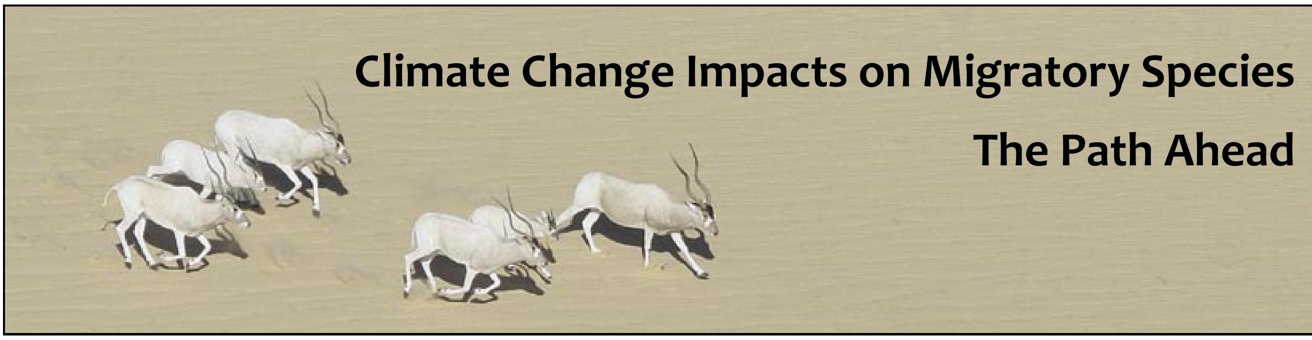


Climate Change Impacts on Migratory Species

The Path Ahead

Executive Summary: **The Zoological Society of London (ZSL) is conducting research for the UNEP Convention on Migratory Species (CMS) into the effects of climate change on species protected by CMS. Species have been identified as having a high, medium or low vulnerability to the threat of climate change and have been categorised on the basis of a standardised assessment process. This leaflet summarises the emerging results from an assessment of CMS Appendix I species, in order to provide guidance to policy makers at the earliest opportunity. Results highlight a number of processes by which greenhouse gas emissions and climatic changes will increasingly threaten migratory species; all species assessed will be affected by these impacts. A broad set of biological, geographical and socio-economic factors will influence species vulnerability. Identifying these factors and developing further conservation management practices will be essential for the short term future of these species. In the long term, the reduction of greenhouse gas emissions is vital if we are to avoid unmanageable levels of climate change.**

Assessment background and overview

CMS aims to conserve terrestrial, aquatic and avian migratory species throughout their range. Due to the urgent need to address climate change, the number of decisions responding to this threat has markedly increased within biodiversity-related treaties including the Convention on Biodiversity, the Ramsar Convention on Wetlands and CMS. CMS Parties have made several decisions that prioritise actions to reduce climate change impacts on migratory species. Most recently in 2008, Resolution 9.7 called upon Parties to mitigate climate change and aid adaptation of species to these changes. Section 2 of the resolution requests that research be undertaken to identify which Appendix I species are most vulnerable to climate change, with further research into Appendix II species to follow. Fulfilment of this part of Resolution 9.7 forms the basis of this study.

Investigations to date show that migratory species are particularly sensitive to climatic disturbances and corresponding impacts, including habitat loss/alteration and changes to the composition of biological communities[1,2]. Their vulnerability stems from the large energy investment they make to migrate to high quality habitats, often timing their arrival to coincide with the optimum abundance of resources at their destination.

This study, commissioned by the UNEP/CMS Secretariat, aims to identify how climate change is likely to affect individual migratory species, and the degree of threat that they face. The first wave of assessments have focused on species that undergo cyclic and predictable long-distance migrations, with the final study due to be completed in summer 2010. Almost half of Appendix I species have been assessed to date. Of these species, around half are marine, 38% are freshwater and 13% are terrestrial. Results show that climate change will have negative impacts on populations of all these species.

With carbon dioxide emissions already reaching 387ppm and causing significant and irreversible ecosystem change, it is evident that emphasis needs to be placed not only upon mitigation of greenhouse gas emissions, but also on maximising the adaptive potential of migratory species populations.

