WWF for a living planet®

FUNDACIÓN VIDA SILVESTRE ARGENTINA

For further information contact:
Species Programme
WWF International
Av. du Mont-Blanc
1196 Gland
Switzerland

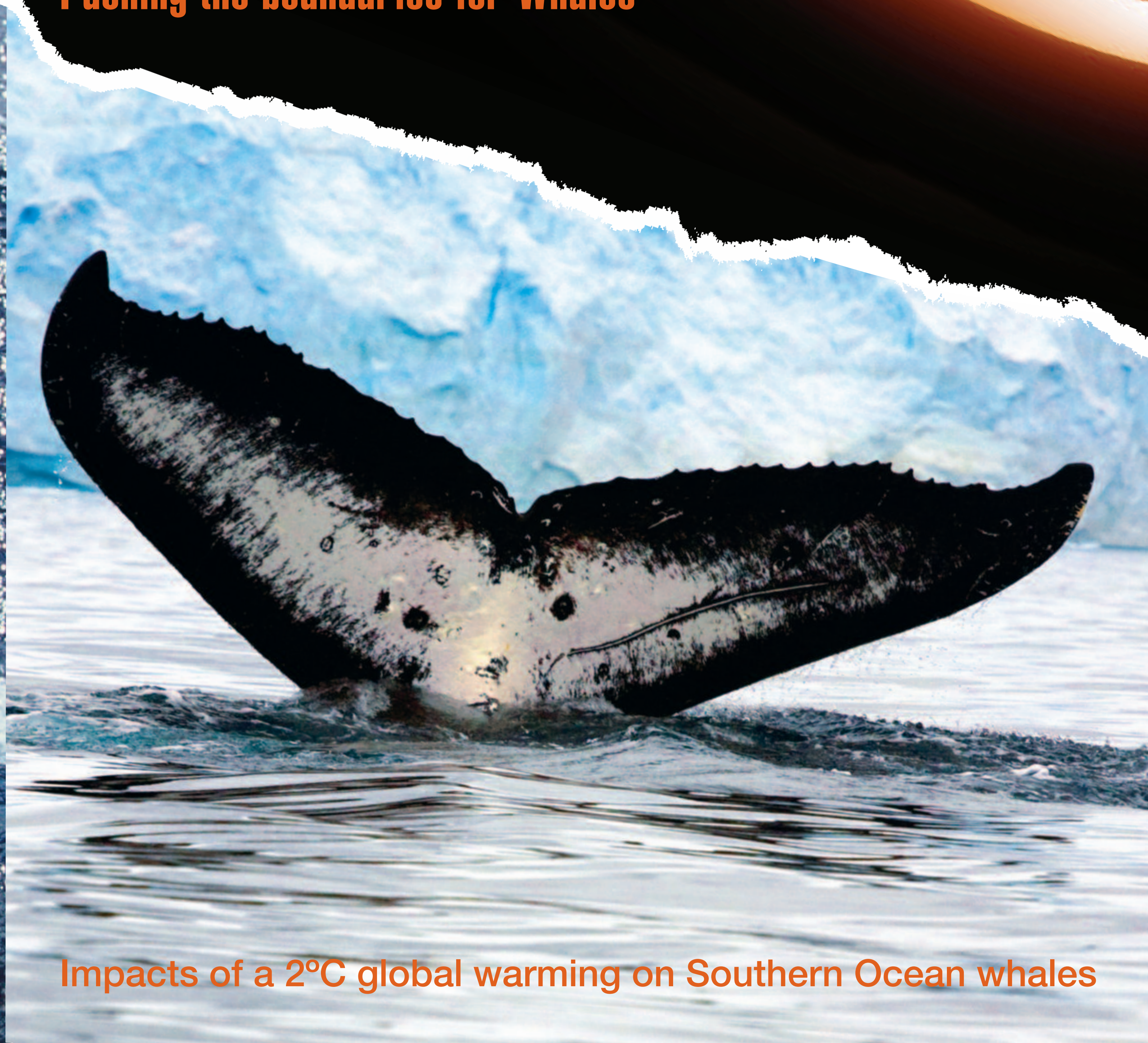
+41 22 364 91 11

www.panda.org/species/iwc

WWF for a living planet®

Ice breaker

Pushing the boundaries for Whales



Impacts of a 2ºC global warming on Southern Ocean whales

Summary

Mean global temperature could reach 2°C above pre-industrial levels by 2042, leading to significant impacts on Southern Ocean whales. According to state-of-the-art climate models, under 2°C global warming, the area of the Southern Ocean covered by sea ice is projected to shrink by an average of 10-15%. This reduction could be up to 30% in some regions, meaning that species that are heavily dependent on sea ice, such as the Antarctic minke whale (*Balaenoptera bonaerensis*) are projected to lose between 5-30% of ice-associated habitat within 40 years – little more than the life time of an individual whale.

Reductions in ice cover is also likely to affect the ice-dependent Antarctic krill (*Euphausia superba*). Less availability of Antarctic krill would have significant ramifications for both resident and migratory whales, as well as the Antarctic ecosystem, as these small shrimp-like zooplankton are a critical component of the Antarctic food web.

