STATE OF THE CETACEAN ENVIRONMENT REPORT (SOCER) 2010

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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. After submission of a prototype State of the Cetacean Environment Report (SOCER), Resolution 2000-7 welcomed the concept of the SOCER at the 52nd Annual Meeting in Adelaide, 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/62/E1** (SOCER 2010) focuses on the Arctic Ocean, summarising key papers and articles that have been published from 2008 through 2010 to date.

ARCTIC OCEAN

General

Beluga whales in Alaska listed as endangered

The Cook Inlet beluga whale population near Anchorage, Alaska, has been listed as an endangered species under the U.S. Endangered Species Act because the population is not recovering despite protection measures. The population declined by nearly 50% between 1994 and 1998, with current numbers between 3 and 400. Recovery has apparently been hindered by strandings, developments along the inlet, oil and gas exploration, industrial activities, disease and predation by killer whales.

(SOURCE: News-in-Brief. 2008. *Mar. Pollut. Bull.* 56: 1962)

Habitat protection/degradation

General

Threats to Arctic marine mammal species

Threats to Arctic marine mammal species include climate change, environmental contaminants, offshore oil and gas activities, shipping, hunting, and commercial fisheries. Oil and gas exploration is occurring in Baffin Bay and the Barents, Beaufort and Chukchi Seas, with additional upcoming exploration in Eurasia, increasing the potential for oil spills from extraction or shipping and transfer accidents. Fisheries in Arctic waters have been limited, but fisheries bodies are preparing for the opening of new fisheries in the near future as a result of easier Arctic access as sea ice recedes. Fishing in the Arctic could lead to conflict between marine mammals and fisheries, if marine mammal prey species are taken (as targeted catch or bycatch). The projected impacts of climate change are numerous: "*Climate change has reduced arctic sea ice, lengthened periods of open water, and raised water temperatures in marginal seas; changes that are expected to continue or even accelerate…Loss of sea ice means fewer habitats for ice-dependent or ice-associated marine mammals...Changes in water temperature will undoubtedly alter primary productivity, the resulting food web, and prey fields for marine mammals...Warmer waters and changed distributions of marine mammals will affect disease prevalence and spread...Furthermore, as sea ice recedes, human activity will increase in the region because shipping and offshore development become economically feasible and advantageous*".

(SOURCE: Huntington, H.P. 2009. A preliminary assessment of threats to arctic marine mammals and their conservation in the coming decades. *Marine Policy* 33: 77- 82)

Changes in Arctic ecosystems

A review of changes in Arctic ecosystems warns of the effects of changing geochemical cycles, shifts in

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distributions, invasive species and an increase in extreme environmental events. It highlights that "*some of the most rapid ecological changes associated with warming have occurred in marine and freshwater environments, associated with changes in sea ice dynamics and external nutrient loading*". It discusses the lack of research and understanding of Arctic ecosystems, which are often ignored by managers as these systems are relatively species-poor. The review concludes that the "*extensive changes in living components of the Arctic associated with recent climate change documented here have been rapid and widespread across terrestrial, freshwater, and marine systems. Foreseeing and mitigating the ecological consequences of future climate change will require more intensive, multidisciplinary monitoring of both the physical drivers of these systems and biological responses to them*".

(SOURCES: Post, E., Forchhammer, M.C., Bret-Harte, M.S., Callaghan, T.V., Christensen, T.R., Elberling, B., Fox, Gilg, O., Hik, D.S., Høye, T.T., Ims, R.A., Jeppesen, E., Klein, D.R., Madsen, J., McGuire, D., Rysgaard, S., Schindler, D.E., Stirling, I., Tamstorf, M.P., Tyler, N.J.C., van der Wal, R., Welker, J., Wookey, P.A., Schmidt, N.M. and Aastrup, P. 2009. Ecological dynamics across the Arctic associated with recent climate change. *Science* 325: 1355-1358)

Current status of polar sea ice

There has been a decreasing trend in summer sea ice cover for the past several decades. The minimum extent of summer sea ice in 2009 was 5.36 million sq. km, 690,000 sq. km more than the second lowest sea ice extent ever recorded in 2008, and 1.06 million square km greater than the record minimum sea ice extent recorded in 2007. Nonetheless, ice extent was the third lowest recorded, and 1.68 million sq. km. below the average extent recorded for 1979-2000, a decline of 11.2% per decade relative to this average value. Satellite image data also show a thinning of sea ice, with a decrease of nearly 0.7 m between 2004 and 2008.

(SOURCES: Ray, G.C., Hufford, G.L., Krupnik, I.I. and Overland, J.E. 2008. Diminishing sea ice. *Science* 321: 1443-1444; Kerr, R.A. 2009. Arctic summer sea ice could vanish soon but not suddenly. *Science* 323: 1655; National snow and ice data center. 2009. Arctic sea ice extent remains low; 2009 sees third-lowest mark. 6 October 2009, http://nsidc.org/news/press/20091005_minimumpr.html; Kwok, R. and Rothrock, D.A. 2009. Decline in Arctic sea ice thickness from submarine and ICESat records: 1958-2008. *Geophys. Res. Lett.* 36: L15501)

Rate of ice loss in Antarctica and Greenland is accelerating

Between 1990 and 2000, melting of both the Greenland and Antarctic ice sheets accelerated. A recent satellite data evaluation of ice sheet loss suggests that this loss is increasing even faster. The mass of both Antarctica and Greenland have decreased, with the rate of ice mass loss doubling in Greenland, and more than doubling in Antarctica between 2002 and 2009. The edges of the ice sheets in both locations were shown to be thinning, which is linked to accelerating flow.

(SOURCES; Velicogna, I. 2009. Increasing rates of ice mass loss from the Greenland and Antarctic ice sheets revealed by GRACE. *Geophys. Res. Let.* 36: L19503; Kerr, R.A. 2009. Both of the world's ice sheets may be shrinking faster and faster. *Science* 326: 217; Pritchard, H.D., Arthern, R.J., Vaughan, D.G. and Edwards, L.A. 2009. Extensive dynamic thinning on the margins of the Greenland and Antarctic ice sheets. *Nature* 561: 971-975)

Marine Debris

Marine plastic debris an issue even in Arctic waters

Thirty-one percent of 102 birds (fulmars) collected in the Canadian high Arctic had pieces of plastic in their digestive system. Two percent of the items was 'industrial' (beads/pre-production pellets), while 98% was 'user' ('post-consumer') plastic. Although the incidence here was lower than the 79-100% occurrence reported in the North Pacific, North Atlantic or North Sea, the proportion represented an increase over the past three decades. The Arctic marine ecosystem is therefore also affected by the worldwide pattern of increasing pollution from marine plastic debris.