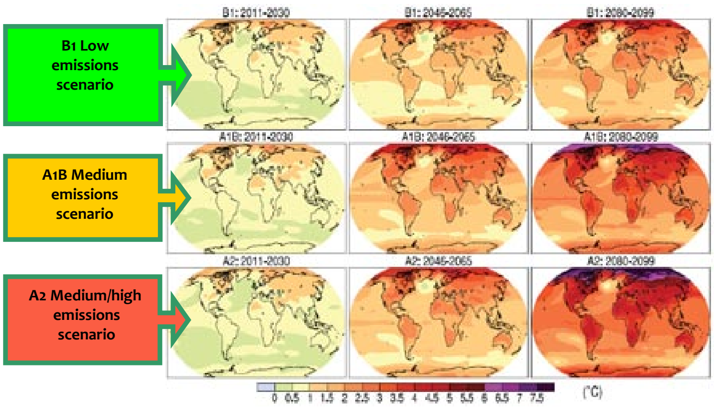
Mexican-free tailed bats

Threats to CMS Appendix I Migratory Species

A broad range of climate change processes will affect migratory species populations. These are outlined below, with examples of significant impacts on species identified in assessments to date.

INCREASING TEMPERATURES

Without mitigation, the IPCC predicts that temperatures will be 3.4°C warmer by the end of the century[3]. However, more recently the UK Met Office has indicated that temperatures are likely to increase by more than 5.5°C within the same time period[4]. Mitigation efforts will be able to reduce this predicted warming. However, due to inertia in the system, even if emissions were halted immediately the climate would continue to warm[5].



Annual mean surface warming (°C) for three emissions scenarios (A1, A1B, A2) and three time periods. Temperatures are relative to the average of the period 1980 to 1999. *Source: IPCC 2007 WGI*

Vital Habitats Due to the Melting of Sea Ice: Polar marine mammals will suffer due to a decline in protective and breeding habitats. The **bowhead whale**[6] and the **narwhal**[7] (Appendix II) require the Arctic sea ice to provide them with protection, whilst other species such as the **ringed seal** (not yet listed by CMS) rely upon this habitat to breed[8]. Intense warming is projected for the Arctic[3], with ice free summers expected by 2025-2040[9,10].

Collapsing Food Webs Linked to Changes in Zooplankton Abundance: Baleen whales, a number of fish (e.g. **basking shark**)[11] and bird species (e.g. **Humboldt penguin, Balearic shearwater, Bermuda petrel, short-tailed albatross**) are reliant on abundant zooplankton either directly, or to nourish their prey: krill, fish and cephalopod populations. These species will be negatively affected by changes in marine ecosystems and food-webs as increasing sea temperatures cause zooplankton abundance to decline[12]. Algae, a vital nutrient within the Arctic ecosystem, is also predicted to decline as this grows beneath the sea ice.

Numerous cetaceans that feed in the Arctic such as the **bowhead whale**[13] and three **right whale** species will be affected as krill abundances decline.

Changing Sex Ratios: Many reptiles are reliant on temperature sex determination[14], as are some birds[15] and fish[16]. Temperatures of 29.2°C produce a 50:50 sex ratio in sea turtle populations; including the **green turtle, hawksbill turtle, leatherback turtle, loggerhead turtle and the olive ridley turtle**. Higher temperatures will lead to the feminisation of populations[17], which will affect breeding success.

CHANGES IN PRECIPITATION

An increase in temperature will intensify the hydrological regime whilst increasing the spatial variability of precipitation. The overall projected patterns show a reduction of rainfall in the subtropics and an increase in rainfall near the equator and at high latitudes[3].

Reducing Wetland Habitats for Breeding and Feeding: Many bird species are particularly dependent on wetland habitats during vital stages of their life cycles. Reduced precipitation in these areas will negatively impact many species including the **Andean flamingo**, **aquatic warbler** and **red-knot.** Decreased precipitation coupled with increased evaporation rates has been identified as a key threat that will cause a reduction in the number of wetland stop-over habitats available to the **swan goose** and the **white-naped crane**[18]. To breed, the **Basra reed warbler** requires aquatic vegetation in or around shallow water, on marshlands and in river basins across Mesopotamia[19]. This habitat is under threat from drought, alongside increased human pressures from water extraction. Water resources for this region are already in decline, and models show a stark decrease in the availability of water from the moderate to the high warming scenarios[20], highlighting the importance of climate change mitigation.