Under 2°C global warming, frontal zones – critical whale habitats - are also projected to move southwards. Frontal zones are boundaries between different water masses, where water can rise from the depths, bringing with it large amounts of nutrients that stimulate the growth of phytoplankton and support substantial populations of prey species for whales. Migratory whales such as humpback (*Megaptera novaeangliae*) and blue whales (*Balaenoptera musculus*) would have to travel even farther south (an extra 200-500 km) to reach and feed at these food-rich areas where they build up reserves to sustain themselves for the rest of the year. These longer migration paths could increase the energy costs of migration and reduce the duration of the main feeding season. As frontal zones move southward, they also move closer together, reducing the overall area of foraging habitat available.

In order to avoid dangerous climate change that would bring irrevocable consequences worldwide, especially to polar marine ecosystems, it is imperative that the world makes immediate and concerted efforts to reduce global climate-damaging emissions. At the same time, it is equally important to make efforts to increase the resilience of ecosystems and species by incorporating observed and projected climate-change impacts into conservation plans, assessments and strategies.

WWF

FUNDACIÓN VIDA SILVESTRE ARGENTINA

Acknowledgements

This brochure was derived from the scientific study by Dr. Cynthia Tynan and Dr. Joellen Russell: Tynan, C. T. and Russell, J.L. 2008. Assessing the impacts of future 2°C global warming on Southern Ocean cetaceans. International Whaling Commission, Scientific Committee document SC/60/E3

The brochure text was written by Wendy Elliott, WWF-International Species Programme, and Dr. Tina Tin, WWF Antarctic Climate Change Focal Project, with input from Dr. Cynthia Tynan, Dr. Joellen Russell, Juan Casavelos, Dr. David Ainley, Dr Mark Simmonds, Heather Sohl and Alison Sutton.

Design by

InsideOut Creative Limited.
www.insidetheoutside.co.uk

June 2008

Image credits

Front cover

Whale tail © Mark Fitzsimmons

Dying Earth © Kativ

Back cover

Humpback whale

© Cat HOLLOWAY / WWF-Canon

Preventing Irrevocable Consequences of Climate Change: why 2 degrees?

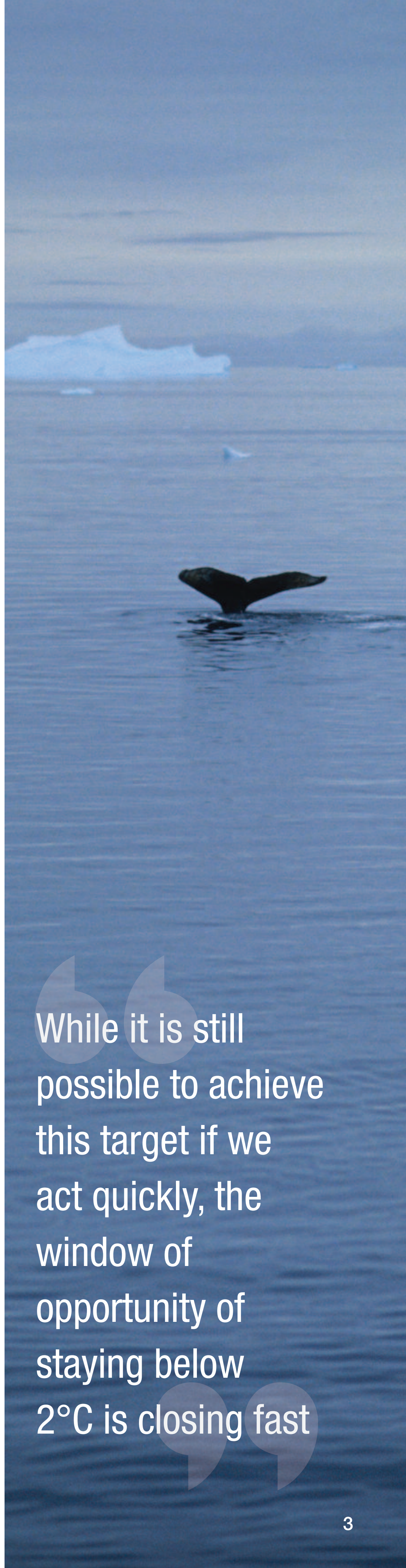
Global warming is real and is happening. Warming is widespread over the globe; the average global temperature has increased by 0.74°C over the past 100 years and warming is widespread across the planet, with 11 of the last 12 years (1995-2006) ranking among the twelve warmest years in the instrumental record of global surface temperature (since 1850) (IPCC, 2007a). The impacts of climate change are diverse and are evident across the planet – from melting snow and ice, to more frequent heat waves and heavy rain events, to rising global sea levels and more areas affected by drought. This global warming is the direct result of human activities since industrial times: Burning fossil fuels, clearing forests and intensive farming have released and accumulated unprecedented amounts of greenhouse gases into the atmosphere.

Leading scientists, some national governments, as well as other organizations such as WWF, have identified the urgent need to limit the emissions to maintain the warming below 2°C above the temperature in pre-industrial times, in order to prevent "dangerous climate change" with irrevocable consequences. While it is still possible to achieve this target if we act quickly, the window of opportunity of staying below 2°C is closing fast.

