# STATE OF THE CETACEAN ENVIRONMENT REPORT (SOCER) 2010

EDITORS: M. STACHOWITSCH*, N.A. ROSE¥ AND E.C.M. PARSONS+

## INTRODUCTION

Several resolutions of the International Whaling Commission, including Resolutions 1997-7 and 1998-5, directed the Scientific Committee (SC) to provide regular updates on environmental matters that affect cetaceans. Resolution 2000-7 welcomed the concept of the State of the Cetacean Environment Report (SOCER) at the 52nd Annual Meeting in Australia and "*request[ed] the annual submission of this report to the Commission*". The first full SOCER (SC/55/E7) was submitted in 2003 and focused on the Mediterranean and Black Seas and the Atlantic Ocean. Subsequent SOCERs have focused on the Pacific Ocean, the polar seas, and the Indian Ocean. This cycle has been continued, with each SOCER also including a Global section addressing the newest information that applies generally to the cetacean environment. **SC/63/E1** (SOCER 2011) focuses on the **Antarctic (Southern) Ocean**, summarising key papers and articles that have been published from 2009 through 2011 to date.

## ANTARCTIC OCEAN

### General

Complex ecosystem dynamics in the Southern Ocean

The structure and status of marine ecosystems depend on the population sizes of and changes in key species. In the Antarctic, the removal of ca. 2 million large baleen whales by whaling is thought to have profoundly affected the Antarctic marine ecosystem. One assumption – that the populations of krill, the major food source for large baleen whales, have increased (the 'Krill Surplus Hypothesis') and populations of smaller krill-eating competitors (*e.g.*, minke whales) have increased correspondingly – was tested with molecular techniques. The results indicate that the Antarctic minke whale population today is not larger than historical values. This may be because minke whales are not resource limited and/or they do not use krill in the same way and at the same time as the larger whales. It could also be because the food webs in the Antarctic are more complex than accounted for in this cetacean-focused scenario. Penguins compete with minke whales for the krill resource. Despite the high likelihood that the removal of so many large baleen whales did reduce predation pressure on krill, the smaller minke was thus not the only competitor who could have benefited. Indeed, Adélie penguin populations have increased in areas where minke whales have been removed by more recent whaling. This calls for considering both top-down and bottom-up forces when attempting to explain how populations are regulated within the Antarctic marine ecosystem. A study that attempted to consider these paired forces focused on pagophilic and pagophobic penguin populations. Thirty years of data collected on pagophilic Adélie and pagophobic chinstrap penguins have shown that both species are in decline, although intuitively, as ice recedes, it might be supposed that pagophilic species would decline as pagophobic species increase. This mutual decline is most likely linked to complex forces, including harvesting- and climate change-induced changes in krill abundance. These results have implications for other marine mammal species in the Southern Ocean ecosystem, including cetaceans.

(SOURCES: Ainley, D. *et al.* [9 co-authors]. 2010. Impacts of cetaceans on the structure of Southern Ocean food webs. *Mar. Mamm. Sci.* 26: 482-498; Ruegg, K.C., Anderson, E.C., Baker, S., Vant, M., Jackson, J.A. and Palumbi, S.R. 2010. Are Antarctic minke whales unusually abundant because of 20th century whaling? *Mol. Ecol.* 19: 281-291; Trivelpiece, W.Z., Hinke, J.T., Miller, A.K., Reiss, C.S., Trivelpiece, S.G. and Watters, G.M. 2011.Variability in krill biomass links harvesting and climate warming to penguin population changes in Antarctica. *Proc. Natl. Acad. Sci.* 108: 7625-7628)

Reduction in ozone hole over Antarctica

Ozone levels above Antarctica appear to be increasing. Although there are still some concerns about the accuracy of the data, overall the trend points to increasing ozone levels. This suggests international regulations on chlorofluorocarbon use introduced in 1989 have been effective.

* Department of Marine Biology, Faculty of Life Sciences, University of Vienna, Austria
¥ Humane Society International, Washington, DC, USA
+University Marine Biological Station Millport (University of London), Great Cumbrae, Scotland and Department of Environmental Science and Policy, George Mason University, Fairfax, Virginia, USA

(SOURCE: Salby, M., Titova, E. and Deschamps, L. 2011. Rebound of Antarctic ozone. *Geophys. Res. Lett.*: doi:10.1029/2011GL047266)

First Antarctic krill surveys in shallow waters indicate high densities

Antarctic krill are an important food source for penguins, seals and some whales in the Southern Ocean. Until recently, surveys were restricted to offshore sampling. The first long-term survey in shallow nearshore waters near Livingston Island using small boats revealed significantly higher and more stable krill biomass density than offshore waters. Such highly productive nearshore areas need to be considered when developing small-scale units for managing the krill resource.

(SOURCE: Warren, J.D. and Demer, D.A. 2010. Abundance and distribution of Antarctic krill (*Euphausia superba*) nearshore of Cape Shirreff, Livingston Island, Antarctica, during six austral summers between 2000 and 2007. *Can. J. Fish. Aquat. Sci.* 67: 1159-1170)

## Habitat protection/degradation

### *General*

The impact of sewage outfalls in the Antarctic

Organic input from sewage or other human sources in Antarctica is increasing via research stations and tourism. Researchers treated benthic communities of differing species composition at various locations in McMurdo Sound to an experimental addition of nutrients (meant to mimic sewage outfalls). The eastern side of McMurdo Sound recovered quickly from the experimental input, as there are many natural sources of increased nutrients (such as seal haulouts). On the western side, natural organic inputs are less common and thus recovery, while similar, was slower, with substantial differences remaining after two years. At other locations around the Antarctic continent, recovery from such organic enrichment is not likely to be as rapid as observed in McMurdo Sound, with its longer history of human settlement. These results inform efforts to minimize environmental impacts in Antarctica from sewage.

(SOURCE: Kim, S., Hammerstom, K.K., Conlan, K.E. and Thurber, A.R. 2010. Polar ecosystem dynamics: Recovery of communities from organic enrichment in McMurdo Sound, Antarctic. *Integr. Comp. Biol.* 50: 1031-1040)

### *Fisheries*

The Ross Sea: Historic exploitation and current status

The analysis of historical records shows that, despite a reputation as the world's least affected stretch of ocean with regard to anthropogenic impacts, the Ross Sea has experienced several impacts since the early 20$^{th}$ century. These include intense extraction of Weddell seals, extirpation of blue whales, minke whale hunting in the 1970s and 1980s and, in recent years, industrial fishing for toothfish. These have led to distinct ecosystem changes, especially in the slope (versus continental shelf) regions, among them a potential expansion of minke whales onto the slope and an increase in Adélie penguins. Without protection from further industrial fishing, this food web will be further altered, causing the loss of the last example of how coldwater food webs once functioned and of a valuable site in which the effects of climate change can be investigated without the influence of other, confounding effects.

(SOURCE: Ainley, D. 2010. A history of the exploitation of the Ross Sea, Antarctica. *Polar Rec.* 238: 233-243)

Decline of killer whales in the Ross Sea potentially related to industrial fisheries

Based on observations from Ross Island, the sighting frequency and average group size of killer whales appears to have decreased. Since these whales apparently feed predominantly on fish, including the Antarctic toothfish, the authors attribute this change to the industrial fishery-driven contraction of the toothfish stock. Considering the closely coupled food web in this region, this might force killer whales into more direct competition with other predators for smaller-sized fish, leading to a population decline, a scenario already documented off the Pacific coast of Canada.

(SOURCE: Ainley, D.G., Ballard, G. and Olmastroni, S. 2009. An apparent decrease in the prevalence of "Ross Sea Killer Whales" in the southern Ross Sea. *Aquat. Mamm.* 35: 335-347)

Recent developments in the Antarctic krill fishery

The fishery for Antarctic krill is the largest by tonnage in the Southern Ocean, remaining stable for nearly two decades at 120 000 tonnes but recently increasing to more than 200 000 tonnes. New developments in harvesting technology and potential products derived from krill indicate renewed interest in exploiting this resource. This adds to already existing concerns over the effect of diminishing ice edge cover, as larval krill consume algae adhering to the underside of sea ice. Considerably reduced winter sea-ice in the south-west Atlantic has extended and shifted the fishing season to the winter. This, combined with a reported major decline in krill stocks over the last three decades, is a cause for concern, calling for suitably precautionary management to account for an uncertain future. Observers, who frequently accompany other Antarctic fishery vessels, could be placed on krill fishery vessels to help collect data and gain a clearer idea of krill status, but several countries taking krill from Antarctic waters are resistant to this idea. These developments are highly relevant to the functioning of the Antarctic food web, in which krill and whales are intimately associated and play a dominant role.

(SOURCES: Nicol, S., Foster, J. and Kawaguchi, S. 2011. The fishery for Antarctic krill – recent developments. *Fish and Fisheries* 12: doi:10.1111/j.1467-2979.2011.00406.x; Schiermeier, Q. 2010. Ecologists fear Antarctic krill crisis [News]. *Nature* 467: 15)

## *Marine Debris*

Marine plastic debris present even in Antarctica

A broad survey of plastic debris in the marine environment reported lower densities on remote island shores, on the continental shelf seabed and the lowest densities (but still a documented presence) in the deep sea and Southern Ocean. Despite this low presence, the longevity of plastic is estimated to be hundreds to thousands of years and is likely to be far longer in deep sea and polar environments.

