EVIDENCE FOR STERN REVIEW TEAM

Introduction

This document contains a number of references relating to the importance of natural capital, biodiversity and ecosystem services to human well-being and the estimated and predicted impacts of climate change on biodiversity. The references have been grouped under the following headings:

A. Natural capital, ecosystem services supporting economic growth
B. Biodiversity impacts
C. Health, and other impacts
D. Forests, small islands and land use changes
E Further evidence of the effects of climate change on species
Appendix: case study on UK seabirds

This is not a comprehensive list of references but does cover a range of studies which highlight the interactions between climate change, biodiversity and people. The RSPB's primary interest and expertise in this field has been in researching the impacts of climate change on birds and biodiversity more broadly. Some of the work the RSPB has been involved with is referenced in Section B on biodiversity impacts.

A. Natural capital, ecosystem services supporting economic growth (fisheries, agriculture, forestry, water…etc)

"Where is the wealth of nations" Kirk Hamilton. (2005)
World bank report examines linkages between development outcomes and the composition & management of wealth. Key points include:
- Natural capital is a larger share (25%) of total wealth than produced capital (16%) in low income countries. About 2/3 of the capital is intangible capital (knowledge, labour, health, institutions, etc)
- Nearly 70% of natural capital in low income countries is agricultural land
- The value of total natural (natural resources, protected areas etc.) wealth per capita rises with income (about 200 USD/cap for low income and about 900 USD/cap for OECD countries, excluding the oil exporters). This is explained because of better resource management rather than population.
- When resource depletion and population growth is taken into account, most poor countries face declining wealth per capita
- Managing natural resources must be a key part of development strategies in poor countries
- The large share of natural capital in poor countries make a strong argument for the role of environmental resources in reducing poverty, fighting hunger, and lowering child mortality.

http://web.worldbank.org/servlets/ECR?contentMDK=20744819&sitePK=407255

The CC impacts are discussed at –
http://web.worldbank.org/WBSITE/EXTERNAL/NEWS/0,,contentMDK:20746661~pagePK:34370~piPK:34424~theSitePK:4607,00.html

Millennium Ecosystem Assessment (Evidence of the degradation and unsustainable use of ecosystem services)
Notes that approximately 60% (15 out of 24) of the ecosystem services evaluated (including 70% of regulating and cultural services) are being degraded or used unsustainably.

The Greenfacts web site has a user friendly version of the Millennium Ecosystem Assessment.
http://www.greenfacts.org/ecosystems/index.htm

The degradation of ecosystem services often causes significant harm to human well-being. The website provides evidence to demonstrate four points regarding the impact the degradation of ecosystem services has on livelihoods, health, and local and national economies.

1. *Most resource management decisions are most strongly influenced by ecosystem services entering markets; as a result, the non-marketed benefits are often lost or degraded.* These non-marketed benefits are often high and sometimes more valuable than the marketed ones. For example, one of the most comprehensive studies to date, which examined the marketed and non-marketed economic values associated with forests in eight Mediterranean countries, found that timber and fuelwood generally accounted for less than a third of total economic value of forests in each country. Values associated with non-timber forest products, recreation, hunting, watershed protection, CO2 and passive use (values independent of direct uses) accounted for between 25% and 96% of the total economic value of the forests.

2. *The total economic value associated with managing ecosystems more sustainably is often higher than the value associated with the conversion of the ecosystem through farming, clear-cut logging, or other intensive uses.*.

3. *The economic and public health costs associated with damage to ecosystem services can be substantial.*

4. *The impact of the loss of cultural services is particularly difficult to measure, but it is especially important for many people.*

Real Net Savings and GDP measures of economic progress
When estimates of the economic losses associated with the depletion of natural assets are factored into measurements of the total wealth of nations, they significantly change the balance sheet of countries with economies significantly dependent on natural resources. Many countries that record positive growth in net savings, reflecting a growth in the net wealth of the country, actually experience losses in net savings when depletion of natural resources (energy and forests) and estimated. Link is to a Partha Dasgupta essay will examples for a number of developing countries.
http://www.newstatesman.com/aldaily/al20031103.htm
(also see)
Human Well Being and the Natural Environment, Partha Dasgupta. (2001) OUP

Investing in Environmental Wealth for Poverty Reduction. David Pearce for the Poverty Environment Partnership (2005) Demonstrates the dependence of the poorest rural communities on the goods and services that ecosystems provide. Adopts an asset based measure of poverty comprising natural, man-made, human and social capital
http://www.undp.org/pei/pdfs/InvestingEnvironmentalWealthPovertyReduction.pdf

Biodiversity and Poverty Reduction; The importance of biodiversity for ecosystem services. UNEP-WCMC (2006)
Recent report for DFID examines the linkages between biodiversity, ecosystem services and poverty.