While remote, the polar regions of the world have not escaped from the effects of global climate change. In fact, they are among the regions that are exhibiting the most dramatic effects of climate warming. Over the past 50 years, the Western Antarctic Peninsula has warmed more than four times faster than the average rate of Earth's overall warming (IPCC, 2007a). The vast Southern Ocean has warmed all the way down to a depth of 3,000 m (Jacobs, 2006). Not all of Antarctica is warming, nor has the warming been uniform. However, in areas where significant warming has been experienced, terrestrial and marine ecosystems have undergone major changes (IPCC, 2007b). Where sea ice cover has reduced because of the warmer temperatures, populations of Antarctic krill, Weddell seal (*Leptonychotes weddellii*) and Adélie (*Pygoscelis adeliae*) and emperor penguin (*Aptenodytes forsteri*) have dropped. On the other hand, species that do not like sea ice, such as shallow-water sponges and chinstrap (*Pygoscelis antarcticus*) and gentoo (*Pygoscelis papua*) penguins, have expanded into ice-free territories (Ainley et al., 2005 ; Atkinson et al., 2004; Ducklow et al. 2007). On land, warmer summer temperatures have probably caused the two only native flower plants in Antarctica to increase in numbers and area (Fowbert and Smith, 1994).

Assessing the impacts of climate change on cetacean species (whales, dolphins and porpoises) is not a straightforward task. However, emerging scientific evidence points out that climate change is likely to decrease or restrict the preferred habitat of all cetacean species listed as threatened by the IUCN for which projections can be made (Learmonth et al. 2006). The impacts of climate change on whale species are likely to be most significant in the polar regions, where the effects of warming on ecosystems are happening first, and fastest.

It is with this in mind that WWF commissioned new research from US scientists Cynthia Tynan and Joellen Russell. Combining the projections of state-of-the-art climate models with expert knowledge on the Southern Ocean whale ecology, Tynan and Russell (2008) assess what a globally-averaged 2°C rise in temperature will mean for the Antarctic ecosystem, and for the whales that rely on it.



Right;
Antarctic sunset © André Schafer

Modeling the Southern Ocean under 2°C global warming

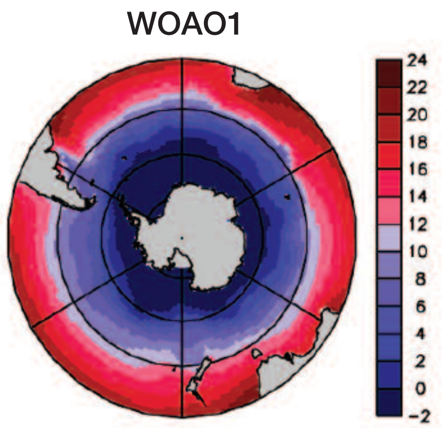
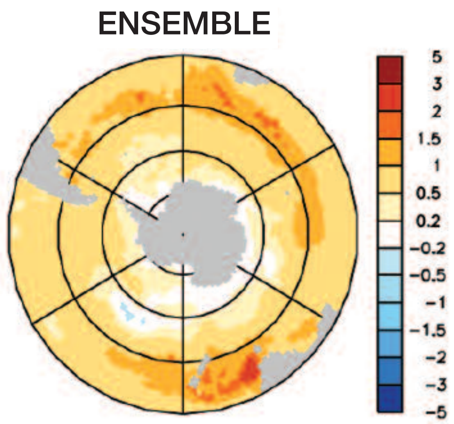


Figure 1
Observed annual mean sea surface temperatures (°C, 0-100m average) from the World Ocean Atlas (WOA01, Conkright et al., 2002)



The change in sea surface temperature from the ensemble average of the four models at the year of 2°C global warming. Orange and yellow colours indicate an increase in temperature, blue colours indicate a decrease.

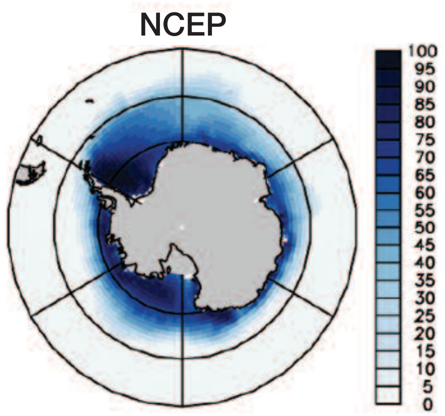
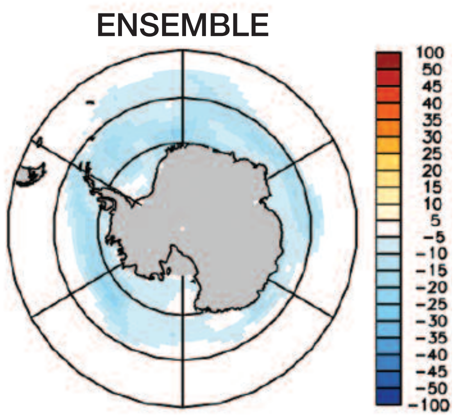


Figure 2
Observed annual mean sea ice coverage (%) from the National Center for Environmental Prediction reanalysis (NCEP, Reynolds et al., 2002)



The change in sea ice coverage from the ensemble average of the four models at the year of 2°C global warming. Orange and yellow colours indicate an increase in sea ice, blue colours indicate a decrease.