(SOURCE: Barnes, D. K. A., Galgani, F., Thompson, R.C. and Barlaz, M. 2009. Accumulation and fragmentation of plastic debris in global environments. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 364: 1985-1998)

## *Acidification*

Ocean acidification an issue in the Antarctic

The Antarctic Climate and Ecosystems Cooperative Research Centre (Australia) identifies ocean acidification due to $CO_2$ emissions as an issue with a wide range of potential repercussions in Antarctic waters. With respect to cetaceans, more acidic seawater is projected to affect the health and abundance of organisms at the base of the food web, namely phytoplankton and zooplankton, including krill. Moreover, water with higher acidity conducts sound better, meaning that a more acidic ocean will be a noisier one, for cetaceans and other marine life.

(SOURCE: Anonymous. 2010. Report Card, Southern Ocean Acidification. ACE CRC, ISBN: 978-1-921197-12-3)

## Chemical pollution

Review of persistent organic pollutants in the Antarctic

The Scientific Committee on Antarctic Research reviewed the information available on POPs in the Antarctic and concluded that long-range atmospheric transport is the primary mechanism transporting POPs into the region. It also determined that data are sparse on many substances (calling for new databases and inventories), suggested including additional substances not yet listed by the Stockholm Convention and explored the use of new methods of monitoring for these substances. With regard to cetaceans it determined that DDT and HCB concentrations in the blubber of Antarctic minke whales have increased (compared with a decrease in common minke whales) and that POP concentrations in Antarctic Type C killer whales were lowest of any killer whale population studied to date but were still 5 to 90-fold higher than in minke whales. This probably reflects the diets of minke versus killer whales.

(SOURCE: Fuoco, R., Capodaglio, G. Muscatello, B. and Radaelli, M. 2009. Persistent Organic Pollutants in the Antarctic Environment: A Review of Findings. SCAR, ISBN 978-0-948277-23-8)

‘New’ persistent organic pollutants detected in an Antarctic marine mammal

There is interest in adding additional toxic substances to the ‘dirty dozen’ list of POPs identified by UNEP. A series of such so-called ‘new’ or ‘emerging’ contaminants were reported from Antarctic fur seals. Although the concentrations of PBDEs, for example, were relatively low compared to PCBs and DDTs, there is concern regarding the bioaccumulative and toxic effects of these flame retardants. The detection of these and other compounds such as PCN and HHCB in remote areas like the Antarctic points to the worldwide distribution of such chemicals and their probable accumulation in higher levels of the food web, including cetaceans. The potential toxicological impacts of this suite of existing and novel compounds are unknown.

Mean levels ($\mu g.g^{-1}$ lipid weight) ΣPCB: 1.05; ΣDDT: 2.4; ΣCHL: 0.397; ΣPBDE: 0.011; ΣPCN: 0.163

(SOURCES: Schiavone, A., Corsolini, S., Borghesi, N. and Focardi, S. 2009. Contamination profiles of selected PCB congeners, chlorinated pesticides, PCDD/Fs in Antarctic fur seal pups and penguin eggs. *Chemosphere* 76: 264-269; Schiavone, A., Kannan, K., Horii, Y., Focardi, S. and Corsolini, S. 2009. Occurrence of brominated flame retardants, polycyclic musks, and chlorinated naphthalenes in seal blubber from Antarctica: Comparison to organochlorines. *Mar. Pollut. Bull.* 58: 1415-1419; Schiavone, A. *et al.* [6 co-authors]. 2009. Perfluorinated contaminants in fur seal pups and penguin eggs from South Shetland, Antarctica. *Sci. Total Environ.* 407: 3899-3904)

Persistent organic pollutants in Antarctic seabirds

An analysis of various POPs – chlorinated pesticides, PCBs and PAHs – in the fat tissue of seabirds from King George Island, Antarctica, confirmed that these compounds are distributed globally even though their use is severely restricted. This was particularly evident in species whose range is largely limited to the Antarctic continent, namely penguins. Higher values in the brown skua, for example, were attributed to its high trophic level and migratory habits. These compounds are incorporated in the Antarctic food chain and highest values can be expected at higher trophic levels, which include cetaceans.

(SOURCE: Taniguchi, S., Montone, R.C., Bicego, M.C., Colabuono, F.I., Weber, R.R. and Sericano, J.L. 2009. Chlorinated pesticides, polychlorinated biphenyls and polycyclic aromatic hydrocarbons in the fat tissue of seabirds from King George Island, Antarctica. *Mar. Pollut. Bull.* 58: 129-133)

The Antarctic as a sink for persistent organic pollutants

Antarctica is regarded as a final sink for POPs, including PCBs, DDE, HCB and dieldrin. While the concentrations of some POPs are decreasing in certain birds and pelagic fishes, values in benthic food webs are steady or increasing. The transfer from the open water to the seafloor is associated with seasonal sea-ice dynamics, which in turn depends on different climatic conditions. This complicates the predictability of future trends of emerging compounds in the Antarctic ecosystem. One hypothesis is that climate-induced changes in sea ice dynamics will alter the fluxes of contaminants and lead to higher retention of organic compounds in the pelagic food web, of which whales are key components.

(SOURCE: van der Brink, N.W., Riddle, M.J., van den Heuvel-Greve. M. and van Franeker, J.A. 2011. Contrasting time trends of organic contaminants in Antarctic pelagic and benthic food webs. *Mar. Pollut. Bull.* 62: 128-132)

## Disease and mortality events

### *Disease*

First report of a parasite in an Antarctic marine mammal

The parasite *Cryptosporidium* may be a useful indicator for water-borne contamination. As recently as 2008, it was believed that Antarctica was the last continent with no evidence of *Cryptosporidium* contamination. In this study, 221 fresh faecal samples were collected from five different pinniped species; one showed the presence of *Cryptosporidium.* This is the first record of this parasite in Antarctica and, although the exposure of Antarctic fauna is low, monitoring for its spread is warranted.

(SOURCE: Rengifo-Herrera, C. *et al.* [6 co-authors]. 2011. Detection and characterization of a *Cryptosporidium* isolate from a southern elephant seal (*Mirounga leonina*) from the Antarctic Peninsula. *Appl. Environ. Microb.* 77: 1524-1527)

## Climate change

Changing Antarctic may favour species independent of sea ice

Modern electronic tags help in the study of bird and mammal behaviour, but also provide information on oceanic habitats. This information yields detailed insights into the specific habitat features preferred and used by various species. A study tracking three species of pinniped wearing CTD tags assessed the impacts of climate change on Antarctic species assemblages, based on their foraging behaviour and habitat preferences. Current trends (in population numbers and sea ice cover) and future projections suggest an environment that is changing in favour of pinniped species that are independent of sea ice, with a preference for foraging in deep water off the Antarctic continent. This may also apply to cetacean species with similar habitat preferences.

(SOURCE: Costa, D.P., Huckstadt, L.A., Crocker, D.E., McDonald, B.I., Goebel, M.E. and Fedak, M.A. 2010. Approaches to studying climatic change and its role on the habitat selection of Antarctic pinnipeds. *Integr. Comp. Biol.* 50: 1018-1030)

<u>Whaling records illustrate ice sheet losses</u>

A comparison of historic whaling records showed a southward movement of the Antarctic ice edge in the 1970s and 80s compared to the 1930s through the 1950s, of from 1.89$^{o}$ - 2.80$^{o}$ of latitude (mid-estimate 2.41$^{o}$). The greatest reduction in ice cover was in the Weddell Sea, but ice sheet reduction was also noted south of the Indian Ocean and in the Ross Sea. The author states that "*[t]his corresponds to a reduction in the extent of the sea-ice in the range of 20% to 30%*".

(SOURCE: de la Mare, W.K. 2009. Changes in Antarctic sea-ice extent from direct historical observations and whaling records. *Climatic Change* 92: 461-493)

<u>Unexpected ice loss in East Antarctica</u>

The East Antarctic ice sheet contains about 90% of Earth's solid freshwater and was previously considered stable. Researchers using NASA data from 2002-2009 showed that the ice sheet is losing mass, mostly in coastal regions, at a rate of 57 Gt per year. The loss probably began in 2006. This confirms previous results showing that West Antarctica is losing ice at a rate of about 132 Gt/year. As Earth's biggest ice sheet, loss in East Antarctica could have a large impact on future global sea level rise.

(SOURCES: News. 2010. *Mar. Pollut. Bull.* 60: 3; Chen, J.L., Wilson, C.R., Blankenship, D. and Tapley, B.D. 2009. Accelerated Antarctic ice loss from satellite gravity measurements. *Nat. Geosci.* 2: 859-862)

<u>The future of Antarctic sea ice</u>

Researchers have examined the seeming paradox that Arctic sea ice is diminishing while the extent of Antarctic sea ice has been increasing slightly. They attribute this to increased precipitation in the form of snow in the Southern Ocean surrounding Antarctica. This insulates the upper ocean from the ocean heat below, reducing the amount of melting. However, climate models predict an accelerated warming, which will likely result in sea ice melting at a faster rate from both above and below. Accordingly, on a time scale of decades, the Antarctic would experience a switch in which the sea ice extent begins to decrease. This would clearly affect cetaceans, many of which are closely associated with the ice edge.