DFID biod and Ecos Services report - Jan 27th Final Report.pdf

UNDP Energy and Environment Web Site.
Has useful summary information on CC impacts by sector and outlines its MDG Carbon Facility (financing mechanism designed to direct increased financial flows from the markets in carbon emission offsets toward projects that contribute directly to meeting the Millennium Development Goals (MDGs)
http://www.undp.org/climatechange/adap02.htm

UNEP Workshop - Creating Pro-poor markets for the Ecosystem Services.
This website has some background papers for this workshop held last October. Klaus Toepfer's speech contains some valuations for ecosystems and their services.
http://hq.unep.org/dec/support/mdg_meeting_lon.htm

General impacts from CC
The following link has graphical representations of a number of predicted CC impacts
http://www.grida.no/climate/vital/impacts.htm

CC and agriculture in Africa (focusing on land productivity).

There is a World Bank report due in May/June, co-authored by Ariel Dinar(adinar@worldbank.org)

B. Biodiversity impacts

Extinction Risks from Climate Change (Jan 2004)
The RSPB was involved in this study which combines work on forecast species responses from various regions (Europe, Aus, Brazil, etc) covering about 20% of Earth's land surface and estimates extinction risks for zero and 100% dispersal. Using projections of areas of suitable climate conditions for species under future climate scenarios, the authors predict that, over sample regions that cover some 20% of the Earth's land surface, 15 to 37% of species in the sample will be "committed to extinction" as a result of mid-range climate warming scenarios for 2050. Estimated rates of extinction due to climate change are generally higher than projections of extinction based on habitat destruction.
Thomas et al Nature Vol 427 (2004)


Thomas_02121_final_proof.pdf

Impacts of Climate change on biodiversity andwildlife (RSPB 2001/3)
Since 1997, the RSPB has been involved with 3 conferences working on the impacts of cc on biodiversity. The conferences' reports, co-edited by the RSPB, highlight scientific studies providing evidence on how CC is already affecting wildlife in the Earth's major biomes. Links to both.
http://www.unep-wcmc.org/climate/climatebook/Introduction.htm
http://www.rspb.org.uk/Images/Global climate change low res pdf_tcm5-45204.pdf

Evidence of impacts on birds (2004)
The "State of the World's Birds"(2004) gives a number of examples of the impacts impact off CC on birds and other taxa. Links are to report and RSPB press release.
http://www.birdlife.org/action/science/sowb/case_studies/p46-47.pdf
http://www.rspb.org.uk/Images/soukb04_tcm5-79604.pdf

How biodiversity and climate change interact
(Feb 2004)
A policy brief showing how biodiversity is inextricably linked to climate and examines the interface from both sides.
http://www.scidev.net/dossiers/index.cfm?fuseaction=policybrief&dossier=11&policy=46

Biodiversity and CC

UNEP-WCMC site which contains a table of impacts by biome/ecosystem type

http://www.unep-wcmc.org/climate/impacts.htm

Biodiversity facts and figures

SciDev website with several links for basic information and data on biodiversity

http://www.scidev.net/ms/biofacts/index.cfm?pageid=429

Climate change and Migratory Species (Book) (Oct 2005)

CC could affect and disrupt breeding, hamper migrations, and increase disease transmission in migratory birds and animals

http://www.defra.gov.uk/wildlife-countryside/resprog/findings/climatechange-migratory/index.htm

Siberian peat bog melting (2005)

The world's largest frozen peat bog is melting which could unleash billions of tonnes of methane into the atmosphere.

http://www.newscientist.com/article.ns?id=mg18725124.500

Half of world's coral reefs may disappear (10/28/2005)