(SOURCE: Mallory, M.L. 2008. Marine plastic debris in northern fulmars from the Canadian high Arctic. *Mar. Pollut. Bull.* 56: 1501-1504)

Entanglement of marine mammals in marine debris in southeast Alaska

Entanglement in marine debris is a contributing factor to Steller sea lion injury and mortality in southeast Alaska and northern British Columbia. Packing bands, rubber bands, nets, ropes and monofilament line were the most common neck entangling items, whereas the most commonly ingested fishing gear was

lures, longline gear, hook and line, spinners/spoons and bait hooks. Marine debris is clearly a threat even in remote waters, and such items are also known to affect cetaceans.

(SOURCE: Raum-Suryan, K. L., Jemison, L.A. and Pitcher, K.W. 2009. Entanglement of Steller sea lions (*Eumetopias jubatus*) in marine debris: Identifying causes and finding solutions. *Mar. Pollut. Bull.* 58: 1487-1495)

Chemical pollution

Anthropogenic sources a strong contributor to mercury levels in Arctic wildlife

A comparison of mercury (Hg) levels in historical and pre-industrial versus present-day tissue samples from Arctic species showed that the median man-made contribution today is over 92%. The steep onset of mercury exposure began in the latter half of the 19th century and represents an order-of-magnitude increase. The analysis of beluga whale teeth showed that the large 20th century effect on this species occurred mostly before 1960, when man-made Hg had already attained 75% of the total. Older animals exhibited a larger man-made percentage than younger animals, which was predicted because of the multiplicative effects of lifetime bioaccumulation of Hg. In a second study, the Hg contents of Beaufort Sea beluga whales were linked to the Hg contents of their prey: highest Hg levels in the whales matched highest food web Hg levels. This points to a variation in dietary Hg uptake and underlines the importance of examining Hg sources at the bottom of the food web along with food web length.

(SOURCES: Dietz, R., Outridge, P.M. and Hobson, K.A. 2009. Anthropogenic contributions to mercury levels in present-day Arctic animals – a review. *Sci. Total Environ.* 407: 6120-6131; Loseto, L.L., Stern, G.A., Deibel, D., Connelly, T.L., Prokopowicz, A. Lean, D.R.S., Fortier, L. and Ferguson, S.H. 2009. Linking mercury exposure to habitat and feeding behaviour in Beaufort Sea beluga whales. *J. Mar. Syst.* 74: 1012-1024)

Polar cod suggested as a species to monitor future oil pollution in the Arctic

Arctic waters are predicted to open as a trade route and site of oil and gas exploration due to climate-related loss of ice. This would be associated with an increased risk of oil pollution, as the Arctic is subject to a specific set of additional risk factors such as rough weather conditions and drifting icebergs. Spilled petroleum hydrocarbons persist longer at the low temperatures here and cleaning up spills in such remote regions is difficult, posing an additional potential threat to cetaceans. Due to the high abundance and circumpolar distribution of polar cod, these fish are suggested to be well-suited organisms to monitor oil pollution.

(SOURCE: Jonsson, H., Sundt, R.C., Aas, E. and Sanni, S. *Mar. Pollut. Bull.* 60: 390-395)

Insufficient funding and research on oil spills in the Arctic

One of the predicted effects of global warming is increased boat traffic and oil exploration in the Arctic. This increases the risk of oil pollution in these waters. The logistics of combating oil spills here are more difficult than elsewhere: oil degrades much more slowly in cold waters, the Arctic has fewer locations from which to launch cleanup efforts, and the fate and recoverability of oil under ice is unknown. Elsewhere, under ideal conditions, cleanup crews can recover 30% of spilled oil. That figure would be much lower in the Arctic, making it virtually certain that most of the oil will remain in the environment. The US national oil-spill research plan has not been updated in over a decade and the funds spent to study spills in the Arctic are inadequate here compared to Norway, for example.

(SOURCE: Torrice, M. 2010. Science lags on saving the Arctic from oil spills. *Science* 325: 1335)

Climate change

Important role of Arctic sea ice in pumping carbon dioxide into the oceans

Arctic sea ice apparently plays a much larger role than previously recognized in capturing and removing carbon dioxide from the atmosphere and storing it in the world's oceans. Current climate models do not factor in the role of sea ice, which increases the seasonal uptake of CO_2 in the region by 50%. The predicted total loss of summer sea ice from the Arctic within the next few decades may have dramatic effects on this role, leading to further increases in CO_2 in the atmosphere and thus further altering key cetacean habitats.

(SOURCE: News. 2009. *Mar. Pollut. Bull.* 58:1593)

New evidence indicates an ice-free Arctic within a decade

Ice thickness was measured in early 2009 along a 450-km-long route across the northern Beaufort Sea by the Catlin Arctic Survey and analyzed by the Polar Ocean Physics Group, University of Cambridge. The data show that the ice layer consisted of relatively thin 'first year ice' rather than the normal, thicker, multi-year ice. These data support the emerging thinking that the Arctic Ocean will be largely ice-free in summer within a decade. Beyond the broad climate feedbacks that this may set in motion, increasing ship traffic across this ocean would pose a potential threat (*e.g.*, ship strikes, noise, pollution) to cetaceans and other marine mammals. In the USA, the North Pacific Fishery Management Council has banned fishing trawlers from following the retreating Arctic ice and fishing in previously ice covered waters.

(SOURCES: News. 2009. *Mar. Pollut. Bull.* 58: 1770; News. 2009. *Mar. Poll. Bull.* 58: 462)

Arctic may remain ice-covered in winter despite warming

The late Cretaceous period (65-99 million years ago) is often regarded as a possible indicator of what a world with elevated carbon dioxide levels could look like. Carbon dioxide levels were in excess of 1,000 ppm (possibly four times current concentrations). Temperatures in the Arctic Ocean are estimated to have been up to 15°C during this period and the pole was probably ice free. However, a new study analysing sediment deposition patterns has suggested that there may have been thin, seasonal ice cover in the winter. This suggests that even with atmospheric CO_2 levels much higher than present, winter sea ice may still occur, although in much smaller amounts, with subsequent implications for Arctic ecosystems.