(SOURCE: News. 2011. *Mar. Pollut. Bull.* 60: 1638)

<u>Climate change and krill dynamics – implications for Southern Ocean ecosystem studies</u>

A high concentration of humpback whales was observed west of the Antarctic Peninsula in 2009 (5.1 humpbacks per km$^2$ versus an average of 0.51 per km$^2$). The whales were feeding on an aggregation of krill with an estimated biomass of 2 million tons covering a 100 km$^2$ area. It has been hypothesized that in the autumn adult krill migrate from continental shelf and offshore areas to inshore waters and overwinter under sea ice. The researchers state that their observations "*support this hypothesized movement and suggest that krill may coalesce into very large super-aggregations in the autumn in the bays of the* [West Antarctic Peninsula]". As a result of climate change, sea ice formation around the Antarctic Peninsula is occurring more than 50 days later than 30 years ago. Because of open water areas, humpback whales were calculated to have consumed an additional 3,225–7,224 tons of krill during this ice free period. The researchers emphasized that "[f]*ailure to account for the effects of climate change on* [krill] *dynamics will undermine our ability to understand changes in the standing biomass of Antarctic krill and also to predict the recovery of whale populations from a century of mismanagement and overexploitation*".

(SOURCE: Nowacek, D.P., Friedlaender, A.S., Halpin, P.N., Hazen, E.L., Johnston, D.W., Read, A.J., Espinasse, B., Zhou, M. and Zhu, Y. 2011. Super-aggregations of krill and humpback whales in Wilhelmina Bay, Antarctic Peninsula. *PLOS One* 6 (4): e19173.; see also Stammerjohn, S.E., Martinson, D.G., Smith, R.C., Yuan, X., and Rind, D. 2008. Trends in Antarctic annual sea ice retreat and advance and their relation to El Nino-Southern Oscillation and Southern Annular Mode variability. *J. Geophys. Res. Oceans* 113: C03S90)

Accelerating ice sheet loss in Antarctica and Greenland

Researchers used two remote sensing techniques to estimate ice loss in Antarctica and Greenland. Over an 18-year period, the acceleration in ice sheet loss in Antarctica was 14.5 ± 2 Gt/yr$^2$ and in Greenland 21.9 ± 1 Gt/yr$^2$ – a total of 36.3 ± 2 Gt/yr$^2$. The acceleration of melting rates for these ice sheets is three times that of mountain glaciers. The melting rate, coupled with thermal expansion of seawater from rising temperatures, should lead to a 0.3 m increase in sea level by the mid-21$^{st}$ century.

(SOURCE: Rignot, E., Velicogna, I., van den Broeke, M.R., Monaghan, A. and Lenaerts, J. 2011. Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. *Geophys. Res. Lett.* 38: L05503, doi:10.1029/2011GL046583)

Major ecosystem shifts in western Antarctic Peninsula

In the past 50 years, mid-winter temperatures have increased by approximately 6°C in the western Antarctic Peninsula and there has been a 90-day increase in the ice-free season. In the past 30 years, phytoplankton bloom biomass has decreased by 12%. As a result of these phytoplankton changes, the ecosystem is shifting from one in which krill dominates to one in which pelagic tunicates dominate. This will have profound ramifications for Antarctic biota, including cetaceans.

(SOURCE: Schofield, O., Ducklow, H.G., Martinson, D.G., Meredith, M.P., Moline, M.A. and Fraser, W.R. 2010. How do polar marine ecosystems respond to rapid climate change? *Science* 328: 1520-1523)

## GLOBAL

### General

Modelling exposure of individual dolphins to anthropogenic threats

For 50 years, the purse seine fishery for yellowfin tuna has significantly affected the lives of dolphins in the eastern tropical Pacific (ETP). However, little is known about how frequently an individual dolphin is exposed to the fishery, and no methods have been available to accurately assess an animal's prior exposure. A new method estimates an index of exposure based on a model of dolphin movement, which in turn was based on data collected from multiple tracking studies. Although this index was developed to estimate exposure to the ETP tuna fishery, the model can easily be modified to examine the exposure of cetaceans to other events, such as anthropogenic noise sources, pollution outflows, or oil spills. By determining the locations and times of the sources/events of interest and constructing a movement model for the species in question, one might assess the cumulative impact of repeated exposures on populations over a period of time and examine physiological or behavioural reactions in sampled individuals.

(SOURCE: Archer, F.I., Redfern, J.V., Gerrodette, T., Chivers, S.J. and Perrin, W.F. 2010. Estimation of relative exposure of dolphins to fishery activity. *Mar. Ecol. Prog. Ser.* 410: 245-255)

Rate of species loss nearing 'mass extinction'

It has been claimed that the current rate of species loss is equivalent to historical mass extinctions. The fossil record shows five periods when more than three-quarters of the species on the planet disappeared. A recent analysis investigated species loss during these events versus current known rates of extinction. The comparison concludes that the number of recently extinct species would not rate as a mass extinction event. However, if species currently considered to be 'critically endangered' were to become extinct, it "*would propel the world to a state of mass extinction that has previously been seen only five times in about 540 million years*". Moreover, "*[a]dditional losses of species in the [IUCN Red List] 'endangered' and 'vulnerable' categories could accomplish the sixth mass extinction in just a few centuries*".

(SOURCE: Barnosky, A.D. *et al.* [11 co-authors]. 2011. Has the Earth's sixth mass extinction already arrived? *Nature* 471: 51-57)

A status review of vertebrates shows a high proportion of threatened species and areas of decline

Using IUCN criteria, a review of the conservation status of vertebrates determined that approximately one-fifth of vertebrate species are threatened. For marine species, western Africa, central and eastern Australasia, eastern South Africa, the Mediterranean, southwest Europe and western South America were hotspots for vertebrate decline. Other areas with higher levels of marine vertebrate decline included the eastern and southwest coast of North America (including the Gulf of California), the western coast of South America, the Red Sea, and the Hawaiian, Galapagos and South Pacific islands. These patterns "*highlight regions where large numbers of species with restricted distributions…coincide with intensive* *direct and indirect anthropogenic pressures, such as deforestation…and fisheries*". Only two vertebrate species have gone extinct in the past 50 years and both were marine mammals – the Yangtze River dolphin and the Caribbean monk seal. For any single threat, "*deteriorations outnumber improvements; conservation actions have not yet succeeded in offsetting any major driver of increased extinction risk*". Fisheries interactions have been mitigated better for marine mammals than for marine birds, and the status of some large whales has also improved due to protection from commercial whaling. The conclusion: "*[T]he current level of action is outweighed by the magnitude of threat, and conservation responses will need to be substantially scaled up to combat the extinction crisis*".

(SOURCE: Hoffman, M. *et al.* [173 co-authors]. 2010. The impact of conservation on the status of the world's vertebrates. *Science* 330: 1503-1509)

Ecosystem and habitat models used to predict the future of biodiversity

A marine trophic model (using Ecosim with Ecopath), based on historical biomass and catches, predicted that "*future increases in landings, partially driven by fisheries subsidies, can only be achieved by intensifying pressure on groups that are not currently fished in large quantities*". A general shift 'down the food web' of marine species is predicted. Another prediction is that less destructive fishing practices and reduced fishing effort could increase some fish stocks. The effects of climate change, including changes in ocean temperatures, could shift bottom-dwelling marine species toward the poles (at 4 km/yr), with faster speed for shifts in pelagic species due to more rapid temperature changes at the surface. Species may also shift in depth. Reducing greenhouse gas emissions could slow temperature increases and rate of habitat shift, potentially giving species more time to adapt to changes in habitat distribution.

(SOURCE: Pereira, H.M. *et al.* [22 co-authors]. 2010. Scenarios for global biodiversity in the 21$^{st}$ century. *Science* 330: 1496-1501)

The state of global biodiversity

The Convention on Biological Diversity met in Nagoya, Japan in October 2010, the International Year of Biodiversity. Marine mammal species are in decline, as are species important for marine ecosystems; more coral species are being added to the IUCN Red List. The Secretariat of the CBD predicted that there could be a "*catastrophic loss of biodiversity and ecosystem functioning, threatening the livelihoods and food security of hundreds of millions of people*". It added that "*resilience of coral reefs – and their ability to withstand and adapt to coral bleaching and ocean acidification – can be enhanced by reducing overfishing, land-based pollution and physical damage*". Moreover, since 1977 global fish stocks have experienced an 11% decline in total biomass and there has been an increasing trend of fish stock collapse, with 14% of stocks collapsed by 2007. Funding for biodiversity conservation has increased slightly in recent years, but still remains a minor component of nations' budgets. No progress has been made in the CBD's goal to reduce unsustainable consumption of biological resources; the new CBD goal for 2020 is to continue to reduce consumption and to end overfishing and destructive fishing practices. Although the proportion of protected terrestrial areas is increasing, less than 0.5% of the oceans are protected. However, the goal is to have 10% of marine eco-regions protected. In May 2010, for example, the U.K. designated the largest marine reserve in the world: The Chagos Archipelago (544 000 km$^2$).

