to describe physical or biological features of the Earth's land, oceans or atmosphere. The development of satellite Earth observation technology is relatively new. The first non-military satellite observations date from the late 1970s and early 1980s and were provided by the NIMBUS-7 CZCS[1], NOAA–AVHRR[2] and Landsat-MSS[3] sensors. CZCS was designed to observe aerosol and chlorophyll pigment concentration, AVHRR for global meteorological observations and MSS to collect information about land cover. Currently many publicly and privately funded satellites are in operation collecting a wide variety of optical, passive and active microwave data and, more recently, infrared-laser based (i.e. LiDAR[4]) data. However, there are only a handful of EO derived environmental information products being generated and disseminated operationally (i.e. they can be found and acquired via the internet).

To survive and thrive, migratory species rely on sufficient resources being available or accessible at the right time, and in the right place. Depending on the species in question the resource requirements and the type of climate related changes that will jeopardize their survival will be different. Consequently the EO data types which could help monitor the situation will be species-specific.

Table 1 lists the physical and biological features for which, at present, EO data are routinely being collected and products are being derived in an operational or near-operational manner that could potentially be relevant as climate change indicators for migratory species. The features are split into their relevance to monitoring resource availability (timing and quantity) on land or in the oceans. The columns identify the type of EO signal recorded and the direct and indirect measures that can be extracted or calculated from that EO signal.

Land, vegetation leaf phenology

EO derived vegetation indices (VI) (e.g. NDVI[5], EVI[6]) are sensitive to changes in leaf chlorophyll content and leaf intra-cellular structure. Currently the provision of 1km to 8km daily to monthly global coverage of VIs is operational and algorithms exist which enable the derivation of a range of phenological metrics (Zhang *et al.* 2006). Shifts in the timing of the onset of greenness or shortening of the growing season could be potentially useful indicators. VI time series can also be used to locate areas or periods with anomalous phenological behaviour. It is important to remember, however, that time series of VI and measures derived from these may not be suitable for monitoring trends in resources for species that rely on the abundance of plant parts which are not green (e.g. fruit, flowers) or insects. Still in some cases these resources may be strongly correlated with the observed leaf phenological cycle.

Land, open inland water

Migratory species rely on either the presence of a single large water feature or a network of small ones. Open inland water has very distinguishable features in the optical and microwave spectrum (Bartsch *et al.* In press) and is therefore relatively easily detected using both techniques. Global and regional land cover products routinely identify permanent open water features such as lakes, canals and rivers. The main limiting factor is the spatial resolution of a sensor which determines the minimum size/width of a water feature that will be detected. The detection and monitoring of ephemeral lakes and rivers adds a temporal dimension. Depending on the expected dynamics, less or more frequent (e.g. seasonally: Castaneda *et al.* 2005 or daily: Bryant *et al.* 1999) observations will be required. The currently available satellite sensor setups have the potential to monitor water features,

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[1] CZCS: Coastal Zone Color Scanner
[2] AVHRR: Advanced Very High Resolution Radiometer
[3] MSS: Multi Spectral Scanner
[4] LiDAR: Light Detecting And Ranging
[5] NDVI: Normalised Difference Vegetation Index
[6] EVI: Enhance Vegetation Index

and operational global or continental products are being developed (e.g. GLOBWETLAND project: http://www.globwetland.org/).

Altimeters (300m to 2km footprints), although primarily designed for ocean and ice studies, have proven successful in monitoring water surface level in large lakes and inland seas and operational products are available: http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/. These data could be potentially useful to monitor inter- and intra- annual variability in water levels and detection of extreme dry or wet conditions.

Land, wetlands

EO derived land cover has the potential to provide information on the distribution of wetlands and their medium to long term dynamics, however, global wetland identification and monitoring from EO is difficult and therefore poorly developed. Wetlands can be divided into particular forms and types depending on the vegetation present and their physical and chemical characteristics which may, or may not, be convertible into distinct spectral characteristics. In addition, similar wetland types may have different spectral characteristics depending on where there are found on the globe. As a result, the global and continental land cover maps that are currently being produced are unlikely to provide the level of detail and accuracy required to monitor migratory species-specific wetland types, whilst regionally developed land cover products will. Detailed and sophisticated land cover maps produced for different regions, on the other hand, are often difficult to compare.

Algorithms to estimate soil moisture from microwave passive and/or active measurements exist (Wagner *et al.* 1999) and there are operational products available (e.g. from the NASA National Snow and Ice Data Centre: http://science.hq.nasa.gov/research/daac/nsidc_daac.html and from the Vienna University of Technology: http://www.ipf.tuwien.ac.at/radar). These products currently have very coarse spatial resolution (from 5km to 50km) and are less reliable in heavily forested areas. Nevertheless, their daily coverage would enable intra- and inter- annual comparisons and the identification of localised anomalous (very wet or very dry) soil conditions in and around wetlands.

Land, snow and freeze/thaw

The presence or absence of snow determines whether migratory species have access to resources or not. For snow cover, algorithms and operational daily to monthly products exist (from 500m to >1^o spatial resolution) that use either optical spectral reflectance (i.e. Normalised Difference Snow Index) (e.g. Salomonson & Appel 2004) or active microwave measurements (e.g. Weaver *et al.* 2006), for example from the US National Snow and Ice Data Center: http://nsidc.org/data/mod10_l2.html, http://nsidc.org/data/noaa_snow_ps.html and the NOAA satellite information service: http://www.ssd.noaa.gov/PS/SNOW/ .

A related parameter, the timing of freeze/thaw, is detectable from active microwave measures (Bartsch *et al.* 2007). However, there is currently no evidence of an operational product.

Sea, Plankton

In the oceans and sea, plankton and algae blooms are detectable in the optical spectrum due to their chlorophyll absorption feature. One of the first non-military sensors, the CZCS, designed to monitor plankton and algae blooms, produced ocean colour information for the period between 1978 and 1986. To date several similar or related daily to monthly products are available: ocean colour (~4km or 9km spatial resolution) (http://www.globcolour.info/data_access.html and http://oceancolor.gsfc.nasa.gov/), sea surface temperature (from ~5km to 0.25^o spatial resolution) (http://www.neodc.rl.ac.uk/ and http://podaac.jpl.nasa.gov/DATA_PRODUCT/SST/index.html) and modelled monthly ocean NPP which uses, amongst others, ocean chlorophyll and temperature as input data (http://web.science.oregonstate.edu/ocean.productivity/).

Sea, Sea ice, Ice shelf

Sea ice can hinder or assist access to resources. Sea ice is visible in both the optical and microwave spectrum. It is mainly detected and characterised using passive microwave systems although products derived from optical data exist. There are many sea ice related products available, a large number of which are listed on the US National Snow and Ice Data Center url: http://nsidc.org/data/seaice/alpha.html. Products vary from a 'Sea Ice Index' (http://nsidc.org/data/seaice_index/) - a climate change indicator which produces trends and anomalies from monthly measures of ice extent and concentration - to an 'Ice Edge Monitoring Service' (http://polarview.org/services/iem.htm).

Suitability of the EO derived information:

In addition to the 'maturity' of an EO derived product (i.e. the algorithms used are robust, generation is operational and occurs routinely, access by end users is easy and fast) there are other factors which have to be considered when assessing the suitability of a product for its use as a climate change indicator for migratory species. First and foremost there is the available temporal coverage. The reliable determination of future trend changes and anomalous events requires relatively long continuous historical time-series, which is where EO products often fail. Either the historical coverage is too short (e.g. NDSI), or there is an interruption (e.g. Ocean Chlorophyll) or there is not always a guarantee that future acquisitions will continue. It is also important to establish whether the temporal and spatial resolution and the level of accuracy provided match the species specific information needs. Finally, there will be very few occasions (e.g. Sea Ice Index) where no additional processing is required to transform the EO derived products into useable climate change indicators.