(SOURCE: Davies, A., Kemp, A.E.S. and Pike, J. 2009. Late Cretaceous seasonal ocean variability from the Arctic. *Nature* 460: 254-259)

Two thousand years of Arctic climate data show cooling trend, then abrupt warming in past 50 years

An extensive analysis of climate proxy data over a 2000-year period indicated a long-term cooling trend in the Arctic. During the 20th century, following that trend, temperatures should have continued to cool, but this trend was reversed; the last half of the 20th century was the warmest in the 2000-year proxy data record. The researchers conclude that "*our synthesis, together with the instrumental record, suggests that the most recent 10-year interval (1999-2008) was the warmest of the past 200 decades. Temperatures were about 1.4°C higher than the projected value based on the linear cooling trend and were even more anomalous than previously documented*".

(SOURCE; Kaufman, D.S., Schneider, D.P., McKay, N.P., Ammann, C.M., Bradley, R.S., Briffa, K.R., Miller, G.H. and Otto-Bliesner, B.L., Overpeck, J.T. and Vinther, B.M. 2009. Recent warming reverses long-term Arctic cooling. *Science* 325: 1236-1239)

Climate change impacts on Arctic seals and whales

In a warmer Arctic, endemic marine mammal species will face extreme levels of habitat change, most notably a dramatic reduction in sea ice. The authors identify three cetacean species as 'ice-loving' (pagophilic) – bowhead whales, white whales and narwhals – based on, among other factors, their lack of dorsal fins, their thick blubber, and their ability to break young ice with their backs. Altered distributions and foraging are predicted for bowheads and white whales, which are also vulnerable to increases in pollution levels. Narwhals, which are less numerous, have a significantly more restricted distribution, are less flexible in their choice of habitats and food types, and are ranked among the three most sensitive species to climate change among Arctic endemics. For dolphins, porpoises and migrating whales, a range of potential effects are cited, among them range expansions and mis-matched migrations; *i.e.*, timing of arrival will not match prey peaks. Finally, all of these changes could substantially alter predator-prey dynamics throughout the region.

(SOURCE: Kovacs, K.M. and Lydersen, C. 2009. Climate change impacts on seals and whales in the North Atlantic Arctic and adjacent shelf seas. *Sci. Progr.* 91: 117-150)

Changing Arctic Ocean conditions causing a shift in phytoplankton composition

Warming temperatures, increasing freshwater inputs from melting ice, increased direct sunlight, increasing precipitation, and less ice coverage are changing the nature of the Arctic Ocean. An analysis of the effects of these changes on phytoplankton concluded that, although total plankton biomass stayed roughly the same, "*the smallest phytoplankton cells thrive but larger cells languish*", with a net shift to smaller phytoplankton size, and a change in species composition. The authors state that "*[p]icoplankton-based systems tend not to support large exports of biogenic carbon…for extraction (e.g., harvest)*". This

means that the carrying capacity of this changing system for marine mammal populations, and also human fisheries, would likely be diminished.

(SOURCE: Li, W.K.W., McLaughlin, F.A., Lovejoy, C. and Carmack, E.C. 2009. Smallest algae thrive as the Arctic Ocean freshens. *Science* 326: 539)

Increased catches of narwhals in Greenland attributed to climate change

Catch statistics show a significant increase in narwhal catches by hunters in Siorapaluk, the northernmost community in Greenland, after 2002. Hunters attribute this to changes in sea-ice conditions providing boat access to the hunting area earlier in the season. This calls for collaborative management schemes and sustainable quotas for this stock. The goals are local acceptance of regulations and the ability to respond rapidly to climate change. The developments here could serve as a template for climate-change-induced effects on other hunted Arctic whale species.

(SOURCE: Nielson, M.R. 2009. Is climate change causing the increasing narwhal (*Monodon monoceros*) catches in Smith Sound, Greenland? *Polar Res.* 28: 238-245)

Abrupt climatic change could occur in the Arctic within a couple of years

Ice core data from Greenland suggest that the warming periods succeeding the previous two glacial periods may have been even more dramatic than previously thought, with changes in the ice cores indicating dramatic shifts in atmospheric circulation patterns within just a 1- to 3-year period. This ultimately led to warming of air temperatures over a 50-year period. The study "*confirms the potential for extremely abrupt reorganizations of the Arctic atmospheric circulation, whether going from cold to warm or vice versa*" and that major and abrupt changes in Arctic climate have occurred before, leading to air temperature increases of as much as 10°C.

(SOURCE: Steffensen, J.P., Andersen, K.K., Bigler, M., Clausen,H.B., Dahl-Jensen, D., Fischer, H., Goto-Azuma, K., Hansson,M., Johnsen, S.J., Jouzel, J., Masson-Delmotte, V., Popp, T., Rasmussen,S.O., Röthlisberger, R., Ruth, U., Stauffer, B., Siggaard-Andersen, M.-L., Sveinbjörnsdóttir, Á.E., Svensson, A. and White, J.W.C. 2008. High-resolution Greenland ice core data show abrupt climate change happens in few years. *Science* 321: 680-684)

Ocean acidification and ice meltwater reduces Arctic calcium carbonate, affecting phytoplankton

The decreasing pH due to increased carbon dioxide dissolved in seawater, and an increased input of freshwater from melting ice sheets, have decreased levels of a soluble form of calcium carbonate (aragonite). Because this calcium carbonate is essential for marine phytoplankton in the Arctic (especially diatoms), this reduction "*will affect both planktonic and benthic calcifying biota and therefore the composition of the Arctic ecosystem*". As a result, the authors warn that "*the Arctic ecosystem may be at risk and requires observation in order to predict future possible impacts on marine organisms, fisheries*".

(SOURCE: Yamamoto-Kawai, M., McLaughlin, F.A., Carmack, E.C., Nishino, S. and Shimada, K. 2009. Aragonite undersaturation in the Arctic Ocean: Effects of ocean acidification and sea ice melt. *Science* 326: 1098-1100)

Noise impacts

General

Underwater noise from artificial island for oil and gas development travels 7 km underwater

Northstar Island is a man-made island for oil and gas development in the Beaufort Sea, 5 km offshore in 12 m of water. Sounds were recorded during ice-auguring, pumping, backhoe trenching the seafloor, and pile driving at substantial distances from the site, with pile driving producing the loudest sounds. Sound levels were above ambient for a distance of up to 7.5 km from the site. Levels of sound transmitted by ice were also measured and these were above ambient for a distance of up to 10 km from the site (and levels were above ambient in air up to 3 km from the island).