(SOURCES: Stokstad, E. 2010. Despite progress, biodiversity declines [News]. *Science* 329: 1272-1273; Secretariat of the Convention on Biological Diversity. 2010. *Global Biodiversity Outlook 3*. Secretariat of the Convention on Biological Diversity, Montréal, Canada, 94 pp.)

## Habitat protection/degradation

### *General*

Whale faeces play a key role in marine productivity

The role of whales and other marine mammals in recycling nutrients has largely been ignored. Researchers demonstrated that whale faeces increase primary production, and in turn secondary production (resulting in bigger fisheries), wherever whales occur in high densities. In carrying nutrients such as nitrogen from deeper waters where whales feed to the surface, they function as an 'upward biological pump', reversing previous assumptions about the role of whales in nutrient cycling. Recovering whale populations are expected to play an ever more important role in increasing nutrients, helping fisheries and improving the health of marine ecosystems.

(SOURCE: News. 2011. *Mar. Pollut. Bull.* 60: 2165)

## *Fisheries*

Changes in the trophic level of fish catches as an indicator of ocean health

Previous studies suggest that a decrease in mean trophic level in fisheries, the so-called ‘fishing down the food web’ phenomenon, may indicate overexploitation of the oceans. However, a recent analysis of trawl catches and stock assessments proposed that, because catch data show catches occurring at all trophic levels, there may be no ‘fishing down the food web’ after all. Accordingly, there may have been no wide-scale depletion of top predators and analysing stock assessments and catch data could be a better predictor of marine ecosystem status. However, other researchers have criticized this approach, emphasizing that areas fished should be taken into account, as recent fisheries have expanded into new areas such as the high seas and the Southern Ocean. Also, other researchers noted that increases in catch at higher trophic levels may be skewed because of the susceptibility of larger species to be caught in trawling gear and because socioeconomic factors might influence catches, *i.e.*, catch data would not necessarily reflect the underlying species composition but rather those most lucrative or easily caught.

(SOURCES: Branch, T.A. *et al.* [7 co-authors]. 2010. The trophic fingerprint of marine fisheries. *Nature* 468: 431-435; Stokstad, E. 2010. Key indicator of ocean health may be flawed [News]. *Science* 330: 1029; Powers, J.E. 2010. Measuring biodiversity in marine ecosystems. *Nature* 468: 385-386)

New perspective on cetacean bycatch highlights gravity of threat

Using Franciscana dolphins as a case study, combined demographic and genetic data indicate that pairs of dolphins (reproductive pairs and mother-offspring pairs) are likely to be entangled in fishing gear simultaneously. Such joint entanglements pose an even greater threat than entanglement of random individuals, due to the loss of related animals and thus genetic diversity. Such impacts may be generally valid for toothed whales, making bycatch more detrimental than previously considered.

(SOURCE: Mendez, M., Rosenbaum, H.C., Wells, R.S., Stamper, A. and Bordino, P. 2010. Genetic evidence highlights potential impacts of by-catch to cetaceans. *PLoS One* 5: e15550. doi:10.1371/journal.pone.0015550)

## *Marine Debris*

New approach to address marine debris problem

UNEP identified marine debris, especially plastics, as an emerging issue in 2011. In a 10-year project, the Republic of Korea has linked four types of technology – prevention, deep-water surveys, removal, treatment (recycling) – to develop ‘A Practical Integrated System for Marine Debris’. These efforts encompass a wide range of components, including developing removal devices, producing refuse-derived fuel, reclaiming raw material for recycled goods and incineration. This combined ‘end-of-pipe’ and ‘front-of-pipe’ technology is a promising approach to addressing the problem here and elsewhere.

(SOURCES: Jung, R.-T., Sung, H.-G., Chun, T.-B. and Keel, S.-I. 2010. Practical engineering approaches and infrastructure to address the problem of marine debris in Korea. *Mar. Pollut. Bull.* 60: 1523-1532; *UNEP Year Book 2011: Emerging Issues in Our Global Environment*, http://www.unep.org/yearbook/2011/)

## *Acidification*

Human impacts on ocean chemistry: Acidification and hypoxia

In 2008, burning of fossil fuels released 8.7 Gt of carbon into the atmosphere, with 2.3 Gt taken up by the oceans. This uptake has altered the ocean’s chemistry, resulting in an average acidity increase of 0.1 pH units (a 30% increase in acidity), with a predicted additional increase of 0.2-0.3 units by the end of the century (pH 7.67-7.81) unless major reductions in $CO_2$ emissions are achieved. This increase in acidity affects the availability of biologically important forms of calcium carbonate, *i.e.*, aragonite (important to corals and molluscs) and calcite (important to molluscs and certain plankton). When atmospheric $CO_2$ levels reach 400-450 ppm in the Arctic or 550-600 ppm in the Antarctic, structures containing calcium carbonate will begin to dissolve. Recent studies have already shown that foraminifera are 30% lighter than historically. Many coastal areas have even lower pHs, because of nutrient pollution and acid rain effects. The rate of acidification is 30 to 100 times faster than periods of acidification in the geological past. A 14% decrease in calcification during the 1990s has already been observed in coral in the Great Barrier Reef, and globally reefs will erode when levels of $CO_2$ reach 550 ppm in the atmosphere. Increasing $CO_2$ may, however, benefit certain types of algae, promoting HABs. In addition, acidity will make atmospheric iron (carried by dust) more biologically available, which may have a nutrient enhancing effect on phytoplankton.

Half of the nutrients in river systems currently being deposited into the oceans are anthropogenic. This may increase the frequency of HABs and eventually deoxygenate marine waters, causing anoxic or 'dead zones'. An estimated 400 such systems exist in coastal areas, covering an area of approximately a quarter of a million $km^2$. Waters off the coast of Oregon have decreased in oxygen content in the past 30 years, with the chance of hypoxic events occurring on the coast increasing from 10% to 60% per year. Low oxygen zones may extend over 30 million $km^2$, or 8% of the world's oceans. In the equatorial Atlantic, Pacific and Indian Oceans, an estimated area of 4.5 million $km^2$ (double the area of Argentina) has insufficient oxygen levels to support fish. Research is needed to investigate possible synergistic effects of these biochemical changes, and whether biological systems can acclimate.

(SOURCES: Bernie, D., Lowe, J., Tyrrell, T. and Legge, O. 2010. Influence of mitigation policy on ocean acidification. *Geophys. Res. Lett.* 37: L15704, 1-5; Doney, S.C. 2010. The growing human footprint on coastal and open-ocean biogeochemistry. *Science* 328: 1512-1516; Gerwin, V. 2010. Dead in the water [News]. *Nature* 466: 812-814; Kerr, R.A. 2010. Ocean acidification unprecedented, unsettling [News]. *Science* 328: 1500-1501; Stramma, L., Schmidtko, S., Levin, L.A. and Johnson, G.C. 2010. Ocean oxygen minima expansions and their biological impacts. *Deep-Sea Res. I* 57: 587-595)

## Chemical pollution

Mercury may impair vitamin D protection in dolphins

Mercury, with its well-studied neurotoxic effects, is one of the few environmental contaminants known to cause human fatalities. High levels in dolphin tissues have raised human health concerns in countries where cetacean products are consumed, but its impact on the animals themselves is of growing interest. Researchers exposed bottlenose dolphin skin cells to MeHgCl at levels comparable to or lower than the physiological levels detected in dolphin blood. This exposure disrupted the vitamin D pathway *in vitro*. Given vitamin D's protective effects in cancers, autoimmune disorders and inflammatory disease, this suggests a mechanism for *in vivo* impacts on immune response. The authors conclude that mercury "*might negatively impact…innate immunity. Given the wide range of vitamin D-associated functions and pathologies, these findings pose several ramifications relevant not only to the dolphin, but possibly humans, who are exposed to and affected by methylmercury in a similar manner as marine mammals*".

(SOURCE: Ellis, B.C., Gattoni-Celli, S. and Kind, M.S. 2010. The impact of methylmercury on 1,25-dihydroxyvitamin D3-induced transcriptomic responses in dolphin skin cells. *Biol. Chem.* 391: 245-258)

New potential threat to cetaceans by whalewatching

In a study on southern resident killer whales in British Columbia, Canada, and Washington State, USA, exhaust gases from whale-watching vessels were identified as a potential threat. While current whale-watching guidelines would keep pollutant exposure to levels at or just below those at which adverse health effects would be expected, such levels would be exceeded under certain conditions. The recommendations are to position vessels downwind of whales and to restrict the number of vessels within 800 m of whales to 20 at any given time, along with limiting viewing periods.

(SOURCE: Lachmuth, C.C., Barrett-Lennard, L.G., Styen, D.Q. and Milsom, W.K. 2011. Estimation of southern resident killer whale exposure to exhaust emissions from whale-watching vessels and potential adverse health effects and toxicity thresholds. *Mar. Pollut. Bull.* 62: 792-805)

Global heavy metal study on sperm whales

In a 5-year circumnavigation of the world, the organization Ocean Alliance collected skin biopsies from more than 300 sperm whales. These whales were used as an indicator species because of their vast range and status as top predators. All but three and 24 individuals had detectable levels of mercury and lead, respectively. Overall, values were high and were not affected by size or gender. Whales from the Mediterranean had the highest mean level of mercury (6.1 $\mu g.g^{-1}$). This first world-wide toxicological dataset for these heavy metals in marine mammals confirmed that mercury and lead are global contaminants in this group of animals.