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Physical and biological features and associated EO products which could be relevant for use as climate change indicators for migratory species

	Physical or biological feature observed by EO	EO signal	Measure directly derived from EO (value, thematic data)	Measure indirectly derived
Land	Vegetation (grasslands, shrub/woodland, forests)	• Reflectance in optical spectrum	Time series of vegetation indices (e.g. NDVI[7], EVI[8])	Leaf phenology metrics; intra- and inter- annual dynamics; anomalies (timing, below or above average values); NPP[9]; spatial extent and location of green vegetation.
	Open inland water (permanent, ephemeral)	• Reflectance in optical spectrum • Active microwave signal	Land cover	Surface water extent; medium to long term dynamics of extent; intra- and inter- annual dynamics of ephemeral waters; timing of water availability.
		• Active microwave signal	Lake surface water height	Intra- and inter- annual dynamics; anomalies
	Wetlands (fully or partly vegetated)	• Reflectance in optical spectrum	Land cover	Wetland types; medium to long term dynamics.
		• Active microwave signal • Emission from thermal spectrum	Soil moisture	Intra- and inter- annual dynamics; anomalies (timing, below or above average values).
	Snow	• Reflectance in optical spectrum	NDSI[10]	Extent
		• Active microwave signal	Extent, timing of freeze/thaw	

[7] NDVI: Normalised Difference Vegetation Index
[8] EVI: Enhance Vegetation Index
[9] NPP: Net Primary Productivity
[10] NDSI: Normalised Difference Snow Index

Physical and biological features and associated EO products which could be relevant for use as climate change indicators for migratory species

	Physical or biological feature observed by EO	EO signal	Measure directly derived from EO (value, thematic data)	Measure indirectly derived
Sea	Plankton	• Reflectance in optical spectrum	Sea colour	Extent and locations of blooms; intra- and inter- annual dynamics.
		• Emission from thermal spectrum	Sea surface temperature	Ocean NPP (from Sea colour and Sea surface temperature)
	Sea ice, Ice shelf	• Active microwave signal	Extent and location	Timing of melting and breaking up; intra- and inter- annual dynamics.

Appendix 2 Key processes likely to be affected by climate change according to the literature summarised by taxonomic group

SPECIES GROUPS	EXAMPLES	KEY PROCESSES	RESULT OF PROCESS
PLANKTON	Zooplankton / Phytoplankton	Changes in water temperature, salinity and climate patterns (El Niño / North Atlantic Oscillation); changes in growth, recruitment and transport.	Temporal and spatial changes in distribution, abundance and composition - impact on food chain
CRUSTACEANS	Krill	Changes in water temperature, ocean circulation, sea-ice dynamics; variation in recruitment	Temporal and spatial changes in distribution, and abundance; changes in availability to predators- impact on food chain (e.g. Antarctic Seals)
CEPHALOPODS	Veined/Short-fin Squids	Changes in prey availability Changes in water temperature, salinity, pH and CO_2	Temporal and spatial changes in distribution, and abundance; changes in availability to predators– impact on food chain (e.g. marine mammals)
FISH	Cod / Herring Salmon	Change in water temperature, and sea-ice dynamics, changes to prey availability Changes in river flow and temperature impacting on juvenile survival	Temporal and spatial changes in distribution, and abundance; changes in availability to predators (e.g. marine mammals) Impact on food chain (e.g. marine mammals)
SEA TURTLES	Green Turtle	Rise in sea level Temperature increase Increase in storm frequency and wave conditions Disease	Loss of egg-laying beaches Sex determination – long-term importance uncertain, impact on hatchling survival, increased occurrence on 'southern' species Impact on hatchling survival Increased incidence of disease

SPECIES GROUPS	EXAMPLES	KEY PROCESSES	RESULT OF PROCESS
MAMMALS			
Cetaceans	Right whales Cool water coastal dolphins	Changes in water temperature, sea-ice dynamics, changes in prey availability, impacts on reproductive success Loss of shallow coastal habitats	Decreased calf production – population declines Distribution changes, range contraction
Pinnipeds	Ice-breeding seals Eared seals	Ice retreat, loss of breeding habitat Changes in water temperature, changes in prey availability	Decreased pup survival – population declines
Other marine mammals	Polar Bear	Changes in sea-ice dynamics, prey availability	Reduced body condition and cub survival – population declines
Terrestrial mammals	Caribou Wildebeest African hoofed mammals Saiga antelope	Ice retreat Temperature increase Changes in rainfall patterns, drought Prey availability Mismatch between forage and calving times	Range shift not possible Decrease in survival and pregnancy rates Influence on seasonal plant growth and migration route / extent / destinations, conflicts between movements and land-use patterns Mass mortalities
Bats	Cave dwelling bats European bats Caribbean endemics	Temperature increase Changes in prey availability Increased storm frequency	Range shift not possible Earlier emergence from hibernacula Changes in distribution and abundance Likely to affect fruit and flower feeding bats

SPECIES GROUPS	EXAMPLES	KEY PROCESSES	RESULT OF PROCESS
BIRDS			
Shore and waterbirds	Redshank, Spoon-billed Sandpiper Baikal Teal Ringed Plover	Rise in sea level Habitat loss Changes in rainfall Temperature increase	Loss of stop-over and wintering sites Loss of tundra – range shift not possible Loss of wetland habitat Shift in wintering location
Seabirds	Sooty Shearwater, Antarctic species	Changes in prey availability	Decline in survival and productivity (ultimately abundance)
Long-distance Migrants	Pied Flycatcher Blackcap, Chiffchaff Sedge Warbler Aquatic Warbler	Temperature increase Reduced precipitation Increased storms	Mismatch between arrival and food availability Increased productivity (positive effect) Earlier breeding Change in distribution (northwards shift) / over-wintering of migrants Loss of stop-over or wintering wetland sites (reduced survival and/or productivity) Increased incidence of disease Influence on ability to complete journeys Reduced breeding success
Montane species (Incl. Cloud Forest / Temperate regions)	Dotterel	Temperature increase	Altitudinal range shift – range shift not possible for some species
AMPHIBIANS	Monteverde Harlequin Frog Anurans (Central America)	Temperature increase Change in climate patterns	Promotion of infectious disease Earlier breeding El Niño implicated in decline of Anurans

Appendix 3 Recommended protocols for data collation and collection

The following recommendations are guided by the literature, in many cases direct contact with experts in the field and/or directed by websites of expert groups. For more precise information on data collection, collation and analytical methods, it is recommended that the relevant expert groups carry out a detailed costing and feasibility assessment.

Relative abundance of Trans-Saharan migrant birds (see section 4.1 of main report)

(a) Introduction

A robust indicator of the impact of climate change for Trans-Saharan migrant birds could be produced with relative ease. Methods used are harmonised, proven and statistically robust. Data would come from 20 European countries and this number is set to rise. The production of this indicator would be timely, relevant, capable of annual update in the future, and suitable for development to meet policy needs. It has all the qualities of an effective headline indicator.

The Trans-Saharan migrants indicator proposed here would come from the Pan-European Common Bird Monitoring scheme (PECBMS), developed through a consortium of individuals and organisations from many European countries, cooperating through the European Bird Census Council (EBCC) to measure mean population change in breeding Trans-Saharan migrant bird populations. The overall project goal of PECBMS is to explore the use of bird population trends as indicators of biodiversity in Europe and to develop indices capable of measuring the 2010 targets (Gregory *et al*. 2005). For this project, a similar indicator could be developed for the subset of Trans-Saharan migrant species.

(b) Methods: sample design and data

PECBMS currently collates single-species trends in relative abundance in 20 European Countries (Ireland, UK, Netherlands, Denmark, Sweden, Norway, Finland, Estonia, Latvia, Poland, Czech Republic, Hungary, Austria, Germany, Switzerland, Belgium, France, Spain, Portugal, Italy)**.** The number of European countries with annual breeding bird surveys based on nationwide samples is currently 20 (Ireland, UK, Netherlands, Denmark, Sweden, Norway, Finland, Estonia, Latvia, Poland, Czech Republic, Hungary, Austria, Germany, Switzerland, Belgium, France, Spain, Portugal, Italy). The data are collected using a variety of field methods (spot / territory mapping method, line or point transects, each with between 1 and 12 visits to each site per year; (see Bibby *et al.* 2000, Gregory *et al.* 2005). These sample surveys record all bird species encountered, but by their very nature, they are unlikely to cover very rare species and so the trends represent the commoner and more widespread birds in the environment.

(c) Methods: data analysis

An index would be produced for each species by combining national results for that species. Difficulties, such as gaps in data, both at site and country level, would be taken into account using a standard indexing programme. The individual European species indices would be combined (averaged) to create multi-species supranational indicators. For more details on this approach see Gregory *et al.* (2005).

(d) Practicality of applying data collection protocols in developing countries

Trans-Saharan migrants breed in Europe, the Middle East and into parts of Asia. Monitoring is already well established in many European countries, with some gaps in coverage in parts of south and east Europe. However, it is expected that the number of European countries contributing data and number of sites monitored within countries will increase over time, through the efforts of the EBCC and the PECBMS project which will improve spatial and likely species coverage. Providing support to EBCC in the longer term to improve volunteer infrastructure in countries where there is current little or no coordinated monitoring of breeding bird populations would facilitate this process.