(SOURCE: Greene, C.R., Blackwell, S.B. and McLennan, M.W. 2008. Sounds and vibrations in the frozen Beaufort Sea during gravel island construction. *J. Acoust. Soc. Am.* 123: 687-695)

GLOBAL

General

Conservation papers take three times longer to be published than papers in other biology fields

A review of time taken to publish papers found that conservation scientists can take more than three times longer to submit manuscripts and have papers published than other biology specialists. The delay between last data collection and submission for conservation papers was 696 days (*i.e.*, nearly two years), compared to just 189 days for evolution papers. Rejection rates were also much higher for conservation papers. The longer time did not reflect editorial processes, the number of authors on a paper or the time spent being rejected from other journals. The delay is probably because of (a) lack of competition among conservation biologists, making publication less urgent; (b) lack of funding and conservation biologists being involved in other (income-generating) activities, with publishing taking a lower priority; or (c) conservation research being conducted by a different demographic compared to other biological fields, for example, by government scientists, who may require papers to be vetted by their agencies before publication. The researchers conclude that "*[t]he cause for the excess submission delay in conservation papers must be determined and addressed; research that is critical for conservation of our planet's biodiversity is being delayed before it even reaches the desks of journal editors*". This has implications for reviews such as the State of the Cetacean Environment Report, which review publications on a cyclical basis.

(SOURCE: O'Donnell, R.P., Supp, S.R. and Cobbold, S.M. 2010. Hindrance of conservation biology by delays in the submission of manuscripts. *Conservation Biology* 24: 615-620)

Habitat protection/degradation

General

Absence of reaction is not absence of impact

It is sometimes claimed that cetaceans will eventually habituate to a disturbance (such as underwater noise), or if animals appear to have habituated to a disturbance, then it is not having an adverse impact. True habituation is defined as a learning process that occurs over time. What many refer to as habituation is in fact 'tolerance'. Sensitive animals may be the first to be displaced from a population as the result of disturbance, leaving 'tolerant' animals. This could lead to the mistaken conclusion that no adverse impact has occurred if a study is conducted after the disturbance is in place. Moreover, many factors could potentially cause animals to tolerate disturbance: the importance of a disturbed area for feeding or breeding, the investment an animal has made in a site (*e.g.*, establishing a territory, learning information about local resources), lack of appropriate habitat to move to, or increased competition or predation outside of the current habitat. Therefore, lack of displacement does not indicate lack of disturbance. Moreover, physiological factors (*e.g.*, increased 'stress' responses) can affect the fitness of animals even when no behavioural response is observed. In summary, with respect to disturbance, absence of evidence (such as displacement or behavioural changes) is not evidence of absence (of a negative effect on cetaceans). Managers should therefore be precautionary in their decisions.

(SOURCE: Bejder, L., Samuels, A., Whitehead, H., Finn, H. and Allen, S. 2009. Impact assessment research: use and misuse of habituation, sensitization and tolerance in describing wildlife responses to anthropogenic stimuli. *Mar. Ecol. Prog. Ser.* 395:177-185)

Offshore wind farms a potential threat to cetaceans

Offshore wind farms are a highly propagated form of renewable energy production. They can potentially affect cetaceans in two ways: by noise from construction, operation, and decommissioning and by creating physical structures in the animals' habitat. The authors begin by pointing out the difficulty in determining potential impacts due to uncertainties about cetacean distribution. They then demonstrate that a protected population of bottlenose dolphins would have been injured by the noise of pile-driving within 100 m of this activity (wind turbine installation) and that behavioural disturbance (modified behaviour) could have occurred up to 50 km away.

(SOURCES: Thompson, P.M., Lusseau, D., Barton, T., Simmons, D. Rusin, J. and Bailey, H. 2010. Assessing the responses of coastal cetaceans to the construction of offshore wind turbines. *Mar. Pollut. Bull.*, in press, doi:10.1016/j.marpolbul.2010.03.030; 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.*, in press, doi:10.1016/j.marpolbul.2010.01.003)

Water quality standards for cetaceans

Cetaceans are potentially vulnerable to a wide range of human and livestock disease agents, and sewage effluents are a key route by which such pathogens can be transferred. The EU Habitats Directive requires Member States to consider the potential impact of sewage discharges on protected wildlife populations. There is ongoing discussion whether water quality standards for human bathers can be applied to develop standards for coastal dolphins. Considering that the standards for human bathers are based on extremely limited scientific data, and that the relevant data collection from wild populations of dolphins would be nearly impossible, the author argues that more precautionary measures should be introduced to reduce disease risks to cetaceans.

(SOURCE: Thompson, P.M. 2007. Developing water quality standards for coastal dolphins. *Mar. Pollut. Bull.* 54: 123-127)

Fisheries Interactions

Bubble lesions found in other marine mammal species – linked to effects of bycatch

Gas bubble lesions were discovered in short-beaked common and Atlantic white-sided dolphins and harbour porpoises, as well as harbour, gray and harp seals, that had been bycaught in fishing gear. In total, 15 out of 25 bycaught animals exhibited bubble lesions. This pertained especially to those animals that had a longer time from collection to necropsy, were brought to the surface faster or from greater depths, and which had higher body core temperatures. Forty-one stranded animals of various species were also examined and only one animal, a Cuvier's beaked whale, possessed bubble lesions. Bubbles were found in brain, heart, liver, lung, spleen, pancreas, gonad, intestinal and lymph node tissues, as well as skeletal tissues, blood and even in the eye. It was suggested that normal diving behaviour allows animals to offload gases through anatomical and physiological adaptations, while entanglement in fishing gear prevents this natural behaviour and leads to bubble lesions. The authors stress "*when gas bubbles are encountered in beached animals, serious consideration should be given to these findings and any resultant pathology, because it seems that animals that have been able to surface normally blow off supersaturated gases, and for bubbles to persist, this may represent a pathologic condition perhaps reflecting stressors that have precluded behaviours that normally manage gas tensions to keep bubble growth to a minimum*". One relevant aspect of this information is that bubble lesions in bycaught animals may affect the survivorship of such animals that are released.