(SOURCE: News. 2010. *Mar. Pollut. Bull.* 60: 1149)

The effects of mixing pollutants on endocrine disruption

Mixtures of POPs were examined for their ability to disrupt endocrine systems, specifically the actions of oestrogens. PCBs 138 and 180 had a significantly greater anti-oestrogenic effect when combined, but mixtures of DDE and *trans*-nonachlor had an oestrogen-enhancing effect that diminished as concentrations in the mixtures increased. These results were then compared to the concentrations of these contaminants in the blood of bottlenose dolphins from the U.S. Atlantic coast and Gulf of Mexico – the levels in dolphin blood were lower than the minimum levels at which oestrogenic or anti-oestrogenic effects were detected in the first part of the study. Nonetheless, significant oestrogenic activity was detected in the blubber of several test populations. In summary, "*these results suggest that select bottlenose dolphin populations may be exposed to contaminants that act in concert to exert estrogenic effects at biologically relevant concentrations*".

Lowest concentrations at which compounds have an effect ($\mu mol.L^{-1}$) DDE: 20; nonachlor: 3; PCB 138: 20; PCB 180: 21.

(SOURCE: Yordy, J.E. *et al.* [9 co-authors]. 2010. Complex contaminant exposure in cetaceans: a comparative e-screen analysis of bottlenose dolphin blubber and mixtures of four persistent organic pollutants. *Environ. Toxicol. Chem.* 29: 2143-2153)

Contaminant levels in blood and blubber provide support for hypotheses about the impacts of pollutants

There is a direct correlation between levels of POPs in bottlenose dolphin blood (*i.e.*, where POPS are biologically available) and in the blubber (*i.e.*, where POPs are stored). Levels in blood plasma increased significantly as the lipid content of blubber decreased, confirming that, as lipids are used by cetaceans, they are released into the bloodstream. Moreover, certain contaminants may be more likely to be mobilized than others. The study confirms the hypothesis that during periods when blubber is depleted (*e.g.*, lactation, warmer temperatures, starvation) contaminants are released into the bloodstream, where they can affect cetacean health. This adds strength to the hypothesis that increasing ocean temperatures or commercial fishing-related prey depletion could simultaneously cause a release of contaminants from blubber storage, leading to synergistic effects on cetacean health.

(SOURCE: Yordy, J.E., Wells, R.S., Balmer, B.C., Schwacke, L.H., Rowles, T.K. and Kucklick, J.R. 2010. Partitioning of persistent organic pollutants between blubber and blood of wild bottlenose dolphins: implications for biomonitoring and health. *Environ. Sci. Technol.* 44*:* 4789-4795)

## Disease and mortality events

### *Harmful Algal Blooms*

Domoic acid transferred from prey to minke whale

High concentrations of the neurotoxin domoic acid were found in a minke whale carcass found stranded after a severe HAB in California in 2007. Remains of the diatom *Pseudo-nitzschia australis*, as well as the remains of a common *Pseudo-nitzschia* vector, the northern anchovy, were found in the whale's stomach and/or faeces, indicating that it was exposed to the neurotoxin through prey consumption. The faecal concentration of domoic acid was higher than that reported for any other marine mammal species. Domoic acid intoxication was the identified cause of death for this animal, adding to the limited body of knowledge on the impact of domoic acid on large whales.

(SOURCE: Fire, S.E. *et al.* [6 co-authors]. 2010. Trophic transfer of the harmful algal toxin domoic acid as a cause of death in a minke whale (*Balaenoptera acutorostrata*) stranding in southern California. *Aquat. Mamm.* 36: 342-350)

Algal bloom in freshwater lake poses threat to marine mammals

A bloom of cyanobacteria in a freshwater lake and its tributaries was responsible for the deaths of southern sea otters in the Monterey Bay National Marine Sanctuary, California. 'Super-blooms' of cyanobacteria that produce microcystins (potent biotoxins) are an emerging global health issue in freshwater habitats. This is the first report of marine mammal deaths due to biotoxins originating in freshwater and confirms the presence of a novel class of HAB. It involves a flow from land to sea with a transfer along the food chain via marine invertebrates. Both animals and humans are at risk.

(SOURCE: Miller, M.A. *et al.* [14 co-authors]. 2010. Evidence for a novel marine harmful algal bloom: Cyanotoxin (microcystin) transfer from land to sea. *PLoS ONE* 5: e12576 doi:10-1371/journal.pone.0012575)

## *Ship strikes*

Ship strikes: A technical approach provides new perspectives

Ship strikes are a concern in cetacean management efforts and represent the greatest known threat to certain endangered species such as the North Atlantic right whale. In an effort to better understand the effects of ship/whale collisions, scale models of a container ship and right whales were tested in an experimental flow tank. The results showed that the impacts on whales at the surface increased with ship speed, independent of whale orientation. Submerged whales were affected by propeller suction, which drew the animals toward the hull and increased the probability of propeller strikes. This technical perspective supports policy decisions that limit vessel speeds.

(SOURCE: Silber, G.K., Slutsky, J. and Bettridge, S. 2010. Hydrodynamics of a ship/whale collision. *J. Exp. Mar. Biol. Ecol.* 391: 10-19)

## *Oil spills*

Deepwater Horizon oil spill – preliminary concerns

On April 20, 2010, the Deepwater Horizon oil rig exploded and sank in the Gulf of Mexico, releasing an oil gusher at a depth of over 1.5 km that spilled approximately 800 million litres of oil before being capped in July 2010. It was the worst oil spill in the history of the United States and occurred in a particularly environmentally sensitive (and economically important) region. While information on impacts is still meagre and preliminary, the most recent data suggest that cetaceans and their prey were hard hit. For cetaceans, inhaling oil at the surface can lead to unconsciousness, pneumonia, organ damage and death. Direct contact with oil and dispersants can cause skin and eye infections. Oil in prey accumulates in predator tissue, causing disease and lowering reproductive rates. Strandings to date (170 cetaceans, most dead or dying soon after, including an unusually large number of neonates) were initially characterized as a 'minor' response, but modelling suggests that the stranding rate vastly underestimates mortality. Impacts to prey (and other elements of the ecosystem) are still largely hidden and may never be fully known. Monitoring and research are ongoing and should be expanded.

(SOURCES: Gaskill, M. 2010. What will get sick from the slick? [News]. *Nature* 466: 12-15; Williams, R. *et al.* [7 co-authors]. 2011. Underestimating the damage: Interpreting cetacean carcass recoveries in the context of the *Deepwater Horizon*/BP incident. *Conserv. Lett.* doi:10.1111/j.1755-263X.2011.00168.x; http://www.nmfs.noaa.gov/pr/pdfs/oilspill/species_data.pdf)

## *Disease*

New cases of mother to foetus transmission involving a pathogenic yeast and parasitic nematode

The pathogenic yeast *Cryptococcus gattii*, which causes invasive, potentially life-threatening infection in humans and animals, was found in a dead, stranded female harbour porpoise and her foetus in Washington State, USA. During 1997-2007, infections by this species were diagnosed in 15 harbour porpoises, 10 Dall's porpoises, two adult Pacific white-sided dolphins and three unrecorded species (30 individuals) along the northwest Pacific coast. This foetal case of cryptococcosis may have major human and animal health implications. A second investigation on bottlenose dolphins from Florida revealed a 77% prevalence of nematode worms (*e.g.*, lungworms). The highest prevalence of active infections was found in neonates and calves, including one stillborn calf. The study supports the theory that lungworm transmission between mother and foetus (transplacental infection) is possible.

(SOURCES: Fauquier, D.A. *et al.* [6 co-authors]. 2009. Prevalence and pathology of lungworm infection in bottlenose dolphins *Tursiops truncatus* from southwest Florida. *Dis. Aquat. Organ.* 88: 85-90; Norman, S.A. *et al.* [6 co-authors]. 2011. Maternal–fetal transmission of *Cryptococcus gattii* in harbor porpoise. *J. Gen. Virol.* 91: 166-173)

New type of virus identified in marine mammals

Astroviruses, small RNA viruses, have only been discovered relatively recently, and their presence in wildlife was first reported a few years ago. Six species are known from mammalian hosts. This is the first report of astroviruses in marine mammals, including bottlenose dolphins. The viruses are apparently novel species, and evidence was found for recombination between human and marine forms. The marine environment may play an important role in the ecology of astroviruses, which cause infections of the gastrointestinal tract and can result in diarrhoea.