A report by the IUCN, concludes that nearly half of the world's coral reefs may be lost in the next 40 years unless urgent measures are taken to protect them against the threat of climate change. http://www.enn.com/today.html?id=9125

Climate change brings sharks north (9/16/2005)

Climate change and warmer coastal waters are thought to have contributed to a massive increase in the number of basking sharks feeding in Scottish waters.

http://news.scotsman.com/topics.cfm?tid=226&id=1945672005

Climate change, malnourishment, impacts sea bird survival rates (11/9/2005)

New environmental conditions lead fish to migrate, leaving the birds that feed on them malnourished. New research shows that lack of a specific nutrient in red-legged kittiwakes damages their cognitive abilities and could leave them too daft to find food.

http://www.newscientist.com/article.ns?id=dn8287

Review of climate change indicators in the UK (Defra)

Data on trends in a set of indicators for the UK

http://www.edinburgh.ceh.ac.uk/iccuk/

Modelling natural resource responses to climate change
Link is to the Report of the first phase of the Monarch (Modelling Natural Resource Responses to Climate Change) project. The first report from MONARCH showed how species distribution might look under a changed climate, using plants and animals from land, sea and freshwater environments as examples.
http://www.ukcip.org.uk/resources/publications/pub_dets.asp?ID=26

C. Health, and other impacts

Loss of Life (Dec 2003)
WHO claim 150,000 people died around the world in 2000 because global warming triggered heat waves, floods or droughts, or made worse some infectious disease. While the overwhelming bulk of those deaths took place in the world's poorest countries, the health fallout from climate change is also already claiming lives in the rich countries of Western Europe and, less so, in Canada and the United States. A further 5.5 million healthy years of life were lost worldwide due to debilitating diseases caused by climate change.
http://www.who.int/globalchange/news/fsclimandhealth/en/index.html

CC Impacts on the environment, human health and the economy (Nov 2005)
A Harvard Medical School, Swiss Re and UNDP study predicts that climate change will significantly affect the health of humans and ecosystems and these impacts will have economic consequences. "The report examines the physical and health risks of climate instability and formulates future climate change scenarios and potential impact on both the environment, human health and the economy".
Report can be downloaded from:
http://www.swissre.com/internet/pwswpspr.nsf/fmBookMarkFrameSet?ReadForm&BM=../vwAllbyIDKeyLu/fstn-6hrreq?OpenDocument

CC and Pollution (2005)
Almost a fifth of all ill health in poor countries and millions of deaths can be attributed to environmental factors, including climate change and pollution, according to World Bank's Environmental Matters (2004) report.
http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/0,,contentMDK:20372139~pagePK:148956~piPK:216618~theSitePK:244381,00.html

Climate linked to malaria in African highlands (March 2006)

A small increase in temperature could have led to the recent dramatic rise in malaria in the highlands of East Africa
http://www.scidev.net/content/news/eng/climate-linked-to-malaria-in-african-highlands.cfm
(This link has further references to CC and health impacts)

How will climate change affect living conditions in Africa?
This link has a number of articles looking at CC impacts in Africa
http://www.scidev.net/ms/climate_africa/index.cfm?pageid=476

Insurance costs (Aug 2005)
The global insurance industry is paying out more in claims caused by extreme weather-related natural disasters
http://www.yubanet.com/cgi-bin/artman/exec/view.cgi/8/23821

Insurance/Financial costs of climate change (Nov 2005)
A Report to the ABI estimates annual losses from the three major storm types affecting insurance markets (US hurricanes, Japanese typhoons and European windstorms) could increase by two-thirds to $27 bn by the 2080s.
http://www.abi.org.uk/Display/Display_Popup/default.asp?Menu_ID=1090&Menu_All=1,1088,1090&Child_ID=552

Higher temperatures linked to stronger hurricanes (3/17/2006)
Rising ocean temperatures are directly linked to a worldwide increase in hurricane strength over the past 35 years, a research team reported Thursday — a finding that could add fuel to the debate over possible links between global climate change and hurricanes.
http://www.statesman.com/news/content/news/stories/nation/03/17hurricanes.html

CC, the El Niño effect and impacts on African food supplies (2/21/2006)
"Climate change that strengthens the El Nino weather patterns could endanger food supplies for more than 20 million people in Africa a report from the Millennium Institute in Arlingto claims.
http://www.enn.com/today.html?id=9923