(e) Recommended actions and costing
It would be necessary to get support for this indicator from the EBCC council and its data providers across Europe. The cost of producing this indicator for countries where data is already collected and collation would need to be determined through the EBCC, although because the logistics are already in place over much of Europe, set up costs covering these countries is expected to be in a lower costing band of less than £50,000. In addition it is recommended that the EBCC carry out a feasibility and costing study is evaluate the cost of introducing national monitoring schemes for breeding birds in countries where there is currently no coordinated scheme.

(f) References

Bibby, C.J., Burgess, N.D., Hill, D.A., Mustoe, S. 2000. Birds census techniques. 2nd edn. Academic Press; London: 2000.

Gregory, R.D., van Strien, A., Vorisek, P., Gmelig Meyling, A.W., Noble, D.G., Foppen, R.P.B., Gibbons, D.W. 2005. Developing indicators for European birds. *Philosophical Transactions of the Royal Society, B.* **360**, 269-288.

Populations of Antarctic Penguins (see section 4.2 of main report)

(a) Introduction
A useful and robust indicator could be produced relatively easily for four Antarctic Penguin species, the Adélie, Chinstrap, Gentoo and Macaroni Penguins for which a standardised monitoring programme is already in place. The production of this indicator would be relevant, capable of annual update in the future and suitable for development to meet further policy and management needs. It has all the qualities of an effective, popular and effective headline indicator.

The proposed indicator of breeding population of Antarctic penguins would be coordinated and produced by CCAMLR Ecosystem Monitoring and Management Group EMM, which was initiated in 1984 (then named CCAMLR Ecosystem Monitoring Programme CEMP). This programme was established in response to the development of a krill fishery in the Southern Ocean, the objectives of this group are to detect and record significant changes in critical components of the ecosystem to serve as a basis for the conservation of Antarctic marine living resources, and to distinguish between changes due to the harvesting of commercial species and change due to environmental variability, both physical and biological.

This group is responsible for the design and coordination of the monitoring program and the analysis and interpretation of the data arising from it. The program’s largest component is the monitoring of dependent species (predators), but in order to distinguish between changes due to harvesting, and those due to environmental variability, the program also monitors harvested species, harvesting strategies and environmental parameters.

The program does not monitor all Penguin species within the Antarctic ecosystem, but concentrates on four species (Adélie, Chinstrap, Gentoo and Macaroni penguin), which are likely to respond to changes in the availability of harvested species, and believed in relation to this project, to be good indicators of climate changes impacts. These penguin species are specialist predators, have a wide geographical distribution and are important ecosystem components.

(b) Methods: sample design and data
Two sets of sites are monitored through the program: a core set of sites within three defined Integrated Study Regions (ISRs – regions for the intensive study of predators, prey and environmental interactions), and a network of additional sites which complement the research within these regions. Within the ISRs sites there may be areas adjacent to harvesting areas or isolated from them, contributing to a controlled experimental design.

Sites Integrated regions / sites	Penguin species
1. ANTARCTIC PENINSULA REGION	
Anvers Island (Palmer Archipelago, South Coast)	Adélie
Livingston Island (S. Shetland Is., North Coast)	Chinstrap & Gentoo
King George Is. (S. Shetland Is., North & South Coasts)	Adélie, Chinstrap & Gentoo
Elephant Island (S. Shetland Is., West Coast)	Chinstrap, Gentoo & Macaroni
Seal Island (S. Shetland Is.)	Chinstrap & Macaroni
2. SOUTH GEORGIA REGION	
Bird Island	Macaroni & Gentoo
3. PRYDZ BAY REGION	
Mac. Robertson Land	Adélie
Network sites	
Northwestern Ross Sea (Cape Hallett & Cape Adare)	Adélie
Budd Coast	Adélie
Edmonson Point	Adélie
Ross Island	Adélie
Ongul Islands (near Syowa Station)	Adélie
Shepard Island	Adélie
Signy Island, South Orkney Islands	Adélie, Chinstrap, Gentoo
Laurie Island, South Orkney Islands	Adélie
Marion Island	Chinstrap, Gentoo, Macaroni
South Sandwich Islands	Chinstrap
Bouvet Island	Chinstrap, Macaroni
Kerguelen Island	Macaroni

Table S1. Sites within the Integrated Study Regions and additional network sites at which standardised monitoring of Breeding Population Size of Penguins has been initiated.

Several parameters are monitored for each penguin species, of which it is proposed that breeding population size should form the basis of the indicator here. It should be noted however that long-lived penguin populations might be relatively insensitive to changes in abundance (Reid *et al*. 2005). Therefore, an alternative measure should not be discounted if this is believed to be more appropriate for the purposes of this indicator. An example might be mass of offspring just before independence, which is likely to be suitable proxy for the parents' foraging success.

Standard methods for collecting information on breeding population size for penguins are well documented in a *Standard Methods* document (BIOMASS 1982, CCAMLR 2004). In short three visits are made to each colony to ground count nests in entire colonies. For each visit, the total number of occupied nests and total number of incubated nests are counted and date recorded. The same colonies are counted annually.

Fieldwork and data acquisition for the program are carried out voluntarily by CCAMLR Member States. The data is submitted to the CCAMLR Secretariat, which carries out specified standard analyses. The secretariat also collects and archives data used by the program which are acquired from other national and international environmental monitoring programs, for example, satellite-derived sea-ice and sea-surface temperature data. At present eight member Members are currently involved in acquiring data. Most data series start in the mid-1980s when CEMP was initiated.

(c) Methods: data analysis

The number of occupied nests and number of nests incubating eggs as the means of the three independent visit counts are determined. The means of the number of occupied and the number incubating nests for several colonies combined can produce a yearly index of breeding population size for each species. These analyses are already carried out on an annual basis by the CCAMLR EMM. These indices could in turn be combined to produce a multi-species indicator, following the methods of Gregory *et al.* (2005).

(d) Practicality of applying data collection protocols in developing countries

Largely because of the remoteness of Antarctic penguin colonies, it is necessary that fieldwork be carried out by professional fieldworks with specialist experience and equipment. As such, any expansion of spatial coverage is likely to prohibitively expensive, and is not seen as a viable option and one that is necessary for the purposes of this project.

(e) Recommended actions and costings

It would be essential to get support for this indicator from the CCAMLR EMM Working Group. The data is already collected according to standard methods (CCAMLR 2004) and collated by CCAMLR. Because the logistics for producing this indicator are largely already in place, the cost of producing this indicator is likely to be in a lower costing bands of less than £50,000. However, it is recommended that the EMM Working Group and other specialist organisations (e.g. British Antarctic Survey and the Scientific Committee on Antarctic Research (SCAR) are consulted in the first instance to assess feasibility and to produce a costing assessment for producing this multi-species indicator.

(f) References

BIOMASS 1982. *Penguin census methods*. BIOMASS Handbook, 20.

CCAMLR 2004. CCAMLR Ecosystem Monitoring Program: Standard Methods. CCAMLR, Tasmania, Australia.

Gregory, R.D., van Strien, A., Vorisek, P., Gmelig Meyling, A.W., Noble, D.G., Foppen, R.P.B., Gibbons, D.W. 2005. Developing indicators for European birds. *Philosophical Transactions of the Royal Society, B.* **360**, 269-288.

Reproductive output of Fish-eating Seabirds (see section 4.3 of main report)

(a) Introduction

There is the potential for producing a robust indicator of the impact of climate change impacts on the reproductive output of fish-eating seabird populations. This indicator would focus on the OSPAR region, covering the North-East Atlantic Arctic and North Seas (see Fig. S1), where the relationship between climate change and seabird reproductive output is perhaps best understood. Data collation would be achieved through an extension to current plans proposed within the OSPAR EcoQO (Ecological Quality Objective) framework, which is currently looking to use seabird population trends as an indicator of seabird community health. Whilst some development work would be needed, the logistics and interest in producing an indicator based on reproductive output are largely in place.

(b) Methods: sample design and data

Coordinators of the OSPAR EcoQO framework are in the best position to collate and produce an indicator of reproductive output for seabirds, using the same network of data providers as currently planned for producing indicators of change in seabird numbers. Data on reproductive output is already collected throughout much of the OSPAR area according to methods recommended in the Walsh *et al.* (1995) *Seabird Monitoring Handbook* and Gilbert *et al.* (1998) *Bird Monitoring Methods*. These recommendations for monitoring are species-specific, but ideally involve a minimum of three visits to each colony and to make repeat visits to individually recognisable nests. In very large colonies a sub-sample of 100 nests may be selected and monitored recording the number of eggs and chicks present in each nest. A scheme for collating these data on an annual basis would be needed.