In order to make projections about the future of whale populations in the Southern Ocean, it is necessary to forecast how their physical environment would change. The location of feeding areas of Southern Ocean whales are closely related to the location of sea ice and 'frontal zones' the boundaries between different water masses (Tynan. 1998; see 'Whales, food and sea ice in the Southern Ocean). Out of 18 state-of-the art climate models, Tynan and Russell (2008) chose the four models that had the best overall simulation of the Southern Hemisphere atmosphere, ocean and sea ice changes (Russell et al., 2006). The models were chosen from the United Nation's Intergovernmental Panel on Climate Change (IPCC, 2007a) Fourth Assessment Report (AR4). The four models were combined to create an "ensemble" which was then analyzed to project future Antarctic air, ocean, and ice conditions.

According to these four models, 2°C global warming could be a reality in less than 40 years. On average, the ensemble of the four models reached 2°C global warming by the year 2042, with the range spanning between 2027 and 2053.

In general, as would be expected, a warmer atmosphere leads to a warmer Southern Ocean (figure 1) and less sea ice around Antarctica (see figure 2). The models project that the ocean surface would warm by more than 0.5°C with greater increases downstream of Australia. Averaged over the Southern Ocean, the area covered by sea ice is projected to decrease by 10-15%, with larger regional decreases of up to 30% projected in particular areas.

Right;
Iceberg, Pleneau Bay. Antarctic Peninsula.
© Sylvia RUBLI / WWF-Canon

Effects of loss of sea-ice coverage on Southern Ocean whales

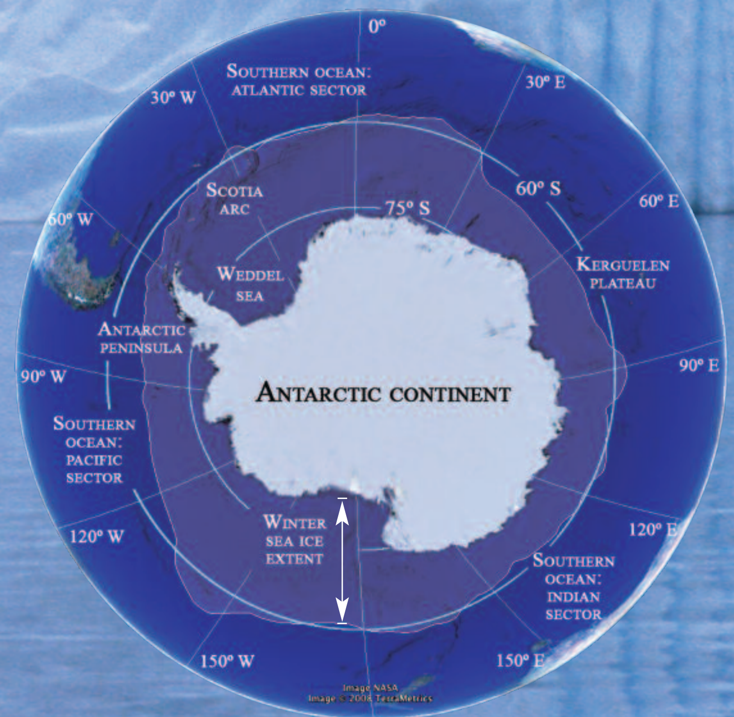
Seasonal changes in sea ice strongly affect the habitat preferences and occurrence patterns of the Antarctic minke whale. The Antarctic minke whale resides primarily in sea-ice habitat (Aguayo-Lobo, 1994; Ainley et al. 2007) and is projected to lose between 5-30% of ice-associated habitat by the time of 2°C warming, depending on the sector of the Southern Ocean concerned. As the sea ice area shrinks, increased densities of Antarctic minke whales could be recorded as they crowd into the remaining suitable sea ice habitat, where they would be competing with other species, such as seals, for space and food (Siniff et al. 2008). Such competition would further decrease prey availability and, ultimately, the populations of these predators.

The loss of sea ice would also probably result in a reduction of one of the most important prey species for whales - the Antarctic krill. The life cycle of krill has evolved in association with sea ice and regional circulation patterns (Nicol, 2006; Nicol et al., in press). Krill occur in regions that are covered by ice in winter, and their life cycle is closely related to the seasonal changes of sea ice cover (Brierley and Thomas, 2002). Less krill would affect not only the Antarctic minke whale but also the majority of the baleen whales in the Southern Ocean, including the blue whales and humpback whales which depend on krill for food. A projected loss of sea ice cover of 25%, would result in a compensatory increase in open water of 25% in the Southern Ocean. It is estimated that this would increase primary production (i.e., the amount of phytoplankton biomass produced per unit area and time) by 10% (Arrigo and Thomas, 2004). However more phytoplankton is not always beneficial. It has been observed in many parts of the global coastal ocean that increases in phytoplankton algal blooms are often accompanied by ecologically harmful shifts in the species composition of phytoplankton (Kahru and Mitchell, 2008). For example, evidence exists that warming along the Antarctic Peninsula has contributed to a shift from large diatoms, which krill prefer to eat, to small cryptophytes (Moline et al., 2004). Therefore, krill populations might be diminished from both a direct loss of ice habitat and subsequent shifts in their preferred phytoplankton food.