(SOURCE: Moore, M.J., Bogomolni, A.L., Dennison, S.E., Early, G., Garner, M.M., Hayward, B.A., Lentell, B.J. and Rotstein, D.S. 2009. Gas Bubbles in seals, dolphins, and porpoises entangled and drowned at depth in gillnets. *Vet. Pathol.* 46: 536-547)

Marine Debris

Floating net debris fatal to sperm whales

The cause of death of two stranded male sperm whales off the northern California coast was determined to be plastic fishing net pieces and rope. The stomachs of the two animals contained 134 different types of nets ranging in size from 10 cm² to 16 m². The size and age of the pieces suggested that the material was ingested from the surface as debris and not bitten off from active gear. In addition to well-documented entanglements, ingestion of marine debris can be fatal to large whales.

(SOURCE: Jacobsen, J.K., Massey, L. and Gulland, F. 2010. Fatal ingestion of floating net debris by two sperm whales (*Physeter macrocephalus*). *Mar. Pollut. Bull.*, in press, doi:10.1016/j.marpolbul.2010.03.008)

Plastic marine debris collects and distributes persistent organic pollutants

Beyond the negative impacts of plastic debris with regard to ingestion and entanglement of marine organisms, such plastic has now been shown to accumulate a wide range of persistent organic pollutants (POPs). Preproduction thermoplastic resin pellets (which are melted and formed into inexpensive consumer goods) and post-consumer plastic fragments collected at the North Pacific Gyre, California, Hawaii and Guadelupe Island, Mexico, contained PCBs, DDT, and PAHs. Plastic can therefore adsorb, accumulate and transport POPs over great distances, and these pollutants enter the food web when marine organisms consume such debris.

(SOURCE: Rios, L.M., Moore, C and Jones, P.R. 2007. Persistent organic pollutants carried by synthetic polymers in the ocean environment. *Mar. Pollut. Bull.* 54(8): 1230-1237)

Marine Protected Areas

Voluntary shipping avoidance area shows high compliance and reduces ship strike risk

The International Maritime Organization adopted the Roseway Basin Area on the Scotian Shelf in the Northwest Atlantic as a voluntary avoidance area to reduce the risk of vessel strikes to North Atlantic right whales. Vessel positions were monitored 12 months before and 6 months after the area's designation; vessel-operator compliance stabilized at 71% within the first 5 months of implementation. It was estimated that the risk of vessel strikes in the area was reduced by 82% overall. It was concluded that such shipping avoidance areas, even if voluntary, could play a role in decreasing risk to cetaceans from ship strikes. Such areas provide yet another useful strategy, beyond conservation areas, traffic separation schemes, and mandatory vessel speed reductions, to protect endangered whales.

(SOURCE: Vanderlaan, A.S.M. and Taggart, C.T. 2009. Efficacy of a voluntary area to be avoided to reduce risk of lethal vessel strikes to endangered whales. *Conserv. Biol.* 23: 1467-1474)

Whale management may require larger protected areas

Human disturbances can have significant impacts on cetaceans. One mechanism is the repeated activation of stress responses, *e.g.*, by noise, leading to chronic stress. Deep-diving and coastal species, as well as those targeted by whalewatching, may be particularly vulnerable. This calls for management attention, with one strategy being the establishment of protected areas. The authors argue that the lack of recovery of some species may be because such protected areas are too small. They call for larger exclusion zones, including acoustic buffer zones around Marine Protected Areas (MPAs), and for excluding sonar exercises from known or likely beaked whale habitats and their surroundings.

(SOURCE: Wright, A.J., Deak, T. and Parsons, E.C.M. 2009. Size matters: Management of stress responses and chronic stress in beaked whales and other marine mammals may require larger exclusion zones. *Mar. Pollut. Bull.*, in press, doi:10.1016/j.marpolbul.2009.11.024)

Chemical pollution

Contaminants decrease first-year survivorship rates in marine mammals

Although not specifically directed at cetaceans, this study tracing survivorship patterns in grey seals produced information that demonstrates impacts of contaminants on marine mammal recruitment. Capture-recapture methods were used in conjunction with tags to estimate first-year survivorship. Higher levels of contaminants decreased likelihood of survival, with PBDE levels, followed by DDT and then PCB levels, being the classes of contaminants with the greatest impact. Although the mechanisms by which these contaminants cause mortality are unknown, their influence on recruitment rates demonstrates that they should be considered in cetacean population modelling.

(SOURCE: Hall, A.J., Thomas, G.O. and McConnell, B.J. 2009. Exposure to persistent organic pollutants and first-year survival probability in gray seal pups. *Environ. Sci. Tech.* 43: 6364-6369)

Disease and mortality events

Disease

Dolphins' health sheds light on human and ocean health

Diseases in dolphins are similar to human diseases, and bottlenose dolphins may be the first natural animal model for type II diabetes. At least 50 new viruses have been discovered in dolphins, including the human papillomavirus. Coastal dolphin populations and human communities share the same seafood resources. Such a similar exposure with regard to diet, coupled with their much stronger exposure to ocean health threats (*e.g.*, toxic algae, poor water quality) could make dolphins an important 'sentinel' species to provide information about the state of ocean health and warning of how human health may be affected by exposure to contaminated coastal water or seafood.

(SOURCE: News. 2010. *Mar. Pollut. Bull.* 60: 491)

Significant population-level impacts predicted of emerging diseases

A review on diseases in cetaceans included potential impacts on populations, the impact of environmental stressors and possible zoonotic effects. Some pathogens can reduce reproductive rates, cause mortality directly, or cause mortality indirectly by synergistically increasing the severity of other infections. Such pathogens include morbilliviruses, papillomaviruses, and the pathogens *Brucella* spp. and *Toxoplasma gondii*. Fungal infection, such as lobomycosis and lobomycosis-like disease (LLD),

might also contribute to cetacean mortality. Contamination by environmental pollutants or other anthropogenic stressors probably increases the severity and hence mortality or morbidity resulting from these pathogens. The risks to human health resulting from zoonotic transfer of *Brucella* and *Toxoplasma* from cetacean carcasses and products may be much higher than assumed, because of the low likelihood of diagnosis of infection by these pathogens, particularly in developing countries.

(SOURCE: Van Bressem, M.F., Raga, J.A., Di Guardo, G., Jepson, P.D., Duignan, P.J., Siebert, U., Barrett, T., Santos, M.C.d.O., Moreno, I.B., Siciliano, S., Aguilar, A. and Van Waerebeek, K. 2009. Emerging infectious diseases in cetaceans worldwide and the possible role of environmental stressors. *Diseases Aquat. Org.* 86: 143-157)

Stress

Whistle rate an indicator of stress in common bottlenose dolphins

The rate of whistle production in common bottlenose dolphins was significantly higher during a capture-release operation on wild dolphins in Florida. Females with dependent calves produced higher whistle frequencies than females without calves. Whistling rate also decreased with repeated captures. The conclusion is that these whistles are indicators of stress and as such, "*acoustic monitoring holds promise as a non-invasive means of assessing the impact of potentially stressful situations on bottlenose dolphins*".