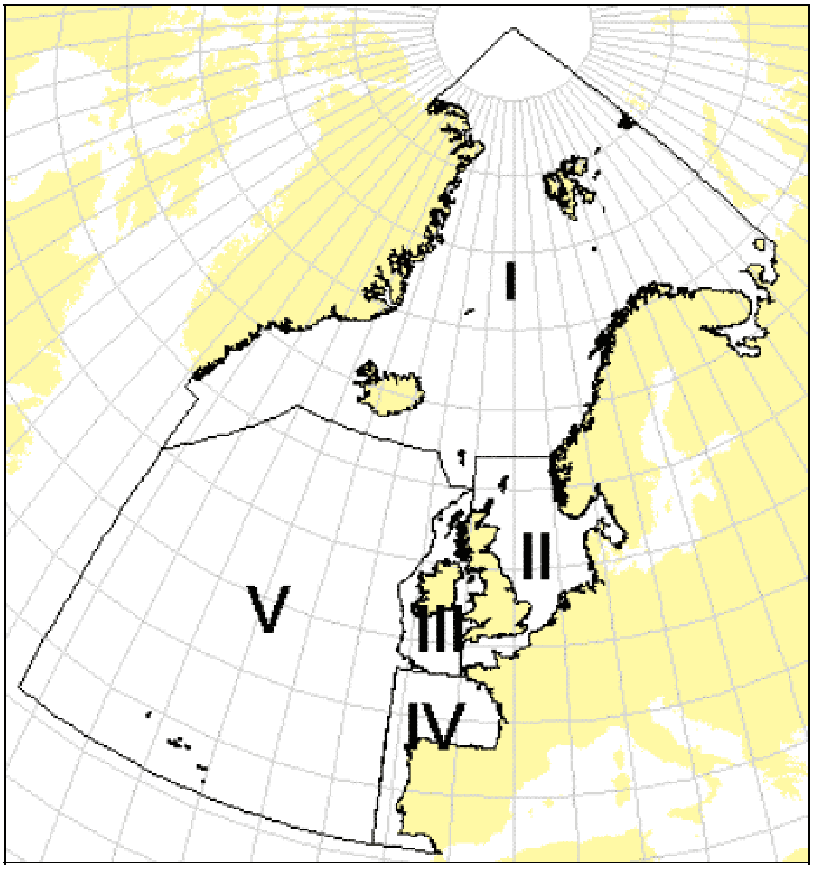

Figure S1. The OSPAR area and subdivisions into five regions (map from http://www.ospar.org/eng/html/)

(c) Methods: data analysis

Two main options exist for obtaining an estimate of reproductive output at fledging and depend on the number of visits that can be made to a colony and effectively the quality of the data that can be obtained. The least preferred option would be to make a single visit to a colony to obtain a figure of mean brood size prior to fledging, which would include nests with young with varying age. With this, it is not possible to correct for partial and complete losses before and after the observation is made. If the relative timing of visits differs between colonies, estimates of reproductive output may not be directly comparable between colonies or years. Multiple visits to a colony where the fate of individually recognisable nests are monitored is preferred and allows for estimates of reproductive success to include unsuccessful nesting attempts and the losses of single chicks before fledging to be taken into account. Unless monitoring is carried out continually throughout development a level of error is unavoidable. However, a modification of an analytical method known as the Mayfield method can be used to improve the reliability of estimates without the need for increased monitoring effort and produce estimates that are comparable across colonies and years. See Newson & Bregnballe (2003) for further discussion of these approaches.

(d) Practicality of applying data collection protocols in developing countries

It is recommended that this indicator should in the first instance be restricted to the North-East Atlantic, Arctic and North Seas where our understanding of climate change impacts is perhaps best understood and the logistics for collating monitoring data are largely in place.

(e) Recommended actions and costings

It is recommended that coordinators of the OSPAR EcoQO framework be consulted to produce a detailed costing and feasibility assessment in the first instance, in collaboration with other expert groups such as the Conservation of Arctic Flora and Fauna (CAFF) Seabird Expert Group (CBIRD – circumpolar seabird group), which is involved in a number of research projects, including monitoring population effects from climate change on seabirds in the Arctic. At present this indicator focuses on the North Atlantic, Arctic and North Seas, where the relationship between climate change and seabird reproductive output is arguably best understood. However, it is considered that climate change is likely to impact seabird populations outside this area. For this reason, it is recommended that the geographical scope of this indicator be reviewed over time and expansion considered. Because the logistics are already largely in place, it is expected that set up costs for producing such an indicator for a limited suite of species for the OSPAR region would be in a medium costing band of £50,000-100,000.

(f) References

Gilbert, G. Gibbons, D.W. & Evans, J. 1998. *Bird Monitoring Methods: a manual of techniques for key UK species*. RSPB.

Newson, S.E. & Bregnballe, T. 2003. Estimating reproductive success of Great Cormorants *Phalacrocorax carbo*: reliability and limitations of current methodology. *Vogelwelt* **124**, 143-148.

Walsh, P.M., Halley, D.J., Harris, M.P., del Nevo, A., Sim, I.M.W. & Tasker, M.L. 1995. *Seabird Monitoring Handbook for Britain and Ireland*. Joint Nature Conservation Committee, Peterborough.

Reproductive output of Arctic shorebirds (see section 4.4 of main report)

(a) Introduction

There is the potential for producing a robust indicator of climate change impacts on the reproductive output of Arctic shorebirds. This indicator would take advantage of the behaviour of wintering shorebirds which breed at low densities across the Arctic, but winter in large numbers at relatively few wintering sites. Mist-netting and the development of cannon-netting techniques employed at high tides roosts have allowed large samples of wintering shorebirds to be captured and ringed since the 1970s. Immature shorebirds of many species can be identified accurately throughout the winter period, making it possible to assess annual variability in productivity through estimation of juvenile: adult ratios in flocks. In Britain the proportion of juveniles in cannon net catches has been recorded since 1990, and many other countries where wader studies are being carried out are doing likewise. Whilst some development work would be needed, data collection and interest in producing an indicator based on reproductive output are in place.

(b) Methods: sample design and data

The British Trust for Ornithology is in the best position for collating and producing an indicator of reproductive output for shorebirds. Information on juvenile / adults ratios are already collected at most major wintering sites across the northern hemisphere, where mist- or cannon-netting is carried out, although agreement from data providers for use of the data for this purpose and a mechanism for data collation on an annual basis is needed.

(c) Methods: data analysis

The approach for producing this indicator would follow the recommendations of Clark *et al*. (2004). In short this approach considers each bird as an individual sample, where an estimate of the proportion of juveniles in any one group is simply the total number of juveniles present divided by the total number of birds aged. Error estimates can be calculated from: Variance = p_{juv} * (1-p_{juv}) / N-1), where N is the total number of birds and pjuv the proportion of juveniles. Standard errors are simply the square root of this and (approximate) 95% confidence intervals are 1.96 x the standard error. However, this approach suffers three potential problems: 1) no account can be taken of factors influencing individual catches; 2) birds are known to flock together in an age-specific fashion, this will introduce extra heterogeneity into the data, meaning that confidence intervals will be underestimated and 3) calculation of the errors can lead to confidence limits for the proportion of juveniles which are negative, or greater than one, which is clearly nonsensical. To overcome such difficulties, linear modelling is recommended (McCullagh & Nelder 1989). This technique allows most of the assumptions (such as complete random distribution of individuals) made by the simple statistics to be relaxed, thus providing more efficient way of analysing the data, and giving more reliable results.

(d) Practicality of applying data collection protocols in developing countries
A large proportion of Arctic breeding shorebirds winter in developed countries. Although mist-netting and cannon-netting techniques to assess adult / immature ratios are not used in all these countries, individuals wintering at single sites are likely to have originated from across a large geographic breeding area. Mist-netting and to greater degree cannon-netting are highly skilled techniques, which is not readily transferable to other countries, although volunteer or professional expeditions to these countries could be used to improve geographical coverage where this is believed to be important.

(e) Recommended actions and costings
It is recommended that the British Trust for Ornithology carry out a detailed costing and feasibility assessment for producing this indicator. This should examine the likely geographical coverage of breeding areas through winter mist-netting and cannon-netting and where important, recommendations for improving geographical coverage made. Data gathering is already in place, but logistics for collating these data and for producing the indicator are needed. It is expected that set up costs for producing such an indicator would be in a medium costing band of £50,000-100,000.

(f) References

Clark, J.A., Robinson, R.A. Clark, N.A. & Atkinson, P.W. 2004. Using the proportion of juvenile waders in catches to measure recruitment. *Wader Study Group Bulletin* **104**, 51-55.

McCullagh, P. & Nelder, J.A. 1989. *Generalized Linear Models.* 2nd Ed. Chapman & Hall.