(SOURCE: Rivera, R., Nollens, H.H., Venn-Watson, S., Gulland, F.M.D. and Wellehan, F.X. 2010. Characterization of phylogenetically diverse astroviruses of marine mammals. *J. Gen. Virol.* 91: 166-173)

Status of coastal landscapes important in transmission of *Toxoplasma* parasite stages

The state of coastal estuaries apparently can play a role in the transmission from land to sea of *Toxoplasma gondii*, a protozoan parasite excreted in the faeces of infected cats that causes the disease toxoplasmosis, including in humans. By evaluating the transport of particles of the same size as the parasite's oocyst stage, it was shown that the number of particles entering the sea via degraded wetlands was two orders of magnitude higher than via non-degraded wetlands. Total degradation of wetlands was estimated to result in transport increased by six orders of magnitude or more. This parasite can be fatal in certain marine mammal species and also infects cetaceans. The results underline the extent to which adjoining habitats must be incorporated into comprehensive management plans for wildlife.

(SOURCE: Shapiro, K., Conrad, P.A., Mazet, J.A.K., Wallender, W.W., Miller, W.A. and Largier, J.L. 2010. Effect of estuarine wetland degradation on transport of *Toxoplasma gondii* surrogates from land to sea. *Appl. Environ. Microb.* 76: 6821-6828)

## Climate change

More intense rainfall events predicted in new climate change analysis

An in-depth analysis of rainfall patterns shows that greenhouse gas emissions contribute to more intense, heavier rainfall in the northern hemisphere than climate models have previously predicted. An inability to account for cloud formation processes, shifts in jet stream air currents and other factors has meant that these models do not match observed patterns of intense rainfall or periods of unusually low rainfall and drought (*e.g*., the floods in the U.K. in autumn 2000). Patterns of extreme rainfall could affect cetaceans by affecting the hydrology, pollution and siltation levels of coastal, riverine or estuarine habitat.

(SOURCES: Allan, R.P. 2011. Human influence on rainfall [News]. *Nature* 470: 344-345; Min, S.K., Zhang, X., Zwiers, F.W. and Heger, G.C. 2011. Human contribution to more intense precipitation extremes. *Nature* 470: 378-381)

State of the global climate

Global average surface and lower-troposphere temperatures during the last three decades have been progressively warmer than all earlier decades, and the period 2000-2009 was the warmest decade on record. Atmospheric greenhouse gas concentrations continued to rise, with $CO_2$ increasing at a rate above the 1978-2008 average. In 2009, extreme warmth was experienced across large areas of South America, southern Asia, Australia, and New Zealand. Australia had its second warmest year on record. India experienced its warmest year on record and New Zealand had its warmest August since records began 155 years ago. Severe cold snaps were reported (U.K., China, Russian Federation). Drought affected large parts of southern North America, the Caribbean, South America, and Asia. China suffered its worst drought in five decades. India had a record dry June. Heavy rainfall and floods affected Canada, the U.S., Amazonia and southern South America, many countries along the east and west coasts of Africa, and the U.K. The U.S. experienced its wettest October in 115 years and Turkey received its heaviest rainfall over a 48-hr period in 80 years. The summer minimum ice extent in the Arctic was the third-lowest recorded since 1979. The 2008/09 boreal snow cover season continued a trend of relatively shorter snow seasons. Preliminary data indicate that 2009 will be the 19$^{th}$ consecutive year that glaciers have lost mass. Below normal precipitation led the 34 widest marine-terminating glaciers in Greenland to lose 101 $km^2$ of ice area. Permafrost temperatures have generally increased during the last several decades in Alaska, northwest Canada, Siberia, and Northern Europe. Earlier tundra green-up in the High Arctic and a shift to a longer green season in autumn in the Low Arctic are occurring. The Antarctic Peninsula continues to warm at a rate five times faster than the global mean warming. There was also significant ice loss along the Antarctic Peninsula in the last decade. Antarctic sea ice extent was near normal to modestly above normal for most of 2009, with marked regional contrasts within the record. The 2008-09 Antarctic-wide austral summer snow melt was the lowest in 30 years.

(SOURCE: Arndt, D. S., Baringer, M. O. and Johnson, M. R., eds. 2010. State of the climate in 2009. *Bull. Amer. Meteor. Soc*. 91: S1-S224)

Global decline of phytoplankton levels linked to climate change

Historical measurements of phytoplankton levels (based on sea water transparency) dating back to 1899 show that phytoplankton has been declining globally (by approximately 1% per year in 8 of the 10 regions analyzed). This decline correlates with increasing sea surface temperatures and indicates that increased ocean warming is contributing to a restructuring of marine ecosystems, with implications for biogeochemical cycling, fishery yields and ocean circulation.

(SOURCE: Boyce, D.G., Lewis, M.R. and Worm, B. 2010. Global phytoplankton decline over the past century. *Nature* 466: 591-596)

Climate change as a factor in cetacean conservation

A special volume of the journal of the American Cetacean Society examined the various facets of climate change as related to cetaceans. The ten contributions underline a range of predicted direct and indirect effects. The former reflect temperature-driven changes in the sea (and in freshwater), the latter climate-driven shifts in human behaviour. Arctic and Antarctic species are probably among the most vulnerable due to a decrease in sea-ice cover. In the Antarctic this is predicted to be associated with a reduced abundance of ice-dependent krill, a crucial component of the Antarctic food web. A concerted effort by scientists and policy-makers will be required to address the problem and implement solutions. The volume includes a review of the peer-reviewed literature on climate change and cetaceans.

(SOURCE: Dutton, I., Gorter, U., Reznick, K. and Bennett, B., eds. 2010. Climate change: Challenges to cetacean conservation. *Whalewatcher* 39: 1-40)

Climate change will cause more intense cold snaps

Critics of climate change science point to recent cold snaps as ‘evidence’ that global warming is not occurring. However, accelerating climatic change is predicted to decrease the frequency but increase the intensity of such cold snaps; cold periods will last longer and drop to lower temperatures.

(SOURCE: Kodra, E., Steinhaeuser, K. and Ganguly, A.R. 2011. Persisting cold extremes under 21st-century warming scenarios. *Geophys. Res. Lett.* 38: L08705, 1-5)

Climate change may affect the whale-watching tourism industry

Climate change has considerable implications for tourism, and efforts are now being initiated to address the potential effects on the whale-watching industry. Changes in the abundance or distribution of cetaceans could a) alter the presence and frequency of species being watched and b) alter the lengths of tourism seasons to correspond with shifts in migration patterns. New conceptual approaches are being designed to evaluate the resilience of whalewatching, *i.e.*, to determine the degree of change in cetacean occurrence experienced before tourist numbers fall below a critical threshold. Such efforts must expand to explore many additional components before operators can be advised on how best to adapt.

(SOURCE: Lambert, E., Hunter, C. Pierce, G.J. and MacLeod, C.D. 2010. Sustainable whale-watching tourism and climate change: Towards a framework of resilience. *J. Sustain. Tour.* 18: 409-427)

Global warming may be behind increasingly shallower thermocline

In the western tropical Pacific Ocean, the chemical composition of gorgonian coral growth rings indicates that the depth of the thermocline has risen. This evidence supports what climate modellers have been predicting as the effects of global climate change, including altered productivity at the bottom of the euphotic zone and altered subsurface ocean circulation. Most cetaceans live and forage in these water layers, and changes in their thickness and position could affect cetacean and prey distributions.

(SOURCES: News. 2010, *Mar. Pollut. Bull.* 60: 2164; Williams, B. and Grottoli, A.G. 2010. Recent shoaling of the nutricline and thermocline in the western tropical Pacific. *Geophys. Res. Lett.* 37: 122601.1-122601.5.doi:10.1029/2010GL044867)

Whale biomass as a means to store carbon

Whales store oceanic carbon, and indeed, because of their large size, store more carbon than smaller marine species of an equivalent total biomass. Researchers estimating the amount of carbon storage in living baleen whales calculated that the decline in large whales due to commercial whaling has reduced the carbon sink by 9 million tonnes, equivalent to 110 000 hectares of forest. The authors argue that “*rebuilding populations of fish and whales would be comparable to other carbon management schemes*”. Their calculations “*suggest that conserving larger species and largest individuals within species should be a top conservation priority*” because of their potential as an oceanic carbon store.

(SOURCE: Pershing, A.J., Christensen, L.B., Record, N.R., Sherwood, G.D. and Stetson, P.B. 2010. The impact of whaling on the ocean carbon cycle: Why bigger was better. *PLoS ONE* 5: e12444)

Ice loss models underestimating actual rate of ice loss

A comparison of data from the era of satellite observations and five climate models for predicting sea ice cover in the Arctic found that the models consistently underestimated the actual amount of observed sea ice loss. The discrepancy was attributed either to a lack of sensitivity in these models or to the fact that actual ice loss per degree of warming is higher than predicted. This could also mean that future ice loss trends based on these models may present a more optimistic future for the Arctic Ocean than warranted.