Water and Climate
The Pacific Institute has a searchable bibliography on this issue at:
http://biblio.pacinst.org/biblio/

Other possible legal costs? Inuit may sue US over climate change (6/15/2005)
Inuit hunters threatened by a melting of the Arctic ice plan to file a petition accusing Washington of violating their human rights by fuelling global warming.

http://www.rednova.com/news/display/?id=156297&source=r_science

D. Forests, small islands and landuse changes

PNG/Costa Rica proposal to the UN (Dec 2005)
A net 7.3 million hectares (18.04 million acres) of forests - the size of Panama or Sierra Leone - was lost each year from 2000-2005, according to United Nations data. PNG and Costa Rica made a proposal at Montreal (UN FCCC) to be financially rewarded for avoided deforestation. The Coalition of Rainforest Nations website has a number of articles on forests and climate change and outlines its own initiatives.
http://www.rainforestcoalition.org/eng/context/papers.php
UNFCCC Concluding text notes PNG proposal:
http://www.rainforestcoalition.org/documents/UNFCCCAgendaItem6DraftText7December2005.pdf

Carteret atoll residents become first climate change refugees (Nov 2005)

For more than 30 years the 980 people living on the six minute horseshoe-shaped Carteret atolls have battled the Pacific to stop salt water destroying their coconut palms and waves crashing over their houses. They failed.
http://www.guardian.co.uk/climatechange/story/0,12374,1650406,00.html

Climate change may lead to Tuvalu resident relocation (2/18/2006)

Salinity and rising sea levels predicted to result from climate change are expected to make Tuvalu uninhabitable within 50 years, leaving the 9000-strong population with nowhere to live.
http://www.theaustralian.news.com.au/common/story_page/0,5744,18190721%255E29277,00.html

The Mauritius Strategy (Jan 2005 – month of declaration)
The adverse effects of climate change and sea-level rise present significant risks to the sustainable development of small island developing States. Relevant text in link.
http://portal.unesco.org/en/ev.php-URL_ID=31487&URL_DO=DO_TOPIC&URL_SECTION=201.html

Water Resources in Pacific islands
Book chapter outlining the possible impact of CC on freshwater resources in Pacific Island Developing Countries (PIDCs) "(PIDCs) are responsible for only 0.03 percent of the world's carbon dioxide emissions,and the average island resident produces only one-quarter of the emissions of the average person worldwide (Hay 1999). Yet it is anticipated that these nations will experience some of the earliest and most severe consequences of climate change over the next two centuries".

http://www.pacinst.org/publications/worlds_water/worlds_water_2002_chapter5.pdf

E Further evidence of the effects of climate change on species

Many recent studies have shown that birds are advancing their laying date in response to long-term increases in spring temperatures (Torti and Dunn 2005)[1]. The life cycles of plants and animals are also changing around the world in line with the predictions originated from hypotheses concerning the impact of global warming and climate change on biological systems. (Gordo et. al. 2005)[2]. In a study reported in the journal *Nature*, Parmesan and Yohe documented that hundreds of species of plants and animals are shifting their habitat range toward the poles (or higher in elevation), or are experiencing spring reproductive events earlier -- in response to decades of atmospheric warming. http://hdgc.epp.cmu.edu/mailinglists/hdgcctml/mail/pdf00008.pdf
Migratory species are of special concern in the face of global climate change, since they may be affected by changes in the wintering area, along the migration route and at the breeding grounds (Ahola et. al. 2004)[3].

A review article in *Nature* (Walther et al. 2003) also notes that there is now ample evidence of the ecological impacts of recent climate change, from polar terrestrial to tropical marine environments. The responses of both animal and plant species span an array of ecosystems and organizational hierarchies, from the species to the community levels. Despite continued uncertainty as to community and ecosystem trajectories under global change, the review exposes a coherent pattern of ecological change across systems. Although we are only at an early stage in the projected trends of global warming, ecological responses to recent climate change are already clearly visible.[4]

The examples below are taken from recent scientific papers and are examples of an increasing bulk of evidence that shows the, sometimes dramatic, effects that climate change is having and will increasingly have on species, in particular highlighting how they respond to environmental changes and how this might affect their ability to survive in the future.