Polar Bear body condition and survival (see section 4.5 of main report)

(a) Introduction
A robust indicator for Polar Bear populations could be produced with relative ease. Methods used are harmonised, proven and statistically robust. Data would come from two of the nineteen known Polar Bear subpopulations, which are well studied and the impacts of climate change best understood (Stirling *et al.* 1999, Rode *et al.* 2007). The production of this indicator would be timely, relevant, capable of annual update in the future, and suitable to trigger policy decisions. It has all the qualities of an effective headline indicator. The Polar Bear Population Project (www.polarbearsinternational.org/pbi-supported-research/population-project) would be the appropriate framework through which to collate these data and produce the indicator. This project has been monitoring polar bear populations through a consortium of individuals and organisations such as the Canadian Federal Government (Environment Canada) and the US Geological Survey in the USA, but several universities also collect data that could feed into this indicator, following agreement with the relevant parties. This project is funded by a series of corporate and individual sponsors.

(b) Methods: sample design and data
The Polar Bear Project has built on previous time-series of the two parameters of interest from subpopulations of Polar Bear in Western Hudson Bay (WHB) and the Southern Beaufort Seas (SBS), which would form the basis of this indicator – a body condition index (BCI; mass/length^2), which standardises body mass for bear length and as supportive information cub survival (number survived in autumn / total number produced in spring). To calculate a BCI it is necessary to capture individuals during two capture periods (March - May and October - November). Polar bears are located by helicopter and adults and sub-adults immobilised by injecting Telazol®. Straight line body length

(length) is measured as the straight line body distance from the tip of the nose to either the end of the last tail vertebrae using a measuring tape extended above the bear in ventral (sternal) recumbancy. Bears are weighed to the nearest kg using a spring or dynamometer scale (Rode *et al*. 2007). Relevant data on the sea-ice dynamics, which would help in interpretation, are also recorded.

(c) Methods: data analysis

An index would be produced as the mean BCI for each year across subpopulations. The index of cub survival and information on sea-ice dynamics would support this indicator.

(d) Practicality of applying data collection protocols in developing countries

This indicator focuses on two well-studied subpopulations for which climate change impacts are best understood. Expanding this indicator to include other subpopulations may be possible, although this would require considerable financial input and would need to be carried out by professionals in this field. However, this would reduce the robustness of the indicator since there are no long-term time series for the other subpopulations.

(e) Recommended actions and costings

The Canadian Federal Government (Environment Canada), he US Geological Survey in the USA and Alberta University through the Polar Bear Population Project are in the best position to collate and produce an indicator for Polar Bear populations. It is recommended that relevant parties are consulted to produce a detailed costing assessment in the first instance. Because the logistics for data collection and collation are already in place, it is expected that set up costs for producing this indicator covering the two subpopulations above would be in a lower costing band of <£50,000.

(f) References

Rode, K.D., Amstrup, S.C. & Regehr. E.V. 2007 Polar bears in the Southern Beaufort Sea III: Stature, mass, and cub recruitment in relationship to time and sea ice extent between 1982 and 2006. U.S. Geological Survey Report to U.S. Fish and Wildlife Service. Anchorage, Alaska. 28 pp.

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**, 294–306.

Antarctic Fur Seal pup production (see section 4.6 of main report)

(a) Introduction

A robust indicator of the impact of climate change on pup production of Antarctic Fur Seals could be produced relatively easily for a large population of this species based on the animals occurring on Bird Island, South Georgia for which the impacts of climate change are perhaps best understood). The production of this indicator would be timely, relevant, and suitable to trigger policy decisions. It has all the qualities of an effective headline indicator.

(b) Methods: sample design and data

Data collection is carried out on Bird Island by the British Antarctic Survey. Pup production data has been collected with consistent methods since 1984 on a designated study beach. Fieldwork is carried out during austral summers, from the onset of the breeding season in mid-November until the end of the pupping period in early January. Twice-daily beach surveys are conducted each breeding season, recording and temporarily marking each newborn pup (see Forcada *et al* 2005).

(c) Methods: data analyses

An index would be produced using the maximum pup counts each year and relating these to the South Georgia SST anomaly index and to an index of krill biomass and availability (BAS in collaboration with the Scientific Committee on Antarctic Research, SCAR).

(d) Practicality of applying data collection protocols in developing countries
This indicator focuses on the best-studied and well-understood subpopulation of fur seals, with the potential to improve geographic coverage to include at least three additional populations in South Georgia or other areas of the Antarctic Peninsula. Expanding this indicator to include other subpopulations or other species of eared seals may be possible but would probably require considerable resources.

(e) Recommended actions and costings
It would be essential to get support for this indicator from BAS). The data is already collected according to standard methods and collated by BAS. Because the logistics for producing this indicator are largely already in place, the cost of producing this indicator is likely to be in a lower costing band of less than £50,000. However, it is recommended that BAS and other specialist organisations (e.g. SCAR) be consulted in the first instance to assess feasibility and to produce a costing assessment for producing this indicator and further work to assess the representativeness of the subpopulation at Bird Island.

(f) References
Forcada, J., Trathan, P., Reid, K. & Murray, E. 2005. The effects of global climate variability in pup production of Antarctic fur seals, *Ecology*, **86**, 2408-2417.

Southern Right Whale calf production in the Antarctic (see section 4.7 of main report)

(a) Introduction
A robust indicator could be produced for Southern Right Whale calf production in the SW Atlantic for which a standardised monitoring programme is already in place. There is also the potential for increasing geographical coverage. This indicator would be relevant, and suitable to trigger policy decisions. It has all the qualities of a popular and effective headline indicator.

(b) Methods: sample design and data
The Ocean Alliance & Whale Conservation Institute (www.oceanalliance.org/wci/wci_rightwhale.html) is a non-governmental organisation that has carried out extensive fieldwork involving photo-identification techniques to identify and catalogue individuals and record annual calf output for over 30 years in one of the most important nursery grounds for this species in the bays of Peninsula Valdés, Argentina (Cooke *et al*. 2003). This was carried out with the help of an automated database comparison (Hiby and Lovell 2001). Some long-term data has also been carried out for populations of this species in other parts of the world, but the methods used have not been standardised internationally.

(c) Methods: data analysis
An index of calving output, which is a measure of deviation from the expected winter calving output has been developed for Southern Right Whales in the SW Atlantic by Cooke *et al*. 2003 and could be used for the purposes of this indicator.

(d) Practicality of applying data collection protocols in developing countries
Some long-term datasets on right whale calf output exist and there is ongoing monitoring by both governmental and voluntary organisations in several parts of the world (e.g. Argentina, Australia, South Africa, Brazil). However, most monitoring is carried by NGOs and funding is not secured. The data has also not been gathered through a standardised international data gathering protocol. If a global indicator is considered useful and feasible, then, based on the SW Atlantic experience, a protocol could be agreed between the different organisations to collate data across much of the range of this species. The feasibility and cost of doing so would need to be determined. A study into how representative the SW Atlantic population indicator would be of the other southern right whale populations could also be carried out.

(e) Recommended actions and costings
The Ocean Alliance & Whale Conservation Institute should be consulted in the first instance. Expert groups, both governmental and NGOs, monitoring other populations in Brazil, South Africa and Australia could also be contacted. These organisations could then examine how appropriate, feasible and cost-effective would the development of a global indicator of calf output for this species be. The logistics of this indicator are only partly in place (for the SW Atlantic) and as such, it is expected that set up costs for producing such an indicator would be in the medium to high costing band £50,000->£100,000.

(f) References
Cooke, J., Rowntree, V. & Payne, R. 2003. Analysis of inter-annual variation in reproductive success of South Atlantic right whales (*Eubalaena australis*) from photo-identifications of calving females observed off Península Valdés, Argentina, during 1971–2000. Unpublished paper SC/55/O23 presented to IWC Scientific Committee, Berlin, June 2003.

Hiby, L. and Lovell, P. 2001. A note on an automated system for matching the callosity patterns on aerial photographs of southern right whales. *Journal of Cetacean Research Management* (Special Issue 2):

Pup survival in Ice-Breeding Seals (see section 4.8 of main report)

(a) Introduction
There is the potential to develop an indicator of pup survival of ice-breeding seals covering three discrete populations, although considerable effort in data collation and analysis would be required in the development of this indicator. In the Beaufort Sea, ringed seals pup survival is monitored by US and Canadian governments in collaboration with Inuit communities and NGOs (www.beaufortseals.com), and in the Baltic, by the Swedish Natural History Museum. In the Caspian, this is carried out by the Caspian Seal Project (www.caspianseal.org), a conservation initiative from the five Caspian countries and advisors from other countries. Funding for this monitoring seems secured at least in the short-term for all three regions.