A number of areas, including the West Antarctic Peninsula, Scotia Arc, Weddell Sea and the Pacific and Atlantic Sectors of the Southern Ocean are projected to experience as high as a 20-30% reduction in sea ice coverage by the time of a 2°C increase in global temperature. This is likely to strongly impact both resident Antarctic minke whales and migratory whale populations in these regions:

- In the Southeast Pacific Sector, the shrinkage of the sea-ice zone would result in a loss of summer and autumn ice edge habitat for migratory and resident whale populations.
- Along the West Antarctic Peninsula, the distribution of humpback and minke whales is closely linked to the boundary between frozen sea ice and open water - the "ice edge" (Thiele et al., 2004; Friedlaender et al., 2006). Since 1980, the Antarctic Peninsula region has experienced the greatest warming of the Southern Hemisphere (Overland et al., 2008). The climate models used in this study project that this region will continue to rapidly lose sea ice, and consequently, loose important foraging habitat for humpback and minke whales.
- In the Atlantic Sector, Scotia Arc, the loss of sea ice coverage could affect the movements and foraging of minke whales and blue whales, which appear to migrate through open waters to the ice-edge zone to feed (Reilly et al., 2004). Averaging across all models, it is projected that whales in the Atlantic Sector, approaching the Weddell Sea, would encounter a 10-20% reduction in ice coverage at the time of 2°C warming, although one model projected a reduction in ice cover of up to 40%.

Figure 3
Map of the Antarctic continent and Southern Ocean.



Effects of poleward displacement of ocean fronts

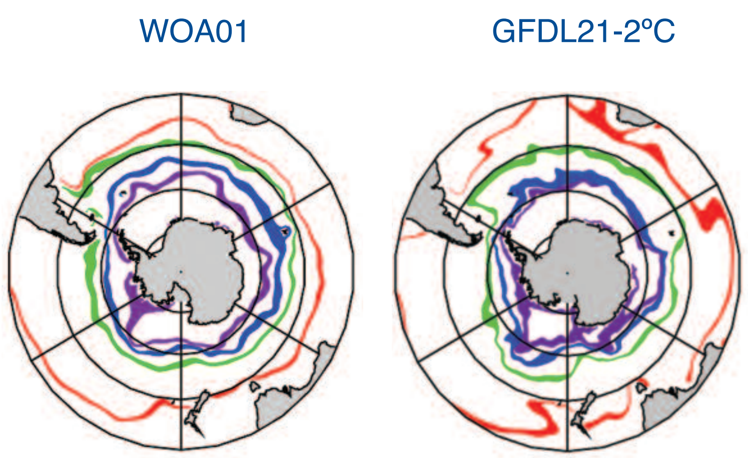


Figure 4: Locations of Southern Ocean fronts;

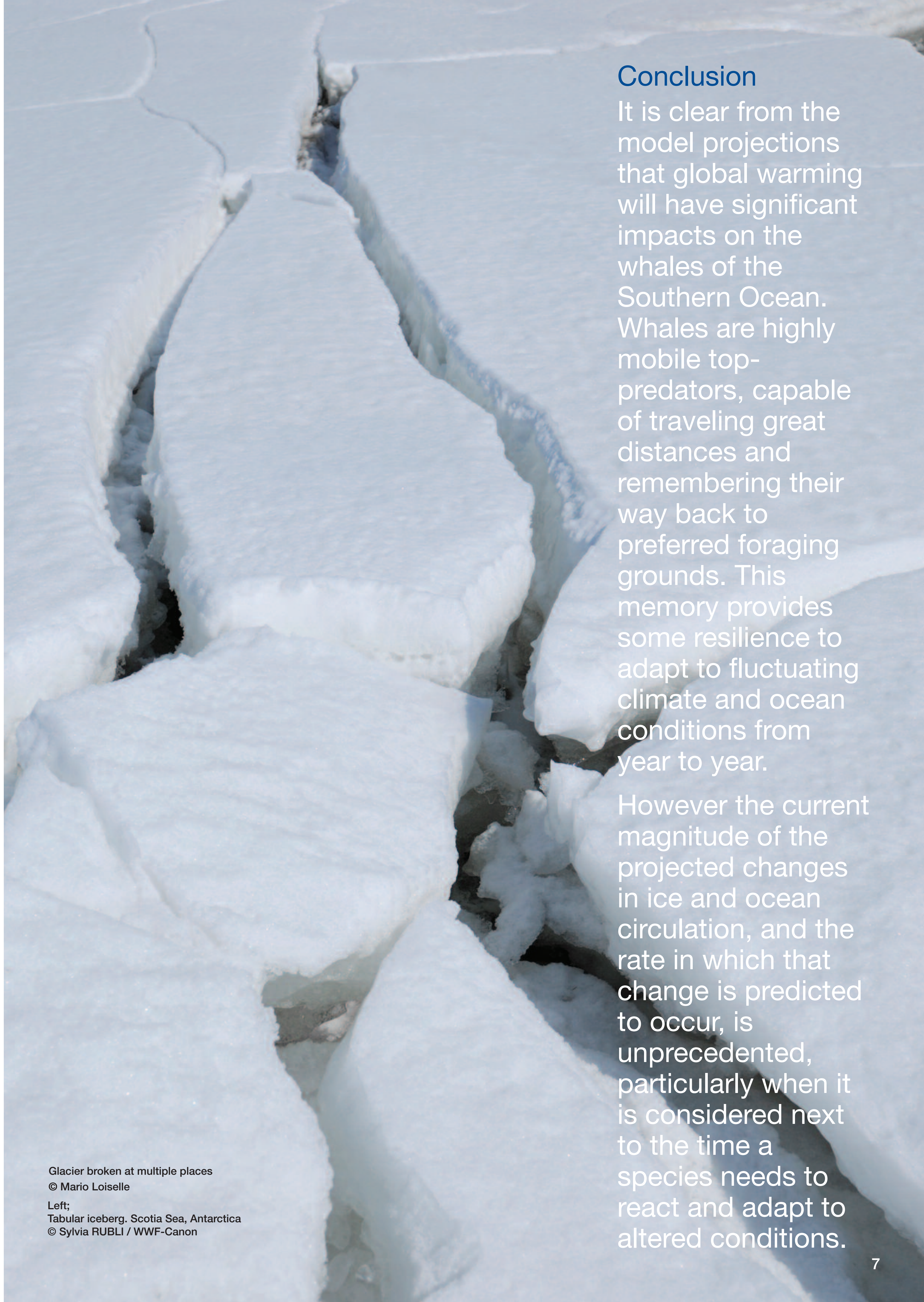
Left: Modern observations;