Reducing Grazing Habitat for Terrestrial Mammals: Terrestrial mammals such as the **addax**, **Cuvier's gazelle** and **dama gazelle** are already adapted to very dry climates. However, a number of models are predicting prolonged periods of drought in the North African region[21] which will further increase pressures on both wild and domestic animals through declines in grazing habitats.

Addax

Variation in Rainfall Affecting Breeding Success: More variable rainfall is likely to affect the breeding success of birds, especially those nesting in close proximity to water. **Relict gulls** for instance, are is very sensitive to changes in water levels as they require low-lying islands on freshwater lakes for nesting[22]. Precipitation across much of this breeding habitat is expected to increase in variability[3], further reducing the low breeding success of the species. Aquatic reptiles such as the **Kemp's ridley turtle** utilise freshwater beaches for egg-laying. Heavy rainfall from storms has the potential to rapidly cool the sand and nest temperature, increasing mortality in hatchlings[23]. The crocodile-like **gharial** is also vulnerable to variations in rainfall. High water levels and faster river flows can destroy nest sites and cause higher mortality, particularly in hatchlings[24]. In 2008, early monsoon flooding destroyed all nests in Katerniaghat, India, a primary reserve for this species.

EXTREME WEATHER

More erratic weather regimes, which increase the incidence of phenomena such as hurricanes, droughts and floods, are predicted to become more frequent[25]. This is likely to increase the vulnerability of many species in the future. Half of the CMS Appendix I species studied to date have been identified as vulnerable to increased incidences of extreme weather, mainly through direct impacts on mortality rates.

West African manatee

Extremes in Temperature: Species which utilise freshwater habitats appear to be much more vulnerable to extreme weather events when compared with marine species, as they are more restricted in their movement and the smaller water bodies they inhabit heat up more rapidly. Extreme temperatures have been known to cause mortality in the **West African manatee** as sections of river can become isolated from the main flow, leaving pools or channels vulnerable to intense heating[26]. Other species such as the **Ganges River dolphin** are also vulnerable to these changes.

Increased Storm Frequency and Intensity: The diet of marine mammals has been shown to be impacted by increased incidence and intensity of storms. Storms can affect zooplankton concentration, thereby disrupting the diet of many marine species. Krill, upon which the **blue whale** depends, have been documented to be affected by tropical cyclones and increased surface turbulence[27] and it is likely that this will also negatively affect other baleen whales and the **basking shark.** The nesting beaches of marine turtles are expected to be damaged by the increased occurrence and intensity of hurricanes and tropical cyclones[28], with **green turtles** being particularly vulnerable as they use beaches prone to storms during peak hurricane season. The storm surges generated have the potential to destroy large numbers of nests[29]. The **Mexican-free tailed bat** is also expected to suffer because the availability of its insect prey is reduced in poor weather[30].

Precipitation Extremes: The **West African manatee** is vulnerable to both high and low extremes in river flow[31]. Precipitation in West Africa is expected to become more extreme with more infrequent, heavy rainfall[3]. Optimum habitat for the manatee is deep, slow moving river waters[31]. Drought leaves them vulnerable to isolation in channels and to the loss of navigable habitat.

Flooding events cause fast flowing water, and can lead to entrapment when the waters recede.

SEA LEVEL RISE

By 2100, the IPCC predict sea levels will rise by 0.18m-0.59m compared to 1980-1999[32] levels. However, other models indicate a much greater magnitude of sea level rise by the end of the century[10], with some predicting it to be in the range of 0.5m - 1.4m[33]. This will have an impact on numerous migratory species utilising coastal habitats.