(b) Methods: sampling design and data
In the Beaufort Sea, monitoring of pup survival is carried out in collaboration with the harvesting Inuit communities and survivorship is based on the birth year of all seals from aged teeth (Ferguson *et al.* 2005). In the Baltic and Caspian, annual aerial surveys take place. A small aeroplane is flown on evenly-spaced transects over the ice at constant height and speed (Härkönen and Heide-Jörgensen, 1990). All seals within 400m strips are counted both visually and from photographs. However, in the Baltic, seals are counted during moulting (since in the breeding season these are under the ice/snow cover) and hence pup survival is not estimated. In the Caspian sea seals rarely use snow lairs and so pups are visible on the ice, where they are counted. Coordination would be needed to assess the feasibility of bringing these data sets together and produce the indicator. The organisation that would be best placed to produce this indicator would need to be decided upon, through consultation with the above organisations. A more feasible alternative would be to use indices of breeding habitat availability such as the duration and extent of ice cover, which could easily be obtained from satellite images.

(c) Methods: data analysis
It is not clear how a combined index of pup survival would be possible since the methods used in the three regions are different. This idea would have to be explored further by the relevant parties.

(d) Practicality of applying data collection protocols in developing countries

The Caspian seal project is a good example of applying data collection methods in developing countries.

(e) Recommended actions and costings

It is recommended that relevant parties be consulted to produce a detailed costing and feasibility assessment in the first instance. The logistics for collating data across geographic areas and for producing this indicator would need to be determined before this indicator could be produced. For this reason, it is expected that the costs for producing this indicator would be in a medium to high costing band £50,000 **-** >£100,000.

(f) References

Ferguson, S.H., Stirling, I. & Cloughlin, P.M. 2005. Climate change and ringed seal *(Phoca hispida)* recruitment in western Hudson Bay. *Marine Mammal Science*, **21**, 121-135.

Härkönen, T. & Heide-Jørgensen, M.P. 1990. Density and distribution of the ringed seal in the Bothnian Bay. *Holarctic Ecology* **13**, 122–129.

Juvenile survival in Salmon (see section 4.9 of main report)

(a) Introduction

An indicator, using juvenile salmon survival could be produced to reflect the impacts of climate change on freshwater habitats. The production of this indicator would be timely, relevant, and suitable to trigger policy decisions. For the Salmon River basin, there are detailed juvenile survival data for 18 populations of Chinook salmon over 11 years and corresponding climatological data. These data are owned by the US National Marine Fisheries Service. Mark-recapture studies using tags to estimate juvenile survival are common in several areas, particularly in order to assess the impact of dams on salmon survival.

(b) Methods: sampling design and data

Methods are described and references given in Crozier & Zabel (2006). Juvenile (parr to smolt) survival estimates are based on data gathered from fish individually tagged in July or August of their first year with PIT tags. When the fish migrate the following spring (April–June), the tags are automatically detected downstream in the juvenile fish bypass systems at hydroelectric dams along the rivers. Using the multiple detection sites to calculate detection rates, survival can be estimated to the first dam the fish encounter. Density data is also collected so that density dependent effects can be taken into consideration.

(c) Methods: data analysis

Methods are described and references given in Crozier & Zabel (2006). Survival is estimated using a capture–recapture program. Separate indices for different population clusters might need to be produced reflecting the fact that climate change will likely have different impacts on different populations. Recognizing this diversity is important for accurately assessing risks (Crozier & Zabel 2006).

(d) Practicality of applying data collection protocols in developing countries

A standardised international data gathering protocol, based on the Salmon River basin long-term study, could potentially be applicable to other parts of the world in order to identify the most important environmental driving factors relating to climate change for a particular population and implement a monitoring system that would feed into the indicator. Chinook Salmon range widely, and the same protocol could potentially be used in countries such as Russia provided support.

International initiatives such as www.stateofthesalmon.org could be a good starting point in considering an indicator encompassing populations of wild Pacific salmon from different areas.

(e) Recommended actions and costings

It is recommended that support be obtained from the US National Marine Fisheries Service. This organisation is perhaps in the best position to collate and produce this indicator. A detailed costing and feasibility assessment should be carried out, and the potential for improving geographic coverage wider than the Salmon River basin explored. The logistics are currently in place to produce an indicator for Chinook Salmon although the long-term security of the monitoring programme is not known. The cost of producing this indicator is likely to be relative low <50,000 for those regions where juveniles are tagged on an annual basis, although would increase considerably if this indicator was extended to include other salmon populations across the world.

(f) References

Crozier, L. & Zabel, R.W. 2006. Climate impacts at multiple scales: evidence for differential population responses in juvenile Chinook salmon. *Journal of Animal Ecology*, **75**, 1100–1109.

4.10. Loss of sea turtle nesting habitat through sea level rise (see section 4.10 of main report)

(a) Introduction

There is the potential to produce a useful and robust indicator of the impact of climate-induced sea level rise on sea turtles, which will be affected through the loss of egg-laying beaches (Fish *et al*. 2005). Whilst some research and development work would be needed to identify key sites and develop an approach for this indicator, once developed the ongoing updating costs would be low.

(b) Methods: sampling design and data

Once a number of indicator sites have been established, the aim would be to remotely assess the loss of nesting beaches using satellite images provided by the US Geological Survey Archive (TerraLook) at no cost to the user. TerraLook was developed to provide both ASTER and Landsat datasets as simulated natural-colour JPEG images (using a standardised international data gathering protocol). TerraLook aims to serve user communities who have a need for images of the Earth but do not have technical remote sensing expertise or access to expensive and specialised scientific image processing software (thus directly transferable to less developed countries). Users who have a need to perform digital analysis can also acquire the source data.

(c) Methods: data analysis

Methodology for constructing this indicator would need to be developed for this purpose.

(d) Practicality of applying data collection protocols in developing countries

Following the recommended research above, coverage would effectively be complete, although on-the-ground validation for a sample of sites may be required

(e) Recommended actions and costings

In the first instance it would be necessary to identify who would be best to develop this indicator and for a detailed feasibility and costing assessment carried out by this person or organisation. Secondly, initial research would be needed to identify the key nesting sites for Turtles. Initial research to identify key nesting sites for Turtles, which is expected to be in the low to medium costing band <£50,000 – £100,000, although following this work, the indicator could be updated on an annual basis at low cost, although the exact costing would need to be determined.

(f) References

Fish, M.R., Côté, I.M., Gill, J.A., Jones, A.P., Renshoff, S. & Watkinson, A.R. (2005) Predicting the Impact of Sea-Level Rise on Caribbean Sea Turtle Nesting Habitat. *Conservation Biology* **19**, 482-491.

Skewed sex ratios in sea turtles (see section 4.11 of main report)

(a) Introduction

There is concern that climate induced warming at sea turtle nesting beaches is leading to a skew in the sex ratio of clutches (Houghton *et al.* 2007). This indicator which would measure temperature at major sea turtle nesting sites, by deploying temperature loggers, would be timely relevant, and suitable for triggering policy decision.

(b) Methods: sampling design and data

Temperature data loggers have been deployed at most major sea turtle nesting sites around the world. This information is readily comparable between sites. In addition, internationally standardised meteorological data for most sites are also publicly available via the Comprehensive Ocean Atmosphere Dataset making large-scale assessments of climatically driven changes in incubation conditions possible.

(c) Methods: data analysis

Methodology for constructing this indicator would need to be developed.

(d) Practicality of applying data collection protocols in developing countries

Because temperature loggers are already deployed at most major sea turtle nesting sites, extending coverage further is not relevant here.

(e) Recommended actions and costings

It is recommended that a feasibility and costing assessment is carried out by an expert in this field. The logistics are not already in place for collating data across studies. For this reason, the set up costs are expected to be in the medium costing band of £50,000-100,000, although ongoing costs are likely to be relatively low cost thereafter.

(f) References

Houghton, J.D.R., Myers, A.E. Lloyd, C., King, R.S., Isaacs, C. & Hays, G.C. (2007) Protracted rainfall decreases temperature within leatherback turtle (*Dermochelys coriacea*) clutches in Grenada, West Indies: Ecological implications for a species displaying temperature dependent sex determination. *Journal of Experimental Marine Biology and Ecology* 3**45**, 71-77.

Caribou / Reindeer calf production and survival (see section 4.12 of main report)

(a) Introduction

An indicator could be produced for this high profile species, which would reflect the impact of climate change on the reproductive success of caribou, through the effect an increase in means spring temperature has on these animals' plant forage. The purpose of the indicator would be to illustrate the effects of climate change on several ecosystems (high Arctic islands, boreal forest and tundra) within the range of caribou/reindeer populations. Reference points could potentially be developed and harvest management changed accordingly. Past (some long-term data series exist) and future data could potentially be available through the CircumArctic Rangifer Monitoring and Assessment network (CARMA). This is an international monitoring programme that aims to manage the caribou harvest in a sustainable way and assess the resilience of the caribou harvesting regime to future changes in climate.