Right: Projections for the year of 2°C warming using the GFDL-CM2.1, one of our four coupled climate models. The red band is the Subtropical Front; the green band is the Subantarctic Front, the blue band is the Polar Front; and the purple band is the southern boundary of the Antarctic Circumpolar Current.

Fronts are transition zones between water masses of different physical characteristics (e.g., temperature, salinity). They are predictably productive foraging areas for many species and are of critical importance to the functioning of the Southern Ocean ecosystem (see 'Whales, food and sea ice in the Southern Ocean). They are particularly important for several migratory whale species including the blue whale, humpback whale, fin whale (*Balaenoptera physalus*), and sperm whale (*Physeter macrocephalus*) which travel thousands of kilometers each year to feed here in the summer. Under 2°C global warming, Southern Ocean fronts are projected to move southward by 2-5° latitude (about 200-500 km). Migratory whales would have to travel even farther to reach and feed at specific frontal zones during their southward migration. These longer migration paths to frontal zones and the ice edge could increase the costs of movement and reduce the duration of their main feeding season. At the same time, as frontal zones move southward, they also move closer together, compressing the space between them and reducing the area of valuable foraging habitat for migratory whales.

The foraging time spent in the Southern Ocean is of critical importance to migratory whales, as it is their primary feeding season. During migration, and during breeding and calving seasons which occur further north, the whales fast – or feed far less - relying on the energy stores they had built up during their time in Antarctic waters.

To provide a regional example, the fronts near the Kerguelen Plateau, at the time of 2°C warming, are projected to move closer together while shifting southward by 3° latitude (300 km). The compression of whale habitat that this will cause is likely to most affect minke whales, humpback whales, sperm whales, killer whales (*Orcinus orca*) and southern bottlenose whales (*Hyperoodon planifrons*) which congregate in high density in these regions (Tynan. 1996, 1997).



Glacier broken at multiple places
© Mario Loiselle

Left;
Tabular iceberg. Scotia Sea, Antarctica
© Sylvia RUBLI / WWF-Canon

Conclusion

It is clear from the model projections that global warming will have significant impacts on the whales of the Southern Ocean. Whales are highly mobile top-predators, capable of traveling great distances and remembering their way back to preferred foraging grounds. This memory provides some resilience to adapt to fluctuating climate and ocean conditions from year to year.

However the current magnitude of the projected changes in ice and ocean circulation, and the rate in which that change is predicted to occur, is unprecedented, particularly when it is considered next to the time a species needs to react and adapt to altered conditions.

The ice edge is an area of intense algal blooms in summer and a refuge for krill larvae in winter

Left;
Krill. *Euphausiacea* Size: 6cm Weight: 1g
Group name: Swarm. It is estimated that the total weight of all the Antarctic krill is more than the total weight of all humans on Earth.
© British Antarctic Survey

Right;
Humpback whales gather in Tonga each winter to give birth and mate before returning to Antarctic feeding areas. © Cat HOLLOWAY / WWF-Canon

Whales, food and sea ice in the Southern Ocean

The Southern Ocean teems with life and supports one of the most productive marine ecosystems on Earth. Most species of baleen whales and male sperm whales in the Southern Hemisphere migrate between low-latitude breeding grounds in winter and highly productive Antarctic feeding grounds in summer. Both migratory and endemic species of whales, seals and birds thrive on the abundance of their principal food in the area: Antarctic krill and cephalopods, such as squids and cuttlefish. These prey species congregate in the waters that contain the most food for them, i.e. the boundaries between frozen sea ice and open water (or "ice edge"), and the transition zones (or "fronts") between water masses of different characteristics (e.g. temperature, salinity, etc).

Why is there more whale food at the sea ice edge?

The ice edge is an area of intense algal blooms in summer and a refuge for krill larvae in winter. As sea water freezes in autumn, microscopic algae and other microbes which are at the very bottom of the food chain are trapped between the newly formed ice crystals. These microbes then live and thrive within the ice throughout the cold dark winter, providing an important source of food for young, growing krill larvae. When summer comes, the ice melts, the microbial organisms are released into the sea water and they thrive under the constant sun. Through photosynthesis, they flourish, bloom and multiply, providing an annual feast for many species including krill and larval fish. These species multiply, providing a prey base for the fish, seal, seabird and whale predators of the Southern Ocean.

Why is there more whale food at ocean fronts?