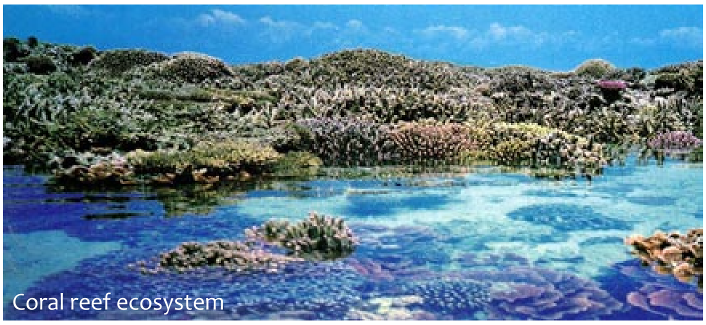
Loss of Low-Lying Coastal Habitats: The **swan goose** for instance, will lose large amounts of its important wintering grounds located on coastal mudflats and estuaries. This will greatly reduce the winter feeding capacity of the species, as there will be less prey available, reducing the amount of energy available for their annual migration[34].

Loss of Nesting Sites: Of species listed on CMS Appendix I, sea turtle populations are likely suffer the most from sea level rise. The IPCC predicts that a sea level rise of 0.5m will eliminate 32% of sea turtle nesting grounds[35]. If sea levels rise significantly higher than this over the next century, which is expected, many more vital nesting sites will be threatened.

OCEAN ACIDIFICATION

CO_2 is the primary molecule influencing the pH of oceans[36]. Since the 1800's, oceans have absorbed 1/3 of anthropogenic CO_2 emissions[37] and the average oceanic pH has dropped by 0.10 units, equivalent to a 30% decrease. If unmitigated, oceanic pH is likely to decrease by a further 0.4 units[36] by 2100. Increases in atmospheric CO_2 are currently more rapid than at any point in the last 650,000 years[38]. A reduction in pH will have impacts on the entire oceanic system, with high latitude cold water oceans affected earlier and more severely than warm water oceans.

Impacts on Food-Webs: Many species including corals, snails and krill are dependent on aragonite and calcite concentrations in the water. As oceans acidify, these minerals will become less abundant and species will struggle to mineralise their exoskeletons. Severe impacts will be felt within polar regions, with aragonite undersaturation expected to occur as early as 2016[40] and both calcite and aragonite concentrations expected to be insufficient for mineralisation in Arctic waters by 2060[41]. This will have serious consequences for the entire ecosystem, as species dependent on these minerals form the basis of food webs in these regions. As zooplankton composition and abundance is expected to change[39,42,43,44], species directly or indirectly dependent on these (e.g. whales, dolphins) are likely to suffer[25].



Coral reef ecosystem

Habitat Loss: **Hawksbill turtles** depend upon coral reef ecosystems at various stages of their life-cycle[45]. The shelves and caves formed by coral reefs provide resting and sheltering areas for this species[46], whilst adult hawksbills feed almost exclusively upon reef fauna[45]. By 2030-2050, reefs globally will be facing severe acidification stress[25]. Coral reef formation depends upon aragonite, which has decreased considerably in tropical seawaters[47]. When atmospheric CO_2 levels reach approximately 450ppm, the ability of coral reefs to withstand erosion and grow will be severely impeded[48]. This combined with increased temperature stress and storm frequency will cause the collapse of coral reef ecosystems globally, possibly within the next 30 years. Considering that coral reefs are the most biodiverse marine ecosystems harbouring up to 3 million species, with more than 1/4 of all marine fish species, the **"Coral Reef Crisis"** is currently proving to be the most urgent threat to biodiversity from climate change. Further degradation could precipitate a 'domino-effect' across marine ecosystems[49], which is likely to have severe implications for many CMS species.

OCEAN CIRCULATION

Marine primary production is the basis of ocean ecosystems and a key component of the carbon cycle[50]. By increasing water temperatures and freshwater discharge from melting ice sheets, climate change will affect nutrient supplies and is likely to change the ocean circulation system[32]. All marine species assessed were found to be vulnerable to these changes; however there is currently still a high spatial and temporal uncertainty as to the extent and magnitude of these impacts[51].

Changes in Food Distribution and Abundance: Ocean circulation affects species abundances, through nutrient upwellings and more directly by transporting species and providing resources for specific oceanic habitats. Numerous species (e.g. **humpback whale**[13], **basking shark**[11]) are likely to be affected by changing ocean circulations as these will affect prey distribution. Migration routes will have to adapt[52] if species are to survive.