(b) Methods: sampling design and data

Methods are described in Post & Forchhammer (2007). This indicator would consist of annual calf production (ratio of calves to mature females). The following support indices could be used: 1) annual survival parameter (difference between the maximum proportion calves observed and the final proportion of calves divided by the maximum proportion observed); 2) index of trophic mismatch (percentage of forage species emergent on the date at which 50% of births have occurred); or 3) the annual mean spring temperature as a proxy for early plant forage emergence.

(c) Methods: data analysis

Currently, the analysis that supports this indicator was carried out on one population and short time series of six summers; methods described in Post & Forchhammer 2007.

(d) Practicality of applying data collection protocols in developing countries

This indicator could potentially be applied to the several populations of this species occurring in Scandinavia, Russia, Alaska, Canada and Greenland, and a combined populations' indicator generated. There are future plans to compile databases, monitor in a standardised way, across different countries, several parameters of caribou populations and to retrospectively analyse existing data series on population and individual animals with relation to climate and productivity (e.g. standard measures of calf production).

(e) Recommended actions and costings

It is recommended that a feasibility and costing assessment is carried out for producing this indicator. CARMA is perhaps best placed to carry out this work. Whilst there are already plans to introduce standardised monitoring across countries, this would need to be evaluated in relation to this indicator. The logistics for producing this indicator are in place through CARMA, however, considerable collation and development work would be needed. For this reason, it is expected that the cost would be in a medium costing band of £50,000 to £100,000.

(f) References

Post, E. & Forchhammer, M.C. (2007) Climate change reduces reproductive success of an Arctic herbivore through trophic mismatch. *Phil. Trans. R. Soc. B.*, **1098**, 1-7.

Populations of large African herbivorous mammals (see section 4.13 of main report)

(a) Introduction

A multi-species composite indicator could be produced for high profile species such as elephants and giraffes, which would reflect the impact of climate change on the size and distribution of large mammal populations in Africa. The main purpose of this indicator would be to monitor the expected responses to climate change of the geographic ranges of migratory mammals in Africa, to help with adaptation measures and policy decisions. Reference points could potentially be developed and harvesting and conservation strategies changed accordingly.

(b) Methods: sampling design and data

The methods of data collection will vary depending on the populations considered. The quality of the data will vary considerably from area to area. Aerial and ground surveys are used as well as indirect methods such as dung counts using line-transect methods. All methods have advantages and disadvantages and will be more or less appropriate depending on the species, funding and region. A critical review of methods available for elephant monitoring is given in the IUCN African Elephant Status Report 2007 (www.iucn.org/themes/ssc/sgs/afesg/aed/pdfs/aesr2007.pdf)

(c) Methods: data analysis
Considerable effort would be required to assess the feasibility of developing such indicator and choose the populations and datasets that would feed into it. In fact, few of the large herbivore mammal populations have long-term monitoring in place. A protocol would need to be established among countries and frameworks developed for data quality control and standardisation.

(d) Practicality of applying data collection protocols in developing countries
Monitoring is already carried out by volunteers or professionals in many African countries, although standardisation of data collection methods would be required, as well as data collation. Considerable coordinating effort would be required. The most appropriate data collection methods would have to be chosen relative to the particular country resources. It would probably be more feasible to use data from populations for which there are long-running monitoring programmes such as in some national parks.

(e) Recommended actions and costings
It is recommended that a detailed feasibility and costing assessment be carried out to evaluate what monitoring data is available and collected on an annual basis and to identify gaps and recommendations for collecting data according to standard methods. The chairs of the IUCN species specialist groups would be a good first point of contact. The logistics for producing this indicator and monitoring protocol are not already in place. For this reason, it is expected that the cost of setting up this indicator would be in a higher band of >100,000.

(f) References
Blanc, J.J., Barnes, R.F.W., Craig, G.C., Dublin, H.T., Thouless, C.R., Douglas-Hamilton, I., Hart, J.A. 2007. *African Elephant Status Report 2007: An update from the African Elephant Database*. Occasional Paper Series of the IUCN Species Survival Commission, No. 33. IUCN/SSC African Elephant Specialist Group. IUCN, Gland, Switzerland.

Population size (and movements) of Wildebeest (see section 4.14 of main report)

(a) Introduction
This indicator would reflect the impact of increased droughts on the size and distribution of the high profile wildebeest. Reference points could potentially be developed and harvesting and conservation strategies changed accordingly. Land transformation (and protected areas) could potentially be adapted to changes in species migration patterns that may be induced by climate change.

(b) Methods: sampling design and data
Long-term (since the 1960s) aerial survey data exists (recording number of individuals), together with some tag data, mostly from the Serengeti National Park but also from other national parks in South Africa. Monitoring in the Serengeti is secured by the Serengeti Ecological Monitoring Programme (see http://serengeti.org/download/Monitoring.pdf). Estimating the numbers of migratory wildebeest in the Serengeti is carried out using aerial photography to sample the herds. The aircraft flies systematic strips and a camera takes photographs at evenly-spaced intervals. The number of animals in the photograph is counted and a density calculated which in turn is used to extrapolate an estimate of the total. Three censuses are conducted periodically every two to three years interval or whenever requested by the park authorities. There has also been some deployment of GPS collars on wildebeest to study movements but this is not a long-term programme. For other national parks monitoring is uncertain. Data availability for the purposes of producing this indicator is not known.

(c) Methods: data analysis
In the Serengeti National Park data is analysed statistically and distribution maps produced (see http://serengeti.org/download/Monitoring.pdf)

(d) Practicality of applying data collection protocols in developing countries
Monitoring of the main wildebeest populations is secured in the Serengeti National Park. However, ongoing data availability and the standardisation of data recorded needs to be assessed. Outside this national park, monitoring is probably not secured.

(e) Recommended actions and costings
It is recommended that in the first instance a detailed feasibility and costing assessment be carried out to determine ongoing data availability and to determine the current level of standardisation in monitoring protocols. The Serengeti National Park would be the logical first point of contact. The logistics for producing this indicator is in place in the Serengeti but not in other areas and for this reason it is expected that the initial set up costs are likely to be high >£100,000. However, the feasibility and costing assessment recommended above should provide a better idea of ongoing costs.

(f) References
Boone, R.B., Thirgood, S.J. & Hopcraft, J.G.C. (2006). Serengeti wildebeest migratory patterns modelled from rainfall and new vegetation growth, *Ecology*, **87**, 1987–1994.

Mduma, S.A.R., Sinclair, A.R.E. & Hilborn, R. (1999) Food regulates the Serengeti wildebeest: a 40-year record. *J. Anim. Ecol.*, **68**, 1101– 1122.

Population size of Saiga Antelope (see section 4.15 of main report)

(a) Introduction
This indicator would illustrate the impacts of climate change on migratory hoofed mammals in central Asia. Reference points could potentially be developed and harvest management changed accordingly. Longer time-series of data would be required to more robustly establish a link between population size and climate change.

(b) Methods: sampling design and data
Long-term counts of individuals from aerial surveys exist for part of the species range and a continued monitoring programme is kept by the Saiga Conservation Alliance (http://www.saiga-conservation.com/) in some areas. Saiga movement and distribution are very variable, both seasonally and inter-annually, which makes surveying fallible and population size estimates have associated uncertainties that are difficult to quantify.

(c) Methods: data analysis
See http://www.saiga-conservation.com/

(d) Practicality of applying data collection protocols in developing countries
The most cost-effective method for carrying out large-scale surveys of this species is through aerial surveys (line transects) over suitable habitat. Whilst this species is relatively easy to monitor using this approach, it is also expensive to monitor. The aerial surveys in Kazakhstan for example, which give an annual population estimate, are government-funded and they are secure for the next few years. No security for other monitoring programmes, although there is now a 3-4 year dataset from Kalmykia on year-round observations of saigas.

(e) Recommended actions and costings
It is recommended that a detailed feasibility and costing assessment is carried out to assess what data are currently collected on an annual basis and the current standardisation of monitoring and data collection protocols used. In addition, costs for surveying populations in Uzbekistan, Russia and continued surveying in Kazakhstan, which together support >90% of this species population should be evaluated and options for securing funding explored. The logistics for producing this indicator are not already in place and initial work is needed to determine the feasibility of producing this indicator. For

this reason, it is expected that the initial set up costs are likely to be in a high costing band >£100,000, although the feasibility and costing assessment recommended above should provide a better assessment of this and ongoing costs.