(SOURCE: Esch, H.C., Sayigh, L.S., Blum, J.E. and Wells, R.S. 2009. Whistles as potential indicators of stress in bottlenose dolphin (*Tursiops truncatus*). *J. Mammal.* 90: 638-650)

Climate change

Historical sea level reconstruction suggests West Antarctic ice shelf collapse and 7 m+ sea level rise

To predict the potential effects of increasing global temperature, many researchers have looked to the last interglacial period (125,000 years ago), a period with comparable temperatures to those envisaged for the near future (+ 3-5°C). A recent study re-examined sea level estimates for this period, taking into account various geological and planetary processes, and estimated an interglacial sea level of at least 6.6 m above present, relatively speaking, and perhaps as much as 9.4 m above. Melting ice sheets in Greenland and Antarctica would have effectively contributed at least 2.5 m of this rise apiece. It was postulated that, because of the volume of increase contributed by Antarctica, the West Antarctic ice sheet collapsed in its entirety. In summary, the imminent predicted increase in global temperatures (1.5-2°C) could lead to a higher sea level rise than previously thought.

(SOURCES; Kopp, R.E., Simons, F.J., Mitrovica, J.X., Maloof, A.C. and Oppenheimer, M. 2009. Probabilistic assessment of sea level during the last interglacial stage. *Nature* 462: 863-867; Clark, P.U. and Huybers, H. 2009. Interglacial and future sea level. *Nature* 462: 856-857)

The impact of ocean acidification on iron and marine productivity

There has been concern over the impacts of ocean acidification, resulting from increased levels of carbon dioxide dissolved in seawater, on corals and the tests of calcareous plankton (such as diatoms). A new study highlights the potential impact of acidification on levels of iron in the ocean. Iron is a major limiting nutrient for marine productivity. The study experimentally examined the effect that decreased pH, as predicted by projected CO_2 levels for 2100, would have on iron uptake by diatoms. The study suggested "*a lowering of the ocean water pH from increasing CO_2 may decrease iron availability to phytoplankton*" (Sunda). This could affect the ocean's ability to absorb more carbon dioxide and thus cause a positive feedback loop that may effectively increase carbon dioxide levels in the atmosphere. Marine productivity in general may also be impacted, which would have wide ecological effects.

(SOURCE: Shi, D., Xu, Y., Hopkinson, B.M. and Morel, F.M.M. 2010. Effect of ocean acidification on iron availability to marine phytoplankton. *Science* 327: 676-679; Sunda, W.G. 2010. Iron and the carbon pump. *Science* 327: 654-655)

Impacts of climate change on cetaceans from changes in human behaviour

The increasing focus on the effects of climate change on cetaceans reveals consequences not only for polar species, but also potentially for tropical coastal and riverine species. Beyond the expected physical habitat and prey changes, climate change will also alter human behaviour in some regions to the detriment of cetaceans. This contribution presents a comprehensive table identifying the specific aspects of climate change that are relevant for 82 cetacean species. The authors note that addressing direct and

human-mediated threats from climate change will require: (1) integrating knowledge about cetacean populations into climate adaptation decisions and (2) including projections about how climate change may influence human behaviours into cetacean-specific management plans.

(SOURCE: Alter, S.E, Simmonds, M.P, and Brandon, J.R. 2010. Forecasting the consequences of climate-driven shifts in human behavior on cetaceans. *Mar. Pol.* doi:10.1016/j.marpol.2010.01.026)

New type of El Niño event may increase with global warming

The El Niño event causes periodic shifts in climate every 3-8 years in the Pacific, resulting in warmer surface waters off the western coast of South America and the 'capping' of a cool water upwelling that normally brings nutrients to the surface. This has major effects on marine productivity here. Since the 1970s, events with high sea surface temperatures have occurred in the central Pacific, with cooler temperatures being reported in the east and west Pacific. This warming event is unlike the east Pacific warming apparent during an El Niño event, and has been called many names, including 'pseudo' or 'central' El Niño. A new climate modelling exercise concluded that this central El Niño is the result of anthropogenic warming and, as temperatures increase, will become more marked and prevalent, at the expense of the eastern, or typical, El Niño event. If this is correct, it could lead to major changes in weather patterns along with oceanographic processes and marine ecosystems in the Pacific.

(SOURCES: Yeh, S.W., Kug, J.S., Dewitte, B., Kwon, M.H., Kirtman, B.P. and Jin, F.F. 2009. El Niño in a changing climate. *Nature* 461, 511–514; Ashok, K. and Toshio Yamagata, T. 2009. The El Niño with a difference. *Nature* 461:481-484)

Noise impacts

General

New way of measuring noise impact – communication space

'Communication space' was posited as a new way of measuring the potential biological impacts of underwater noise on cetaceans. Cetacean calls can only be heard when they rise above ambient levels of sound in the environment; underwater noise can mask these calls. The area over which calls can be heard therefore decreases with increasing noise levels, reducing the ability of cetaceans to communicate with each other. Communication space was modelled for fin whales, right whales and humpback whales when commercial shipping vessels passed a specific location. The researchers determined that "*acoustic communication space for at least one species of baleen whale, the highly endangered North Atlantic right whale, is seriously compromised by noise from commercial shipping traffic*".