---

[1] Torti, V. M., Dunn, P. O. 2005 "Variable effects of climate change on six species of North American birds" *Oecologia*, Springer, New York

[2] Gordo, O., Brotons, L., Ferrer, X., Comas, P. 2005. "Do changes in climate patterns in wintering areas affect the timing of the spring arrival of trans-Saharan migrant birds?" *Global Change Biology*, Blackwell Publishing, Oxford

[3] Ahola, M., Laaksonen, T., Sippola, K., Eeva, T., Rainio, K., Lehikoinen, E. 2004 "Variation in climate warming along the migration route uncouples arrival and breeding dates" *Global Change Biology*, Blackwell Publishing, Oxford

[4] Walther, G-R., Post, E, Convey, P., Menzel, A., Parmesan, C, Beebee, T. J. C., Fromentin, J-M, Hoegh-Guldberg, O and Bairlein, F (2003) "Ecological responses to recent climate change" *Nature*

Species of seabirds that respond to large-scale environmental cues are less affected by climate change than those affected by local conditions.

Breeding at the right time is essential for animals in seasonal climates to ensure that feeding requirements of their young coincide with the peak availability of food. Global climate change is likely to cause shifts in the timing of peak food availability, and in order to adapt successfully to current and future climate change, animals need to be able to adjust the time at which they initiate breeding. Many animals use environmental cues available before the breeding season to predict the seasonal peak in food availability and adjust their phenology accordingly. It was found that species that respond to local conditions (European shag) such as sea surface temperature are more affected that species (black-legged kittiwake and common guillemot) that respond to large-scale environm ental cues such as the North Atlantic Oscillation. Since correlations among climate patterns at different scales are likely to change in the future, these findings have important implications for how migratory animals can respond to future climate change.

Frederiksen, M., Harris, M. P., Daunt, F., Rothery, P., Wanless, S. 2004 "Scale-dependent climate signals drive breeding phenology of three seabird species" Global Change Biology, Blackwell Publishing, Oxford

As the climate warms, there is an increasing mismatch between the timing of egg-laying and the availability of chick food for golden plovers which will reduce the success of early breeding attempts.

The consequences of climate change may be most severe for arctic and sub-arctic waders. Looking at one such species (golden plover *Pluvialis apricaria*), and the timing of emergence of their adult tipulid prey, in combination with historical climate data, models suggest a nine day advancement of golden plover first laying dates occurred during the 1990s, although this remains within the range of natural variation for the 20th Century. The size of predicted changes in laying dates, and the timing of tipulid emergence, were smaller. Given the importance of adult tipulids to young golden plover chicks, these changes may result in a mismatch between the timing of first-laying dates and tipulid emergence, so reducing the success of early breeding attempts. Modelling suggests that these changes could reduce breeding success in a South Pennines population by about 11%.

Pearce-Higgins, J.W.1, Yalden, D.W.2 and Whittingham, M.J. 2005 " Warmer springs advance the breeding phenology of golden plover Pluvialis apricaria and their prey (Tipulidae)". Oecologia, Springer, New York*

Reduced breeding success of pied flycatchers results from a mismatch with prey availability caused by climate change

In southern Europe, Mediterranean pied flycatchers (*Ficedula hypoleuca*) have been less successful at rearing chicks because of climate change. As the climate warms, oak trees are leafing earlier and the caterpillars on which the chicks depend are thus becoming available earlier. However, the pied flycatchers cannot match this with earlier breeding because they are constrained by their late arrival date after migration and the fact that

they breed at high altitude near the southern border of their range. This leads a mismatch between the time of peak food supply and demand from chicks, which has been shown to impact the population by reducing nestling growth and the survival of fledged young.

Sanz, J. Potti, J., Moreno, J. Merino, S. Frias, O 2003. Climate change and fitness components of a migratory bird breeding in the Mediterranean region Global Change Biology, Blackwell Publishing, Oxford

Survival of common lizards is increased with warming temperatures as their body size has correspondingly increased. However, their high altitude habitat is under threat from climate change.