Sea water is not the same everywhere. In different regions and depths, water is different in density, salinity, temperature and other physical characteristics. A large body of water whose properties are essentially homogeneous is referred to as a 'water mass'. At Southern Ocean transition (or frontal) zones, such as the Southern Boundary of the Antarctic Circumpolar Current, there is the potential for older water, low in oxygen and high in nutrients, to move closer to the surface. This allows the increased growth of phytoplankton, which supports the growth of krill, and subsequently the communities of whales, birds, and seals that rely on these dense concentrations of prey. Krill-feeding baleen whales and cephalopod-feeding sperm whales all congregate in high densities near Southern Ocean fronts, indicating the critical importance of these fronts to the function of the entire Southern Ocean ecosystem.

Every country has a role to play in response to the scale and the type of challenges arising in its territory

Recommendations

Emissions Reductions

It is clear that the world must urgently make dramatic changes in order to avoid irrevocable consequences of dangerous climate change by limiting global mean temperature rise to well below 2°C above pre-industrial levels. WWF, and many other organizations and scientists, have demonstrated that technologies and sustainable energy resources known or available today are sufficient to meet this challenge, and there is still sufficient time to build up and deploy them, but only if the necessary decisions are made soon (WWF, 2007). It is critical that emissions peak and start to reduce within the next 5 to 8 years. This is especially true for the energy sector, which is the largest polluting sector and is responsible for 40% of global climate damaging emissions. Reducing energy demand, improving energy efficiency, deploying renewable energy and other low-carbon technologies, stopping and reversing loss and degradation of forests and prairies are all crucial elements to keeping global warming to below 2°C. In addition, the following considerations are imperative:

1. Urgency - Delays will make staying below 2°C increasingly more expensive and difficult, with much greater risks of failure. The case for early, decisive action to agree new emissions targets for post 2012 and begin a reduction in global greenhouse emissions in the next two years is overwhelming.

2 A global effort - Every country has a role to play in response to the scale and the type of challenges arising in its territory.

3 Leadership - Action is needed by governments of the world to agree to targets, to collaborate on effective strategies, and to influence and coordinate the investment of the many trillions of dollars necessary so that future needs are met safely and sustainably. Otherwise trillions of dollars will be spent in recovery from damage related to climate change.

Adaptation

It is clear that our climate is rapidly changing now, will continue to change in the future even under the most optimistic projections for emissions reductions. Therefore, at the same time as making efforts to slow down climate change, it is critically important that climate change considerations be incorporated into conservation plans, assessments and strategies for whales in order to improve the resilience of ecosystems and species to climate change (Simmonds and Isaac. 2007). This could be achieved through three main principles (Hansen et al., 2003):

1) Protection of adequate and appropriate space. This should include the protection of habitats critical for breeding or feeding, and the protection of climate refugia – those areas that are less vulnerable to changes in climate than others. In the design of protected areas, forward planning must be employed to determine how climate induced factors may change the geography of the most important attributes to be protected.

2) Limit all non-climate stresses. There are a myriad of stresses on whales and the marine environment, and climate change will have a synergistic effect on these. Non-climate stressors can be locally controlled (i.e., pollution, fishing, noise), thus increased efforts must be made to reduce all these threats.

3) Adaptive management. Given the uncertainty about the exact nature of impacts of climate change on whales and their responses to it, a responsive and flexible approach is required, combined with rigorous monitoring.

Role of the IWC

The Scientific Committee of the International Whaling Commission agreed in 2007 to hold a special workshop on climate change and whales. WWF urges the contracting parties to the IWC to fully support this initiative and ensure that the Scientific Committee is provided with a strong budget that will enable the workshop to make a significant contribution to the issue.

In addition WWF urges the IWC Scientific Committee to ensure that the workshop not only make projections about future impacts, but discuss potential adaptation strategies and management techniques that will assist whale populations to adapt to their changing environment.

Finally, all IWC contracting Governments with an interest in whale conservation must urgently commit to significant emissions reductions if they are to keep global warming below 2ºC, and ensure that the world's whales have a secure and sustainable future.

Humpback whale (Megaptera novaeangliae), close-up. South Pole, Antarctica
© Wim VAN PASSEL / WWF-Canon

References

Aguayo Lobo, A. 1994. Is there a population of minke whales that overwinter among the Antarctic sea-ice? Ser. Cient. Inst. Antart. Chil. 44: 91-98.

Ainley, D.G., Dugger, K.M., Toniolo, V. and Gaffney, I. 2007. Cetacean occurrence patterns in the Amundsen and southern Bellingshousen Sea sector, Southern Ocean. Mar. Mamm. Sci. 23: 287-305.

Ainley, D.G., Clarke, E.D., Arrigo, K., Fraser, W.R., Kato, A., Barton, K.J. and P.R. Wilson. 2005. Decadal-scale changes in the climate and biota of the Pacific sector of the Southern Ocean, 1950s to the 1990s. Antarctic Science, 17,171-182.

Arrigo, K.R. and Thomas, D.N. 2004. Large-scale importance of sea ice biology in the Southern Ocean. Antarctic Science 16(4): 471-486.

Atkinson, A., Siegel, V., Pakhomov, E. and P. Rothery. 2004. Long-term decline in krill stock and increase in salps within the Southern Ocean. Nature, 432, 100–103.

Brierley, A.S. and Thomas, D.N. 2002. On the ecology of the Southern Ocean pack ice. Advances in Marine Biology, 43: 171-278.