(SOURCE: Winton, M. 2011. Do climate models underestimate the sensitivity of Northern Hemisphere sea ice cover? *J. Climate:* doi:10.1175/2011JCLI4146.1)

## Noise impacts

### *Cetacean Hearing*

Temporary hearing loss: Sound exposure duration, repetition, and frequency

An experiment using a captive common bottlenose dolphin looked at the effect of 3 kHz tones (in the range of mid-frequency active sonar) on hearing ability. Sound exposure level (SEL) was correlated with amount of temporary threshold shift (TTS), but two sounds of equivalent SELs produced different levels of TTS if the duration of exposure was greater (more TTS) than if the sound pressure level was greater (less TTS). The dolphin also experienced repeated exposures, followed by a gap of several minutes (during which some recovery of hearing could occur). Multiple exposures caused TTS to ‘accumulate’, *i.e*., repeated exposure to a sound produces higher levels of hearing loss. Exposure to mid-frequency active sonar, which transmits repeated ‘pings’, therefore has the potential to cause higher levels of TTS than predicted by a single exposure. Another experiment tested a dolphin for degree of TTS when exposed to sounds of 3 kHz and 20 kHz. TTS was much more pronounced when the dolphin was exposed to higher frequency sounds. Previous experiments on captive dolphins had shown no difference between low and high frequency exposures and TTS, but those previous trials had several confounding factors that may have affected results, which this experiment sought to eliminate. However, this dolphin also responded differently than it had when exposed to 3 kHz sounds two years previously, possibly as a result of the test animal experiencing changes in hearing ability during the intervening period. The authors concluded that “*[d]amage-risk criteria for dolphins based on 3-kHz exposures likely underestimate the effects of higher frequency exposures, where sensitivity is better*”.

(SOURCES: Finneran, J.J., Carder, D.A., Schlundt, C.E. and Dear, R.L. 2010. Growth and recovery of temporary threshold shift at 3 kHz in bottlenose dolphins: Experimental data and mathematical models. *J. Acoust. Soc. Am.* 127: 3256-3266; Finneran, J.J., Carder, D.A., Schlundt, C.E. and Dear, R.L. 2010. Temporary threshold shift in a bottlenose dolphin (*Tursiops truncatus*) exposed to intermittent tones. *J. Acoust. Soc. Am.* 127: 3267-3272; Finneran, J.J. and Schlundt, C.E. 2010. Frequency-dependent and longitudinal changes in noise-induced hearing loss in a bottlenose dolphin (*Tursiops truncatus*) (L). *J. Acoust. Soc. Am.* 128: 567-570)

High proportion of stranded and entangled cetaceans with hearing loss

Auditory evoked potential measurements were collected from stranded or entangled cetaceans to analyze their hearing capabilities. More than half of the common bottlenose dolphins tested (57%; n = 4) and a third of rough-toothed dolphins (36%; n = 5) exhibited reduced sensitivities that would equate to severe or profound hearing loss in humans. There was no relationship with gender or age and hearing loss; while no calves exhibited hearing loss, 42% of sub-adults did. The researchers highlighted that “*[h]earing impairment could play a significant role in some cetacean stranding events*”.

(SOURCE: Mann, D. *et al*. [15 co-authors]. 2010. Hearing loss in stranded odontocete dolphins and whales. *PLoS ONE* 5: e13824.doi:10.1371/journal.pone.0013824)

### *Seismic Surveys*

Whales at risk of temporary deafness 1 km or more from seismic survey vessels

A model to assess the possible impacts of seismic surveys predicted a reasonable chance that whales 1 km or more from seismic survey vessels would be susceptible to TTS. The model used a TTS onset level of 183 dB re 1 $\mu Pa^2.s^{-1}$, and factored in movement, avoidance reactions, surfacing and other factors that might influence exposure levels. The authors note that uncertainty is a major factor in making such a risk assessment and that "*[t]he actual risk that may be associated with particular surveys and sound sources will depend on a number of variables including the configuration and size of the airgun array used, bathymetry, bottom composition, sound speed profile, and sound propagation among other factors*".

(SOURCE: Gedamke, J., Gales, N. and Frydman, S. 2011. Assessing risk of baleen whale hearing loss from seismic surveys: the effect of uncertainty and individual variation. *J. Acoust. Soc. Am.* 129: 496-506)

## *Sonar*

Lack of strandings coincident with naval exercises does not equate to lack of impacts

There have been 11 cetacean mass stranding events in the Hawaiian Islands in a 22-year period, of which six have coincided with military exercises. However, despite the occurrence of beaked whales in these waters, none of these mass strandings have involved this deep-diving taxon. Only nine single beaked whale strandings have been recorded on Hawaii's coasts (through 2006). Due to this lack of beaked whale mass strandings in Hawaii, the U.S. Navy has claimed that it is "*extremely unlikely that any significant behavioral response will result from the interaction of beaked whales and the use of sonar*" in these waters. However, an analysis of topography and coastal characteristics indicates that a variety of factors – a lack of beaked whale habitat close to shore, a prevalence of steep cliffs, lower human densities on the coast – decreases the likelihood of strandings occurring and being detected in Hawaii compared to elsewhere (*e.g.*, Canary Islands). The analysis' authors conclude that "*[t]here is significant potential for underestimating the impact naval sonar use may be having on beaked whales, in the main Hawaiian Islands and elsewhere*" and "*it is inappropriate to conclude there has been no impact on beaked whales from anthropogenic activity in the Hawaiian Islands*".

(SOURCE: Faerber, M.M. and Baird, R.W. 2010. Does a lack of observed beaked whale strandings in military exercise areas mean no impacts have occurred? A comparison of stranding and detection probabilities in the Canary and main Hawaiian Islands. *Mar. Mamm. Sci.* 26: 602-613)

Beaked whale reactions to mid-frequency sonar exposure

Blainville's beaked whales exposed to mid-frequency active sonar during foraging dives in the U.S. Navy's underwater testing range in the Bahamas responded at received levels well below those used by U.S. regulators to define disturbance. The whales continued to forage when exposed to 128 dB re 1 µPa, but at higher sound levels, foraging behaviour was reduced and whales swam more than 10 km away from the area of the sound source. Displacement could last 2-3 days. The whales' acoustic behaviour was also examined. Beaked whale vocalizations decreased significantly during the exercises, and although the rate of detected vocalizations increased post-exercise, it did not recover to pre-exercise levels.

(SOURCES: McCarthy, E. *et al.* [8 co-authors]. 2011. Changes in spatial and temporal distribution and vocal behavior of Blainville's beaked whales (*Mesoplodon densirostris*) during multi-ship exercises with mid-frequency sonar. *Mar. Mamm. Sci.* doi:10.1111/j.1748-7692.2010.00457.x; Tyack, P.L. *et al.* [13 co-authors]. 2011. Beaked whales respond to simulated and actual navy sonar. *PLoS ONE* 6: e17009. doi:10.1371/journal.pone.0017009)

## *Marine Renewable Energy*

Potential impacts of wind turbine installation noise on cetaceans

There is a lack of information from marine renewable energy installations for use in models attempting to predict noise levels from construction and operation. Sound levels produced during the installation of two 5 MW wind turbines, near a marine protected area in Scotland, were recorded at increasing distances during the construction phases. Up to 2 km away, the noise produced was broadband, at primarily 100 Hz to 2 kHz, but with substantial levels up to 10 kHz. More than 4 km away, frequencies were primarily 5 kHz or less. Levels were received at 205 dB re 1 µPa at 100 m from the site. At 80 km, sound levels were below the background noise. It was predicted that PTS and TTS could occur within 100 m of the pile-driving site, but "*bottlenose dolphins and [common] minke whales (and other mid- and low-frequency hearing cetaceans) may exhibit behavioural disturbance up to 50 km away*". Moreover, if this level of noise was maintained for a longer period of time (*e.g.*, several months) it "*could potentially lead to avoidance of the area up to 20 km away by harbor porpoises, the species most likely to be impacted as they frequently use this area near the turbine site*".

(SOURCE; Bailey, H., Senior, B., Simmons, D., Rusin, J., Picken, G. and Thompson, P.M. 2010. Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals. *Mar. Pollut. Bull.* 60: 888-897)

Potential impacts of renewable energy installations on cetaceans

Concern has been expressed about the rapid development of marine renewable energy installations and the potential impacts on cetaceans; for example, in the U.K. there were just 16 sites (14 wind farms and two tidal-energy plants) before 2000, but by 2004, there were 34 sites (27 wind farms, five tidal-energy and two wave energy plants). By 2009 there were 89 sites (61 wind farms, 15 tidal-energy and 13 wave-energy plants) planned or in operation. Areas slated to be developed for marine renewable energy can be substantial (*e.g.*, 8660 $km^2$ in the case of Dogger Bank) and include developments in key habitats for cetaceans (*e.g.*, 520 $km^2$ in the Moray Firth, which is also a Special Area of Conservation for common bottlenose dolphins). Potential impacts of these facilities on cetaceans include increased noise from pile-driving, dredging, facility operation or increased shipping for construction or maintenance. There is an entanglement and collision risk (submerged cables and structures), in addition a risk of injury and death from rotating turbines. Anti-fouling treatments and chemical leaks may be a toxicological risk, and increased turbidity and changes in water flow may affect habitat quality. Prey species abundance and distribution may also be affected by habitat changes and the installation of physical structures.

(SOURCE: Simmonds, M.P. and Brown, V.C. 2010. Is there a conflict between cetacean conservation and marine renewable-energy developments? *Wildl. Res.* 37: 688-694)

### *Masking*

Is noise a prey distraction or predator masker?