(SOURCE: Clark, C.W., Ellison, W.T., Southall, B.L., Hatch, L., Van Parijs, S.M., Frankel, A. and Ponirakis, D. 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implication. *Mar. Ecol. Prog. Ser.* 395: 201-222)

Marine protected areas and possibilities for underwater noise management

This review on the management of underwater noise identified several costs to marine mammals with consequences for fitness: "*compromised physiological function, diversion of time and energy, failure to detect important cues, impaired acoustical advertisement and communication, and reduced utilization of important habitats or resources*". The authors criticized the attention focused on "*acute and immediate effects of intense noise exposures: hearing loss, injury, and death*", which examine individuals rather than populations, and they emphasise the need to consider the impacts of chronic noise even though sources are more diffuse and less easy to identify. The review concludes that MPAs could help to manage underwater noise and, due to the wide-ranging effects of anthropogenic sound, this may require establishing buffer zones around these areas. A case study of particular significance with respect to cetaceans is the Stellwagen Bank Marine Sanctuary, where anthropogenic noise levels from shipping "*were >82 dB 50% of the day and as high as 110 dB 5% of the day*". To help remedy the problem, the authors called for: increased acoustic monitoring; incorporation of noise into environmental impact assessments via new tools (such as software showing visual representations of noise levels); new noise metrics and modelling techniques; better coordination between government agencies; and increased public education and outreach. They conclude that "*[t]he quietest marine and terrestrial environments must be vigorously protected, as they are the most vulnerable to noise intrusions. Exceptional environments for hearing natural sounds are also exceptional for detecting noise. Very little noise energy is required to substantially degrade listening conditions when the natural sound levels are very low. Like other crucial and endangered resources, quiet merits the highest standards for preservation and restoration*".

(SOURCE: Hatch, L.T. and Fristrup, K.M. 2009. No barrier at the boundaries: implementing regional frameworks for noise management in protected areas. *Mar. Ecol. Prog. Ser.* 395: 223-244)

Review of anthropogenic sound in the oceans

A review of multiple anthropogenic noise sources in the oceans concludes that, for low frequencies, shipping is the dominant source, although seismic surveys, especially in deep water exploration, are also a major contributor. Airgun sounds could be heard in the North Atlantic almost continuously during summer months, at distances greater than 3000 km. For mid-frequency sound, sonar systems from about 300 vessels were a major contributor. Sonar is used by these vessels "*about 10% of the time these vessels are at sea*". Acoustic harassment devices (seal scrammers) and multi-beam echosounders also contribute noise at mid-frequencies. Recreational and small boat traffic can also contribute substantial mid-frequency noise: "*[o]ver 17 million small boats are owned in the United States alone. Many of these boats use mid-frequency and high-frequency sonar for echolocation, also contributing to local ambient noise*". At higher frequencies, depth sounders from ships are a major contributor. The potential reach of these sounds ranges from tens of metres (for high frequencies) to entire ocean basins (for low frequencies). The review calls for increased research into noise generation, in particular the characteristics of shipping noise affected by vessel size, speed, density and other factors.

(SOURCE: Hildebrand, J.A. 2009. Anthropogenic and natural sources of ambient noise in the ocean. *Mar. Ecol. Prog. Ser.* 395: 5-20)

Sound exposure levels not an optimal measure to predict noise impacts

One way to measure sound level, in particular with respect to its impacts on cetaceans, is sound exposure level (SEL). This metric combines both the sound intensity and the exposure duration, to derive the total amount of energy; *i.e.*, two sounds can have the same total energy when one has a higher intensity but a proportionately shorter duration. Such a metric would theoretically make regulating sound impacts easier because there are many different types of sound (continuous such as shipping, single impulses such as explosions, or multiple pulses such as seismic survey airguns or sonar pings). In practise, however, SEL has drawbacks. When common bottlenose dolphins were exposed to sounds with identical SELs, but varying duration and intensity, temporary threshold shifts (TTS) were more likely to occur in animals exposed for longer periods. This study emphasizes the importance of knowing the properties of the sound to which animals are exposed, as sounds of different types may not be easily and directly comparable when predicting possible impacts on cetaceans. The researchers also note that "*longer duration exposures will often induce greater amounts of TTS, which concurrently requires a greater amount of time for recovery*".

(SOURCE: Mooney, T.A., Nachtigall, P.E., Breese, M., Vlachos, S. and Au, W.W.L. 2009. Predicting temporary threshold shifts in a bottlenose dolphin (*Tursiops truncatus*): The effects of noise level and duration. *J. Acoust. Soc. Am.* 125: 1816–1826)

Military funding appears to result in reporting bias in underwater sound reviews

Concerns have been raised that the US Navy provides 50% of the global research funds for marine mammal research (and 70% of underwater noise impact research), potentially influencing scientific reporting of impacts of underwater noise. An analysis of six reviews documenting effects of anthropogenic noise on marine mammals found that **"***these reviews cite references showing noise has no effect on marine mammals at an increasing frequency as their funding moves from a conservation organization to independent to partial U.S. military sources*". The likelihood of a paper concluding that there is no effect of noise on cetaceans more than doubles if the researchers obtained funds from the US Navy. The researchers conclude that "*conflicts of interest may have led to a misrepresentation of the effects of noise on marine mammals in both the primary and secondary literature, and thus misinform public policy decisions*".

(SOURCE: Wade, L., Whitehead, H. and Weilgart, L. 2010. Conflict of interest in research on anthropogenic noise and marine mammals: Does funding bias conclusions? *Mar. Pol.* 34: 320-327)

Cetacean Hearing

Beaked whale hearing sensitivity curve appears to be similar to delphinids

One hypothesis why beaked whales appear to be more sensitive to underwater noise than other cetacean taxa has been that they are generally more sensitive to sound. However, when the hearing sensitivity of a stranded Gervais' beaked whale was opportunistically tested via auditory evoked potentials, its hearing

sensitivity curve was similar to that of studied delphinids. The animal could detect sounds to a frequency of at least 80 kHz (with greatest sensitivity at 40 kHz).

(SOURCE; Finneran, J.J., Houser, D.S., Base-Guthrie, B., Ewing, R.Y. and Lingenfelser, R.G. 2009. Auditory evoked potentials in a stranded Gervais' beaked whale (*Mesoplodon europaeus*). *J. Acoust. Soc. Am.* 126: 484-490)

Seismic Surveys

Harbour porpoise TTS measured in response to single airgun pulses

A captive male harbour porpoise held in a sea pen was exposed to sound from a seismic survey airgun (20 cubic inches) placed at decreasing distance to the porpoise (150-14 m). The airgun's sound predominated in lower frequencies (below 1 kHz), but the porpoise was also exposed to higher frequencies (*i.e.*, 2-5 kHz; up to 150 dB SPL). Auditory evoked potentials were measured in response to single pulses of the airgun, and the sound level at which TTS occurred was recorded. Aversive behaviour at 4 kHz was observed at a SEL of approximately 20 dB lower than that at which TTS occurred and the animal avoided the testing location for the rest of the 4 ½ month testing period. Recovery from TTS was slow for the porpoise, taking up to 55 hours. The levels of exposure at which TTS occurred were substantially lower than levels considered to have no effect under, for example, current US regulations. Moreover, this study measured the effects of single pulses: bearing in mind the long recovery period of the porpoise, the effect of normal airgun operation (repeated pulses) would probably be greater. Although it examined only one captive animal, the study illustrates the higher than expected sensitivity of porpoises to seismic survey noise.