(f) References

See http://www.saiga-conservation.com/

Abundance of bats at 'underground' hibernation sites in Europe (see section 4.16 of main report)

(a) Introduction

There is the possibility of developing a useful indicator of the relative abundance of European bats at underground hibernation sites. Whilst climate change is predicted to have an impact on the populations of these species, these relationships are currently not well understood. In addition some development of the logistics for data collection, collation and analysis are required. At present key sites that would form the basis of this indicator have been compiled by EUROBATS, which is developing guidelines for standardised monitoring throughout Europe. To date, 15 countries have contributed towards the development of a Pan-European programme for the monitoring of bats at underground hibernation sites. It is envisaged that coordination of the programme will be carried out by BatLife Europe, which is a largely a partnership of NGOs.

(b) Methods: sampling design and data

Monitoring data are collected nationally by most European countries, although work is needed to assess the standardisation of data collection protocols.

(c) Methods: data analysis

There have been little analyses of such data in relation to climate change. However, it is anticipated that national species indices could be calculated and then combined into supranational indices for species, weighted by estimates of national population sizes (obtained from National Reports presented to each EUROBATS Meeting of the Parties), as undertaken by Gregory *et al.* (2005) for wild bird populations. Species trends would then be combined across species for periods in the time series.

(d) Practicality of applying data collection protocols in developing countries

It is recommended that this indicator should focus on European populations only at the current time. These are some of the best-studied bat populations in the world, yet even for these our understanding of climate change impacts are currently poorly understood.

(e) Recommended actions and costings

It is recommended that support is obtained from EUROBATS and BatLife Europe for producing this indicator and that a detailed feasibility and costing assessment is carried out. The framework of BatLife Europe through consultation with the EUROBATS programme may be best placed to carry out this work and to produce the indicator.

(f) References

Gregory, R.D., van Strien, A., Vorisek, P., Gmelig Meyling, A.W., Noble, D.G., Foppen, R.P.B., Gibbons, D.W. 2005. Developing indicators for European birds. *Philosophical Transactions of the Royal Society, B.* 360, 269-288.

Populations of the Straw-coloured fruit bat in Africa (see section 4.17 of main report)

(a) Introduction
There is the possibility of developing a useful indicator of the relative abundance of the Straw-coloured Fruit Bat in Africa. Whilst climate change is predicted to have an impact on this species, the form of this relationship is currently not well understood. In addition some development of the logistics for data collection, collation and analysis are required. This African fruit bat forms very large seasonal colonies (possibly up to one million), many of which are in centres of human population (or national parks). Some of these colonies, mostly in woodland patches in urban centres, have a fairly well-documented history. A trans-African network of colonies is readily accessible for monitoring by city universities or interest groups. A standardised international monitoring protocol would need to be established, perhaps based on one in current use and tested at Kampala.

(b) Methods: sampling design and data
A trans-African network of colonies is readily accessible for monitoring by city universities or interest groups, although data availability and standardisation of data recording protocols across sites need to be assessed.

(c) Methods: data analysis
There have been little analyses of such data in relation to climate change. However, it is anticipated that indices of relative abundance could be calculated, according to similar methodology as in Gregory *et al.* (2005) used for wild bird populations.

(d) Practicality of applying data collection protocols in developing countries
A trans-African network of colonies is readily accessible for monitoring by city universities or interest groups. A standardised international monitoring protocol would need to be established (perhaps based on one in current use, e.g. at Kampala) and tested. This would allow the comparison of roost occupation data (seasonal and population) with vegetation changes over a broad geographical range.
Seasonal data should be of good quality and readily applicable to identifying changes; colony count data for such species will not be highly accurate, but should be sufficient for significant changes to be identifiable over a period of years (analysis of available data from Kampala, which goes back 40 years, may be enough to enable the level of reliability of the count data over a given period of years to be estimated.

(e) Recommended actions and costings
It is recommended that a detailed feasibility and costing assessment be carried out.
The logistics for collecting data using a standardised protocol and producing this indicator need development. For these reasons, it is expected that the set up costs for this indicator are likely to be in a higher band of >£100,000.

(f) References
Gregory, R.D., van Strien, A., Vorisek, P., Gmelig Meyling, A.W., Noble, D.G., Foppen, R.P.B., Gibbons, D.W. 2005. Developing indicators for European birds. *Philosophical Transactions of the Royal Society, B.* 360, 269-288.

Populations of Mexican Free-tailed Bats (see section 4.18 of main report)

(a) Introduction
There is the possibility of developing a useful indicator of the relative abundance of the Mexican free-tailed Bat. Whilst climate change is predicted to have an impact on this species, the form of this relationship is currently not well understood. In addition some development of the logistics for data collection, collation and analysis are required.

(b) Methods: sampling design and data

There is a large and long-term body of population and other data available for the species (O'Shea & Bogan 2003). At the north end of the range, population monitoring of summer, winter and migratory stop-over sites is already carried out through 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). 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; this is an NGO programme, but has the support and participation of its host governments and is producing valuable results for conservation. Similar organisations are being set up in southern South America where the species is believed to be migratory, but where the migratory behaviour is as yet largely unknown and there is as yet no systematic monitoring. The fieldwork is relatively straightforward and could be carried out by volunteers in the southern part of the species range if the logistics were in place to coordinate and collate such data.

(c) Methods: data analysis

There have been little analyses of such data in relation to climate change. However, it is anticipated that indices of relative abundance could be calculated, according to similar methodology as in Gregory *et al.* (2005) used for wild bird populations.

(d) Practicality of applying data collection protocols in developing countries

Standard protocols for monitoring the number of individuals employed in the northern end of the species range could be used throughout the rest of migratory range of this species. The fieldwork is relatively straightforward and could be carried out by volunteers if the logistics were in place to coordinate and collate such data.

(e) Recommended actions and costings

It is recommended that a detailed feasibility and costing assessment be carried out. In addition, the potential for improving the quality of the data collection in the southern part of the species range should be assessed.

The logistics for collecting data using a standardised protocol and producing this indicator need development. For these reasons, it is expected that the set up costs for this indicator are likely to be in a higher band of >£100,000.

(f) References

Gregory, R.D., van Strien, A., Vorisek, P., Gmelig Meyling, A.W., Noble, D.G., Foppen, R.P.B., Gibbons, D.W. 2005. Developing indicators for European birds. *Philosophical Transactions of the Royal Society, B.* 360, 269-288.

Annex 1 Workshop Programme and participants

International Workshop on Developing Indicators of Climate Change for Migratory Species

University of East Anglia, 13th & 14th December 2007

<u>Thursday 13th December</u>

09.30 – 10.00 Coffee/Tea

10.00 – 10.20 Introduction to the Project – Humphrey Crick (*BTO*)

10.20 – 10.40 The Convention on Migratory Species, CMS - Sally Cunningham (*Defra*)

<u>Issues that challenge the choice and usefulness of indicators for</u>:

10.40 – 11.00 Mammal mammals, fish and squid – Sonia Mendes (*Aberdeen University*)

11.00 – 11.20 Terrestrial mammals – Sonia Mendes (*Aberdeen University*)

11.20 – 11.40 Turtles – Jon Houghton (*Swansea University*)

11.40 – 12.00 Birds – Stuart Newson (*BTO*)

12.00 – 12.30 Criteria for indicator development – Nick Dulvy (*CEFAS*)

12.30 – 13.30 Lunch

13.30 – 13.45 Aims of break-out groups – Humphrey Crick (*BTO*)

13.45 – 15.00 Break-out Groups

15.00 – 15.45 Tea

15.45 – 18.00 Break-out Groups

19.00 Dinner

Break-out groups will be organised as follows: Birds; Marine and Terrestrial Mammals including Bats; Turtles; Marine Fish and Squid. Each group will be asked to consider the suitability of the proposed indicators, to score them against the criteria developed by the project, to assess gaps in coverage and how they might be filled, to consider how the methods could be applied in developing countries; to consider whether remote sensing could play a useful role; to consider whether there may be synergies that could be gained from other such initiatives.

<u>Friday 14th December</u>

09.00 – 10.30 report back from 2 groups

10.30 – 10.45 Coffee/Tea

10.45 – 12.30 Report back from 2 groups

12.30 – 13.30 Lunch

13.30 – 14.30 Discussion: Assess total suite of indicators – do they give good coverage? Should any be dropped in favour of more uncertain indicators?

14.30 – 15.20 Discussion: Priorities for gap-filling

15.20 – 15.30 Closing comments – Humphrey Crick (*BTO*)

15.30 Tea & Departure

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