Several impacts of sound have been highlighted, *e.g.*, behavioural changes and masking. Impacts on predation rates have also been hypothesized. In an experimental study, Caribbean hermit crabs were exposed to playbacks of boat noise and then subjected to the simulated approach of a predator. The predator could approach more closely when the boat sounds were being played, but even more closely when the crabs were also exposed to flashing lights. The authors noted that "*[a]nthropogenic sounds may thus distract prey and make them more vulnerable to predation*". This could be equally relevant to cetaceans that are prey for killer whales and sharks.

(SOURCE; Chan, A.A.Y.-H., Giraldo-Perez, P., Smith, S. and Blumstein, D.T. 2010. Anthropogenic noise affects risk assessment and attention: the distracted prey hypothesis. *Biol. Lett.* 6: 458-461)

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**Appendix 1**

## GLOSSARY

Species glossary

| | |
|---|---|
| Antarctic minke whale | *Balaenoptera bonaerensis* |
| Blainville's beaked whale | *Mesoplodon densirostris* |
| Blue whale | *Balaenoptera musculus* |
| Common bottlenose dolphin | *Tursiops truncatus* |
| Common minke whale | *Balaenoptera acutorostrata* |
| Dall's porpoise | *Phocoenoides dalli* |
| Franciscana dolphin | *Pontoporia blainvillei* |
| Harbour porpoise | *Phocoena phocoena* |
| Humpback whale | *Megaptera novaeangliae* |
| Killer whale | *Orcinus orca* |
| North Atlantic right whale | *Eubalaena glacialis* |
| Pacific white-sided dolphin | *Lagenorhynchus obliquidens* |
| Rough-toothed dolphin | *Steno bredanensis* |
| Sperm whale | *Physeter macrocephalus* |
| Striped dolphin | *Stenella coeruleoalba* |
| White-beaked dolphin | *Lagenorhynchus albirostris* |
| Yangtze River dolphin | *Lipotes vexillifer* |
| Antarctic fur seal | *Arctocephalus gazella* |
| Caribbean monk seal | *Monachus tropicalis* |
| Southern sea otter | *Enhydra lutris nereis* |
| Weddell seal | *Leptonychotes weddellii* |
| Adélie penguin | *Pygoscelis adeliae* |
| Brown skua | *Catharacta Antarctica* |
| Chinstrap penguin | *Pygoscelis antarcticus* |
| Antarctic toothfish | *Dissostichus mawsoni* |
| Northern anchovy | *Engraulis mordax* |
| Yellowfin tuna | *Thunnus albacares* |
| Antarctic krill | *Euphausia superba* |
| Caribbean hermit crab | *Coenobita clypeatus* |

Glossary of terms

Auditory evoked potential: An electrical response recorded from the auditory nerves following presentation of an acoustic stimulus.

Benthic: Of or related to the bottom level of the ocean, including the sediment or ocean floor.

Bioaccumulation: Increase in concentration of a pollutant within an organism over time.

Biomass: The total mass of living organisms in an area or ecosystem.

Biota: The plant and animal life of a region.

Boreal: Of the north or northern regions.

CBD: Convention on Biological Diversity.

Chlorofluorocarbons: CFCs, organic compounds widely used as refrigerants, propellants (in aerosol sprays), and solvents. The manufacture of CFCs is being phased out via treaty because they contribute to ozone depletion.

$CO_2$: Carbon dioxide.

*Cryptosporidium*: A wide-spread protozoan parasite that infects a variety of hosts, including marine mammals and humans.

CTD: A type of sensor (such as a tag) that measures salinity (conductivity), temperature and depth of ocean water.

Cyanobacteria: Originally called 'blue-green algae' – a phylum of bacteria capable of photosynthesis, with some species producing biotoxins that can cause serious illness and death in many species.

dB: Decibel – a logarithmic measure of sound pressure level.

DDE: The organochlorine dichlorodiphenyldichloroethylene, a breakdown product of the pesticide DDT.

DDT: The organochlorine pesticide dichlorodiphenyltrichloroethane, which tends to accumulate in the ecosystem and in the blubber and certain internal organs of cetaceans.

Diatom: Common type of phytoplankton, a one-celled alga encased in a silica cell wall. The species *Pseudo-nitzschia australis* produces domoic acid, which poisons mammals, causing paralysis and reproductive failure.

Dieldrin: A chlorinated hydrocarbon used as an insecticide.

Domoic acid: See diatom.

Endocrine system: A system of ductless glands producing hormones that control and moderate metabolic processes in the body.

Endocrine disrupter: Any outside substance (*e.g.*, chemical) that interferes with the endocrine system.

Euphotic zone: The uppermost layer of the ocean, also known as the 'sunlit zone'.

Foraminifera: A phylum of zooplankton, single-celled organisms distinguished by the presence of a shell.

Gorgonian coral: Sea whips or sea fans, a soft coral distributed globally, especially in the tropics.

Gt: Gigatonne (one billion tonnes)

HAB: Harmful algal bloom; population explosion of certain phytoplankton that produce toxic substances that can harm higher levels of the marine food chain and humans who consume contaminated seafood.

HCB: Hexachlorobenzene, an environmentally persistent organochlorine fungicide.

HHCB: Galaxolide, a polycyclic musk (artificial fragrance).

Hypoxia: The state of having low oxygen levels.

Hz: Hertz, a measure of sound frequency (pitch), in wave cycles per second (kHz = 1000 Hertz).

*In vitro*: 'In glass', *i.e.,* in the laboratory.

*In vivo*: 'In the living', *i.e.,* in the organism.

Lipid weight: A basis of measurement whereby concentrations of a substance are compared to the lipid (fat) content of a material.

Masking: A phenomenon wherein the frequency and intensity of ambient noise covers up or 'masks' a biologically important signal, making it undetectable by a receiver.

MeHgCl: Methylmercury chloride – an environmental form of mercury and the most toxic to humans.

Microcystins: Biotoxins from cyanobacteria.

μmol: Micromole – a mole is a unit of measurement for a chemical substance.

μPa: Micropascal – a pascal is a unit of measurement for sound pressure.

MW: Mega watts.

NASA: U.S. National Aeronautics and Space Administration.

Nematodes: Also known as roundworms, the largest phylum of animals on earth.

Neurotoxic: Toxic to the nervous system.

Oestrogen: Any of a group of steroid hormones that promote the development of female characteristics of the body.

Oocyst: A thick-walled structure in which parasite zygotes develop and that serves to transfer them to new hosts.

Organochlorine: Organic compounds that contain chlorine. Many are toxic and used as pesticides. Most of these compounds persist in the environment (are not biodegradable) and also tend to accumulate in fatty tissue (*e.g.,* blubber) of cetaceans and other marine organisms.

Pagophilic: 'Ice-loving', *i.e.*, sea ice is an important element of a species' habitat.

Pagophobic: 'Ice-hating', *i.e.*, sea ice is not an important element of a species' habitat.

PAHs: Polycyclic aromatic hydrocarbons, which occur in oil, coal, and tar deposits, and are produced as by-products of fuel burning.

Pathogen: A disease-causing agent (*e.g.,* bacterium, virus).

PBDE: Polybrominated diphenyl ether(s), a widely used class of flame retardants in textiles, furniture upholstery and plastics.

PCB: Polychlorinated biphenyls (209 different forms that contain differing numbers of chlorine atoms arranged in various positions on the aromatic rings) are industrial organochlorines that were manufactured to be used in electrical transformers and other applications. These man-made chemicals do not occur naturally and all traces reflect pollution.

PCN: Polychlorinated naphthalenes, used as a lubricant for machinery.

Pelagic: Of or related to open (as opposed to nearshore) waters of the ocean.

Permanent threshold shift: PTS, a permanent decrease in hearing sensitivity, *i.e.*, non-recoverable hearing loss.

pH: A measure of the acidity or alkalinity of an aqueous solution – 7 is neutral, with pH levels lower than 7 being acidic and pH levels higher than 7 being alkaline.

Phytoplankton: Free-floating marine plants (versus zooplankton – free-floating marine animals).

POPs: Persistent organic pollutants, organic compounds that are resistant to degradation and thus persist in the environment.

ppm: Parts per million.

Protozoa: Single-celled organisms.

Resource limited: When a species is limited in the type of food it eats.

RNA: Ribonucleic acid, a form of genetic material.

Sound exposure level: SEL, an index of total sound energy (sound pressure level + duration).

Sound pressure level: A measure of the intensity of sound, in decibels.

Temporary threshold shift: TTS, a temporary decrease in hearing sensitivity, *i.e.*, fully recoverable hearing loss.

Thermocline: A thin but distinct layer in a large volume of fluid (such as the ocean), in which temperature changes more rapidly with depth than it does in the layers above or below.

*Trans*-nonachlor: A major constituent of the insecticide chlordane, whose use was banned after 1988.

Trophic level: Each level in a food chain, including decomposers, producers (photo- and chemo-synthesizers), and consumers.

Troposphere: The lower part of Earth's atmosphere, containing 75% of the atmosphere's mass.

UNEP: United Nations Environment Programme.

Vector: A living carrier that transmits a disease-causing agent, such as a pathogen.

Zooplankton: Free-floating marine animals (versus phytoplankton – free-floating marine plants)

Zygote: The initial combination of sex cells (gametes) to form a new organism.