Over the past 18 months, body size of common lizards in Southern France has dramatically increased with daily maximum temperature in August increased by 2.2^{o}C and yearling snout-vent-length increased by about 28%. As productivity of young is strongly dependent on female body size, total reproductive success is also increased. However, there are mixed fortunes for this species as this is contrasted with the long-term habitat-based prediction that these populations located close to mountaintops on the southern margin of the species range should be unable to cope with the alteration of their habitat.

Chamaille-Jammes, S., Massot, M., Aragon, P., Clobert, J. 2006. "Global warming and positive fitness response in mountain populations of common lizards Lacerta vivipara" Global Change Biology, Blackwell Publishing, Oxford.

A number of Mediterranean species have shown changes in their phenology as a result of warming temperatures over the last few decades. These include plant-insect interactions becoming decoupled.

The long term trends in the phenology of 45 plants, 4 insects and 6 migratory insectivorous birds have been studied. These show that since the mid-1970s shows an advancement in plant phenology but, at the same time, a steeper advance in insect phenology, suggesting an increased decoupling of some plant-insect interactions, e.g. between pollinators and flowers, or herbivorous insects and their plant resources. All 6 bird species showed changes in their migration patterns.

Gordo, O. & Sanz, J. J. 2005. "Phenology and climate change: a long-term study in a Mediterranean locality" Oecologia, Springer, New York.

Bird species in North America show variable responses to climate change within and among species.

Long-term temperature change had an effect on the laying dates and clutch sizes of four out of six ecologically diverse species of North American birds using 50 years of nest record data. This study indicates that the relationship between climate change and breeding in birds is variable within and among species. These variable responses within and among species highlight the need for more detailed studies across large spatial scales.

Torti, V. M., Dunn, P. O. 2005 "Variable effects of climate change on six species of North American birds" Oecologia, Springer, New York

The available evidence points to climate change having a range of impacts on birds in Australia.

A review of the documented or predicted effects of climate change on birds, with particular reference to Australian species, suggests that potential impacts include changes in geographic range, movement patterns, morphology, physiology, abundance, phenology and community composition. The evidence suggests that these changes are already happening, both overseas and in Australia, but more research is needed to determine the extent of these impacts and how to conserve birds in the face of climate change.

Chambers, L. E, Hughes, L, Weston, M. A. "Climate change and its impact on Australia's avifauna" Emu, CSIRO Publishing, Collingwood.

60% of studies on birds have shown long term advances in laying dates consistent with global warming although more research is needed to understand the range of effects a warming climate is having.

Much of the evidence for the effects of climate change on birds comes from studies of the timing of breeding. Many species of birds start to lay eggs earlier in years with warmer temperature, and approximately 60% of studies have shown long-term advances in laying dates consistent with global warming. Nevertheless, the magnitude of the responses differs among species and locations in ways that we do not yet understand and could be due to differences in: (1) local temperature changes, (2) diet, (3) body size, (4) life history (migratory or resident; number of broods per season) and (5) the time scales over which species acquire resources for breeding. Although earlier laying of clutches is often associated with larger clutch sizes and greater production of young, the effects of earlier laying on reproductive performance are less clear. Large-scale collaborative studies are needed to monitor the effects of climate change over large areas and to determine how climate change affects the reproductive performance of species throughout their ranges.

Dunn, P. 2004. "Breeding dates and reproductive performance." Advances in Ecological Research, Academic Press Ltd., London.

Components of food chains shifting at different rates in response to climate change will effect the reproduction of many species.

Spring phenology has advanced with climate change but there is no reason to expect that all components of food chains will shift their phenology at the same rate. This will lead to mistimed reproduction in many species, including seasonally breeding birds. This could be because there is a substantial period between the moment of decision making on when to reproduce and the moment at which selection operates on this decision. Climate change is therefore likely to differentially alter the environment of decision-making and the environment of selection.

Visser, M. E., Both, C., Lambrechts, M. M. 2004. "Global climate change leads to mistimed avian reproduction" Advances in Ecological Research, Academic Press Ltd., London.

Changes in day length which provide important behaviour signals to birds may not accord with changes in the environment resulting from climate change which will prove problematic for bird species.