Conkright, M.E., Locarnini, R.A., Garcia, H.E., O'Brien, T.D., Boyer, T.P., Stephens, C. and Antonov, J.I. 2002. World Ocean Atlas 2001: Objective Analyses, Data Statistics, and Figures, CD-ROM Documentation. National Oceanographic Data Center, Silver Spring, MD, 17 pp.

Ducklow, H.W., Baker, K., Martinson, D.G., Quetin, L.B., Ross, R.M., Smith, R.C., Stammerjohn, S.E., Vernet, M. and W. Fraser. 2007. Marine pelagic ecosystems: the West Antarctic Peninsula. Philosophical Transactions of the Royal Society B, 362, 67–94.

Fowbert, J.A., and R.I.L. Smith. 1994. Rapid population increases in native vascular plants in the Argentine Islands, Antarctic Peninsula. Arctic and Alpine Research , 26, 290-296.

Friedlaender, A.S., Halpin, P.N., Qian, S.S., Lawson, G.L., Wiebe, P.H., Thiele, D. and Read, A.J. 2006. Whale distribution in relation to prey abundance and oceanographic processes in shelf waters of the Western Antarctic Peninsula. Mar. Ecol. Prog. Ser. 317: 297-310.

Hansen, L., Biringer, J.L. and Hoffman, J.R. 2003. Buying Time: A User's Manual for Building Resistance and Resilience to Climate Change in Natural Systems. WWF:

IPCC, United Nations Intergovernmental Panel on Climate Change, 2007a. Climate Change 2007 – The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC.

IPCC, United Nations Intergovernmental Panel on Climate Change, 2007b. Climate Change 2007 – Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC.

Jacobs, S. 2006. Observations of change in the Southern Ocean. Philosophical Transactions of the Royal Society A, 364, 1657-81.

Kahru, M and Mitchell, B.G. 2008. Ocean color reveals increased blooms in various parts of the world. EOS 89:170.

Learmonth, J.A., Maclead, C.D., Santos, M.B., Pierce, G.J., Crick, H.Q.P., Robinson, R.A. 2006. Potential effects of climate change on marine mammals. Oceanography and Marine Biology: An Annual Review. 44, 431-464

Moline, M.A., Claustre, H., Frazer, T., Schofield, O. and Vernet M. 2004. Alteration of the foodweb along the Antarctic Peninsula in response to a regional warming trend. Global Change Biology 10: 1973-1980.

Nicol, S. 2006. Krill, currents, and sea ice: Euphausia superba and its changing environment. BioScience 56: 111-120.

Nicol, S., Worby, A. and Leaper, R. 2008. Changes in the Antarctic sea ice ecosystem: potential effects on krill and baleen whales. Marine and Freshwater Research (in press).

Orsi, A.H., Whitworth, T.W. III, and Nowlin, W.D. Jr. 1995. On the meridional extent and fronts of the Antarctic Circumpolar Current. Deep-Sea Res., Part I, 42: 541-673.

Overland, J., Turner, J., Francis, J., Gillett, N., Marshall, G., and Tjernström, M. 2008. The Arctic and Antarctic: Two faces of climate change. EOS 89(19): 177-178.

Reilly, S., Hedley, S., Borberg, J., Hewett, R., Thiele, D., Watkins, J. and Naganobu, M. 2004. Biomass and energy transfer to baleen whales in the South Atlantic Sector of the Southern Ocean. Deep-Sea Res. II 51: 1397-1409.

Reynolds, R.W., Rayner, N.A., Smith, T.M., Stokes, D.C. and Wang, W. 2002. An improved in situ and satellite SST analysis for climate. J. Climate 15: 1609-1625.

Russell, J.L., R.J. Souffer, & K.W. Dixon (2006), Intercomparison of the Southern Ocean Circulations in the IPCC Coupled Model Control Simulations. J. Climate, 19(18), 4560-4575.

Siniff, D.B., Garrott, R.A., Rotella, J.J., Fraser W.R., and Ainley, D.G.. 2008. Projecting the effects of environmental change on Antarctic seals. Antarctic Science, in press.

Simmonds, M. and Isaac, S. 2007. The impacts of climate change on marine mammals: early signs of significant problems. Oryx. 41, (0), 1-8

Thiele, D.C., Chester, E.T., Moore, S.E., Sirovic, A., Hildebrand, J.A., and Friedlaender, A.S. 2004. Seasonal variability in whale encounters in the West Antarctic Peninsula. Deep-Sea Res. II 51: 2311-2325.

Tynan, C.T. 1996. Characterization of oceanographic habitat of cetaceans in the Southern Indian Ocean between 82° – 115° E: Cruise report from the World Ocean Circulation Experiment (WOCE) I8S and I9S. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-64, 53 p.

Tynan, C.T. 1997. Cetacean distributions and oceanographic features near the Kerguelen Plateau. Geophys. Res. Lett. 24: 2793-2796.

Tynan, C.T. 1998. Ecological importance of the southern boundary of the Antarctic Circumpolar Current. Nature 392: 708-710.

Tynan, C.T. and Russell, J.L. 2008. Assessing the impacts of future 2∞C global warming on Southern Ocean cetaceans. International Whaling Commission, Scientific Committee document SC/60/E3

WWF, 2007. Climate solutions. WWF's vision for 2050.

Left;
Mountain range on the Antarctica Peninsula © Alexander Hafemann