Humpback whale

Altering Migrations: Many species depend upon ocean currents to aid movement, with a number of turtle species using ocean currents to migrate. During their juvenile phase, **hawksbill turtles**[54] and **loggerhead turtles**[55] float on ocean currents until they mature. Turtle hatchlings instinctively swim towards local surface currents to help transport them across ocean basins[53]. Changes in ocean circulation are likely to change the distributions and migration patterns of such species[54].

SPATIAL AND TEMPORAL RESPONSES

Species have varied responses to climate change. Some species are already adapting the timings of their annual cycles due to a changing climate, whilst others are altering the locations of their migration or foraging habitats. Such individual and dynamic responses will inevitably interfere with species interactions.

Biome Shifts: Migratory species rely on a number of isolated high quality habitats during their annual cycle. Any disturbance or alteration to a required habitat can leave a species vulnerable[1]. As temperatures rise, the distances between suitable habitats can increase. This threat is particularly pronounced when geological features or human developments limit suitable habitats, when there are barriers to migration, or when food abundances occur in different locations to traditional migratory routes. The distance between the breeding and feeding sites of the **Balearic shearwater** is increasing due to shifts in prey abundances, linked to changing sea surface temperatures[56,57,58,59]. The extra energy required for this migration increases the species vulnerability.

Phenological Shifts: Species display varying phenological responses to climate change, which can lead to mismatches in predator prey interactions. For example, due to increasing sea surface temperatures, changes in **loggerhead turtle** nesting times are occurring[60] which could alter predation on hatchlings.


Loggerhead turtle hatching

Mismatches also occur when food requirements and abundances do not coincide[52,61]. Energy-intensive migrations are timed with critical life stages, including reproduction cycles and growth of individuals, linking them to periods of peak resource availability. Mistiming of these events could have severe consequences for many species.

Habitat Loss: Biome shifts will result in the reduction of certain habitats. For example, tundra habitat cannot advance polewards as temperatures rise due to its position at the northern extent of the Eurasian landmass. These higher temperatures are causing forests to invade areas which were originally treeless tundra[62,63], greatly reducing suitable habitat area for some species. The **Siberian crane** for example is currently affected by these changes as the open tundra that it requires to nest disappears[64,65].

EXACERBATION OF EXISTING THREATS

The majority of the species assessed by this study are already at high risk from anthropogenic pressures. There is evidence that past climatic change increased overexploitation of certain species[66]. The negative socio-economic impacts of current climate change on humans will ultimately result in increased anthropogenic pressures on species and natural systems. For example, harvested species are likely to be even more heavily exploited. Wetland habitats will be starved of water as it becomes increasingly diverted for human use, threatening species such as the **Basra reed warbler**[67]. Sea level rise will encourage the construction of coastal defences, which are likely to negatively impact species reliant on coastal habitats, including sea turtle species and the **West African manatee**[68].

Climate change has the capacity to act synergistically with current anthropogenic threats, so that species are not only dealing with the direct impacts of climate change, but also consequences of climate change impacts on humans. Current anthropogenic threats also weaken a species ability to cope with climate change. Building resilience into species populations, and the habitats on which they depend by reducing conventional threats such as pollution, habitat fragmentation and overexploitation will improve species ability to adapt.

Preliminary Recommendations

Monitoring and Further Research Needs: Little is known about migratory species capacity for adaptation to climate change. If we are to gain a solid understanding of the impacts of climate change on migratory species, intensive monitoring and research is needed. Thorough assessment is not only required for species already protected by CMS, but also for those not currently listed in the Appendices. This knowledge is vital to identify key limiting factors, the 'weakest link', upon which each species survival hinges, and to provide essential building blocks for policy guidance. Further literature on the interactions between climate change and migratory species populations is being gathered and made available online to inform policy and management decisions: www.bioclimate.org

Managing Changing Environments: The advantage that migratory species have in comparison with most non-migratory taxa is their ability to move over large distances. To facilitate this movement, it is vital to improve the connectivity of habitats critical to population survival currently and in the future. CMS is already involved in developing critical site networks and tools such as the African-Eurasian Waterbird Agreement's Wings Over Wetlands Project (www.wingsoverwetlands.org). There is an urgent need to identify and protect further critical site networks with species range shifts in mind. By maintaining viable habitats and reducing current threats, stakeholders may be able to improve the resilience of some species to cope and adapt to climate change.