In birds, the annual change in day length is the most important environmental cue used for synchronising breeding, moult, and migration with changes in environmental conditions with the changing seasons. However, as humans change the environment, this may become an unreliable method of prediction if day length is no longer a predictable of resource availability (e.g. caterpillars to feed nestlings). Equally, as species shift their range in response to climate change, this can expose birds to new conditions of day length. They may not be able to evolve fast enough to keep up with these changes.

Coppack, T., Pulido, F. 2004. "Photoperiodic response and the adaptability of avian life cycles to environmental change" Advances in Ecological Research, Academic Press Ltd., London.

Bird migration is particularly affected by changes in climate conditions at species wintering grounds.

Much research on changes in bird phenology is based on the effects of changing climates at species breeding grounds. However, this research suggests that the spring arrival of long-distance migrants is more likely to be influenced by climate conditions, especially precipitation and temperature in wintering areas given their direct impact on the onset of migration and its progression. The results highlight the level of complexity of the interaction of different impacts resulting from climate change on bird migration.

Gordo, O., Brotons, L., Ferrer, X., Comas, P. 2005. "Do changes in climate patterns in wintering areas affect the timing of the spring arrival of trans-Saharan migrant birds?" Global Change Biology, Blackwell Publishing, Oxford

Dragonflies and damselflies have shifted their ranges northwards over the last 40 years, probably as a result of climate change.

This study presents evidence for 37 species of non-migratory British dragonflies and damselflies shifting northwards at their range margins over the past 40 years, seemingly as a result of climate change. This response by a group of insects associated with fresh water, parallels polewards range changes observed in other taxa.

Hickling, R,. Roy, D. B., Hill, J. K., and Thomas, C. D. (2005) "A northward shift of range margins in British Odonata" Global Change Biology, Blackwell Publishing, Oxford

Unlike many butterflies, the garden tiger moth is expected to decline with climate change.

The garden tiger moth (Arctia caja) was once widespread and common in the UK. However, data collected using light-traps in Great Britain from 1968 to 1998 showed that A. caja abundance has fallen. Contrary to most UK butterflies, which are expected to

increase under the UK climate change scenarios of global warming, modelling showed that warm, wet winters and springs may be detrimental to A. caja and it is therefore predicted to decrease further.
Conrad, K. F., Woiwod, I. P., Perry, J. N. 2002 "Long-term decline in abundance and distribution of the garden tigermoth (Arctia caja) in Great Britain" Biological Conservation

Prey availability for great tits has been mismatched to breeding times as a result of climate warming which affects the number and weight of fledglings.
For great tits, the match between the food needs of the chicks (caterpillars) and the caterpillar biomass has been disrupted in the recent warm decades. This may have severe consequences as both the number of fledglings as well as their fledging weight is affected by this. Using an IPCC climate scenario, it is likely that the birds will start breeding earlier but this advancement is predicted to be at the same rate as the advancement of the food peak, and hence they will not reduce the amount of the current mistiming of about 10 days.
Visser, ME, Holleman, LJM, Gienapp, P. 2006 "Shifts in caterpillar biomass phenology due to climate change and its impact on the breeding biology of an insectivorous bird." Oecologia

Lapwings in the Netherlands are laying eggs three days earlier than 100 years ago.
During the second half of the 20th century, not only did Northern Lapwing (*Vanellus vanellus*) experience an increase in spring temperatures, their meadow habitat also changed dramatically due to agricultural intensification. In The Netherlands, lapwing eggs have long been collected for consumption and, as the finding of the first egg of the season has been an important social event till today, first egg dates are archived. The research shows that the advance in the first egg date was primarily explained by increasing spring temperatures with the first egg was laid on average three days earlier in 2000 compared with 1900. The analysis thus shows that lapwing laying date was primarily affected by climatic factors rather than by the considerable changes in breeding habitat.
Both, A. U., Piersma, C, Roodbergen, T. 2005 "Climatic change explains much of the 20th century advance in laying date of Northern Lapwing Vanellus vanellus in The Netherlands" Ardea

As the climate warms, species ranges are contracting and species richness declining.
This review focuses on the effects of global climate change on bird communities. Plenty of evidence exists demonstrating that range boundaries of birds are correlated with climatic factors. In general, the northern range limit of species seems to be influenced by factors such as cold temperatures. The southern range limit of species appears to be determined by climatic factors such as heat or lack of water in and regions and by biological factors in more humid regions. For communities, the number of species present is best predicted by temperature at high latitudes and by water-related variables in low-latitude, high-temperature regions.

Models predicting range changes under climate change show idiosyncratic responses of different species with range contractions being more frequent than range expansions. Range shifts have been observed in temperate regions with northern range boundaries shifting northwards but no consistent trend of southern range boundaries. Upslope movements have been observed on a tropical mountain. As winters warm, a decline in migratory bird species has been predicted and observed.

Conservation consequences of global climate change are especially high threats to species in and environments, expected movements of species out of protected areas and increasing land use conflicts. Given that range contractions and declines of species richness often initiate conservation efforts, further studies are urgently needed.
Bohning-Gaese, K. and Lemoine, N. 2004 "Importance of climate change for the ranges, communities and conservation of birds" Advances in Ecological Research

The timing of species events

Events, such as first egg laying, hatching, flowering etc - are moving but what effect will these shifts have on the biological success of the species? A phenological yardstick measures how much a species should be shifting to match its change in environment caused by climate change, in this case food availability. A literature review of produced surprisingly few examples, ranging from birds to marine plankton. Most examples produced a significant mismatch: the phenology of 11 focal species shifts changed too slowly (5 out of 11) or too quickly (3 out of 11) compared to the yardstick, suggesting that many species are becoming mistimed due to climate change.
Visser M E and Both, C, 2005 Shifts in phenology due to global climate change: the need for a yardstick. Proc R Soc B

Appendix – Case Study. Seabirds and climate change

In the North Sea, the temperature has risen by an average of 1^{o}C in just 25 years. This warming and led to remarkable shifts in the mix and distribution of plankton, fish and other creatures. Warm water plankton are replacing cold-water plankton in the North Sea, providing less nutrition for the fish and seabirds that feed on them. Plankton peaks, or blooms, are happening at different times of year compared with 20 years ago. Birds and other animals whose life cycles evolved over thousands of years to coincide with abundant plankton are starved of food.

Species we would never have expected off our shores are moving northward at a rate of 50 km a year – warm water fish such as red mullet, anchovies, sunfish and squid. Familiar cold-water fish, such as cod, are retreating northwards. The chemistry of the seas is also changing. As surface waters have warmed, their salinity has fallen. The seas are also becoming more acidic, as they absorb half of humankind's growing burden of carbon dioxide emissions. Increases acidity is leading to a drop in numbers of

phytoplankton, corals and shellfish, which are unable to maintain their calcium -rich shells.

At the top of the marine food web, seabirds are visible signs of the changes taking place below the surface. In the past few years, sand eels have begun to disappear from parts of the North Sea, apparently in response to warming waters. Seabirds have failed to breed on the UK's North Sea coast as a result. Kittiwakes, Arctic terns, guillemots, and shags are among the seabirds that depend on sandeels for food. Sandeels are highly nutritious – without them adult birds do not reach breeding condition and may fail to nest. When sandeels are in short supply, there is not enough food for seabird chicks and they fail to survive. The birds have to forage harder to try and make ends meet. They may attempt to switch to other prey, if it is available, but this may be less suitable for survival.

In 2004, the situation was catastrophic. Entire colonies of seabirds did not return to their breeding grounds and those that did struggled to reproduce. In Shetland, Orkney and Fair Isle, hundreds of thousands of seabirds failed to raise any young. Not a single chick was raised by the entire population of more than 1,000 pairs of Arctic skuas in Shetland, while nearly 7,000 pairs of great skuas produced just a handful of chicks. More than 16,000 pairs of kittiwakes and all the Northern Isles' Arctic terns suffered an almost complete breeding failure. Breeding failure stretched right down to the RSPB nature reserve at Bempton Cliffs in Yorkshire.

Scotland's seabirds suffered yet another poor breeding season across much of the country in 2005, although the picture was mixed. The problem of food shortages and breeding failures spread to the west coast. On Tiree, in the Western Isles, numbers of guillemot, razorbill and Arctic tern chicks crashed. Where normally there are 1,500 guillemot chicks, there were only four.

Seabirds are long-lived but successive years of failure on this scale are bound to lead to population declines.

Envpol rspb 28 march 2008