Difficulty of Adaptation and Importance of Mitigation: The large extent of many migratory species ranges will make the design of adaptation strategies, aimed at minimising climate change impacts, very challenging. For instance, the **Siberian crane's** global population consists of roughly 3000 individuals, which nest over an area of 26,000km². Even if adaptation is facilitated, such as by shifting migratory routes with imprinting and microlight plane guidance (e.g. Flight of Hope project), these measures require a large investment both in terms of time and money.


Siberian Cranes

Unfortunately, even high levels of investment will not ensure viable populations if emissions surpass critical thresholds, as many of the threats highlighted in this study will be difficult to control and adapt to once levels are breached. Furthermore, populations currently dependent on habitats located on the most northerly or southerly ends of landmasses, as well as those close to mountain tops, are particularly vulnerable since migration to follow their climatic niche is not an option. There is potential for the translocation of species to new areas through assisted colonisation/migration, but this again is costly and should only be used as a last resort once adequate research has been done on the long term affects of such drastic intervention.

On a species by species basis, provisions to aid adaptation could be feasible in the short to medium term, but it is clear that for a multitude of species such actions will be too costly and ultimately not sufficient to ensure their survival, especially if rapid levels of climate change are allowed to occur. It is therefore vital that a **dual approach** be taken where; **proactive adaptation measures** are applied to species already threatened by committed levels of climate change alongside **considerable and rapid emissions abatement** to limit further impacts. This is the only cost effective and practical way to safeguard migratory species into the future.

Contributors: ZSL - John Atkinson, Jonathan Baillie, Ben Collen, Katherine Breach, Hannah Froy, Sonia Khela, Aylin McNamara, Ananya Mukherjee, James Peet, Rachel Smith; IUCN - Wendy Foden; CMS - Aline Kühl. *Heading photo credit:* Tim Wacher
Acknowledgements: Thanks to Paul Pearce-Kelly & Phil Holmes - ZSL
For more information contact: ***aylin.mcnamara@zsl.org*** **&** ***akuehl@cms.int***

References

1. Both, C. & Visser, M., E. 2001, *Nature*, 411, 296-298.
2. Robinson, R, et al. 2008, *Endang. Species Res.*
3. Christensen J.H., et al. 2007. IPCC FAR WG1.
4. UK Met Office: www.metoffice.gov.uk/climatechange/policymakers/action/emissions_270908.pdf
5. Plattner G., et al. 2008, *J. Clim*, 21, 2721–2751.
6. Jefferson T., et al. 2008, In: IUCN 2009. V2009.1.
7. Laidre, K. & Heide-Jørgensen, M, 2005, *Bio. Cons*, 121, 509-517.
8. Ferguson, S.H., et al 2005. *Mar. Mam. Sci*, 2, 11, 121–135.
9. Wang M. & Overland J., 2009, *Geophys Res. Letters*, 36.
10. Kerr R., 2009, Science, 323, 5922, 1655.
11. Cotton P.A., et al. 2005, *Fisheries Oceanography* 14, 151-155.
12. Doney, S.C. 2006, *Nature*, 444, p 752.
13. Reilly S.B., et al. 2008, In: IUCN 2009. V2009.1.
14. Janzen F.J., 1994, *Proc. Nat. Acad. Sci. USA*, 91, 7487–7490.
15. Göth A. & Booth D.T., 2005, *Biology Letters*, 1, 31–33.
16. Ospina-Alvarez N, & Piferrer F., 2008 *PLoS ONE*, 3, 7, 2-37.
17. Hawkes L.A., et al. 2007, *Glob. Change Biol.*, 13, 5, 923-932.
18. Arnell N., 1999 *Global Environmental Change*, 9, 31-49.
19. Fadhel O., 2007, *OSME*, 29, 1, 95-97.
20. Kitoh A., et al. 2008, *Hydrological Research Letters*, 2, 14.
21. Biasutti M., et al. 2008, *Climate*, 21, 3471-3486.
22. BirdLife International, 2009, *Larus relictus.*
23. Walling D. & Fang D., 2003, *Global & Planetary Change*, 39,111-126.
24. Chaudhari S., 2008, *Iguana*, 15, 3, 151-153.
25. Meehl G.A., et al. 2007, IPCC FAR WG1.
26. Learmonth J. et al. 2006, *Oceanog, & Mar. Bio*, 44, 431-464.
27. Davis R. et al. 2002 Oceanog. res. papers, 49, 1,121-142.
28. Hirth H. F., 1997, Dept. Interior.
29. Pike D.A. & Stiner J.C., 2007 *Oecologia*, 153, 471-478.
30. Robinson R.A., et al. 2005, BTO Research Report 414, Defra.
31. Powell J. & Kouadio A., 2008 In: IUCN 2009, V2009.1.
32. Bindoff N.L., et al, 2007, IPCC FAR WG1.
33. Rahmstorf S., 2007, *Science*, 315, 5810, 368.
34. BirdLife International 2008. In: IUCN 2009, V2009.1.
35 Fischlin A., et al, 2007, IPCC FAR WGII 211-272.
36 Caldeira K. & Wickett M.E., 2003, *Nature*, 425, 365.
37 Sabine C. L et al., 2004, *Science*, 305, 367-371.
38 Siegenthaler U., et al 2005, *Science*, 310, 1313-1317.
39 Orr et al., 2005 *Nature*, 437, 29.
40 Steinacher M., et al. 2009, *Biogeosciences*, 6, 515-533.
41 Turley C., et al, 2009, UKOARP.
42 Riebesell U. et al. 2000, *Nature*, 407, 6802, 364-367.
43 Feng Y., et al. 2008, *European J. of Phycology*, 43, 87-98.
44 Fabry V.J. et al. 2008, ICES *J. of Mar. Science*, 65, 414-432.
45 Leon Y. & Bjorndal A., 2002, *Mar. Eco. Prog. Series*, 245, 249-258.
46 NOAA, 2009, Office of Protected Resources.
47 Kleypas J. & Langdon C., 2006, *Am. Geo. Uni*, 61, 73-110.
48 Veron J. E. N., et al. 2009, *Mar Poll Bulletin*, 58, 1428-1437.
49 Veron J. E. N., 2008, Harvard Univ Pr.
50 Behrenfeld M. J., et al, 2001, *Science*, 291, 2594-2597.
51 Clark P., 2002, *Nature*, 415, 863-869.
52 Walther G., et al, 2002, *Nature*, 416, 389-395.
53 Lohmann K. & Lohmann C, 2003, Smithsonian, 44-62.
54 Mortimer J.A. & Donnelly M., IUCN 2009, V2009.1.
55 Bolten A.B., 2003. Smithsonian Books, 63-78.
56 Ye´sou P., 2003, *Sci. Mar.* 67 (Suppl. 2), 143-148.
57 Perry A. L., et al. 2005, *Science*, 308, 1912-1915.
58 Poulard J. & Blanchard F., 2005, *ICES J. Mar. Sci*. 62, 1436-1443.
59 Wynn R.B. et al, 2007, *Biol. Lett*. 2007 3, 529-532.
60 Weishampel J. et al. 2004, *Glob. Chan. Biol*, 10, 1424-1427.
61 Visser M. E. et al. 2004, *Adv. Ecol. Res.* 35, 89-110.
62 Piersma T. & Lindström Å., 2004, *Ibis*, 146 (1), 61-69.
63 Johnstone J. & Chapin F.S., 2006, *Ecosystems*, 9, 268-277.
64 Meine C.D. & Archibald G.W., 1996, Switzerland, IUCN.
65 Harding, R. et al., 2002, *Ambio Spec. Rep.* 12, 47-55.
66 Odner, K., 1992, Scandinavian University Press.
67. Pearce, F., 2009, *New Scientist.*
68. Reynolds III, J.E. & Powell, J.A. 2002, Academic Press, San.