(SOURCE: Lucke, K., Seibert, U., Lepper, P.A. and Blanchet, M.A. 2009.Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. *J. Acoust. Soc. Am.* 125: 4060–4070)

Tagged sperm whales reduce foraging behaviour in response to seismic surveys

Eight sperm whales (7 foraging and 1 resting) in the Gulf of Mexico were exposed to seismic surveys and their behaviour recorded via tags. There was no significant change in behaviour state in the whales as the result of exposure, although the one resting animal began to forage immediately after the cessation of the seismic surveys, "*possibly indicating a delay in foraging during exposure*". There was no apparent horizontal avoidance of the airguns; this raises doubt as to whether the current practice of 'ramping-up' (increasing sound levels gradually to allow animals to leave an area) is effective. Swimming behaviour did change, and acoustic behaviour associated with foraging decreased 19% during seismic exposure. This substantive change in underwater behaviour would not have been detected without the use of tags, and surface observations alone would not have recorded any noticeable change. The researchers state that "*our tag data indicate that exposure to airgun sounds may affect the foraging behavior of sperm whales at exposure levels well below the current 160 dB re1 µPa (rms) threshold used by [the US Government] to predict disruption of behaviour*".

(SOURCE: Miller, P.J.O., Johnson, M.P., Madsen, P.T., Biassoni N., Quero, M. and Tyack, P.L. 2009. Using at-sea experiments to study the effects of airguns on the foraging behavior of sperm whales in the Gulf of Mexico. *Deep Sea Research I* 56: 1168-1181)

Shipping

Masking effects of small outboard boats and implications for whale-watching guidelines

Digital acoustic tags were first used to demonstrate that free-ranging delphinids in a coastal deepwater habitat are subjected to varying and occasionally intense levels of vessel noise. Vessel noise and sound propagation measurements from a shallow-water habitat were then used to model the potential impact of high sound levels from small vessels (2-stroke and 4-stroke outboard motor boats) on delphinid communication in both shallow and deep habitats, with bottlenose dolphins and short-finned pilot whales as model organisms. At 50 m (a standard maximum approach distance for many whale-watching guidelines) and a boat speed of 5 knots, communication ranges for pilot whales were reduced by 58% and for bottlenose dolphins by 26%. At 2.5 knots, however, there was little masking noise. At 10 knots there was approximately a 70% decrease in communication distance for both species at 200 m from the boats. At 50 m, communication reduction was over 90% for pilot whales and over 80% for bottlenose dolphins. The boats emitted a loud broadband sound when they changed gears, which could occur several times a minute when manoeuvring around the cetacean groups (up to 200 dB re 1 µPa pk-pk).

Minimizing gear changes would help reduce this boat disturbance. Multiple vessels near cetaceans could have additional impacts, as could following groups for long periods of time. This also has implications for researchers – following focal groups, at a close distance in a small boat, is a common method to study small cetacean behaviour. The authors warn that "*the behaviour and noise profiles of research vessels may be a source of potential bias in studies of free-ranging delphinids and should be considered when designing field experiments*".

(SOURCE: Jensen, F.H., Bejder, L., Wahlberg, M., Aguilar Soto, N., Johnson, M. and Madsen, P.T. 2009. Vessel noise effects on delphinid communication. *Mar. Ecol. Prog. Ser.* 395: 161-175)

Sonar

US Government pledges to increase cetacean surveys and further investigate underwater noise mitigation measures

The US National Oceanic and Atmospheric Administration (NOAA), in response to a request from the US Council for Environmental Quality, has reviewed and revised its policy on underwater noise and will require more fine-scale boat-based and aerial surveys for cetaceans to gain a better understanding of the number of cetaceans that might be impacted by noise-producing activities (in particular military exercises). Moreover, NOAA will host two workshops. One will discuss the concept of an ocean noise budget, which will include discussion of areas where marine noise from human activities is elevated. A second workshop will work towards identifying marine mammal 'hotspots' and thus recognize important habitats. NOAA will also participate in discussing and negotiating mitigation measures during naval activities.

(SOURCE: Letter from Jane Lubchenco, NOAA Administrator to the US Council for Environmental Quality, 19 January 2010. http://www.nmfs.noaa.gov/pr/pdfs/permits/lubchenco_letter.pdf)

Beaked whale mass strandings linked with naval activities

Several papers in the journal *Aquatic Mammals* addressed beaked whale mass strandings coincident with naval exercises. One study found significant correlations between mass strandings and military exercises both in the Mediterranean and Caribbean. No such relationship was found for mass strandings in Japan or California. A second study, however, noted that 10 mass stranding events in Japan occurred close to a naval facility, even if they did not coincide with a specific exercise. An 11th Japanese stranding was also noted adjacent to a different military facility. The paper listed two stranding events that were definitively linked to sonar use during military exercises (Greece in 1996 and Bahamas in 2000) and 10 mass strandings with coincident naval exercises, although more exact details were not available (Greece in 1997, Italy in 1963, Spain in 1996, Madeira in 2000, and the Canary Islands in 1988, 1989, 1991, 2000, 2002, 2004). Twenty-seven mass stranding events occurred either at the same time naval vessels that could have been using sonar were sighted (Italy in 1963 and 1967, Canary Islands in 1985) or adjacent to naval facilities (the 11 Japanese strandings noted above, six mass strandings in Alaska, four in Puerto Rico, and one each in Hawaii, southern California, and Key West, Florida). Eighty-one beaked whale mass strandings could not be associated with US naval bases or military exercises, although other military sonar sources could not be ruled out. Most (126 out of 136) beaked whale mass stranding events recorded since 1874 have occurred since the development of mid-frequency sonar. A third paper investigated gray whale stranding in relation to naval exercises off the Californian coast. Of a total of 180 stranding events identified between 1982 and 2007, approximately 40 coincided with naval exercises (c. 22%), but statistical analysis showed that stranding rates during naval exercises involving anti-submarine warfare were not significantly different from those during non-exercise periods.

(SOURCES: D'Amico, A.D., Gisiner, R.C., Ketten, D.R., Hammock, J.A., Johnson, C., Tyack, P.L. and Mead, J. 2009. Beaked whale strandings and naval exercises. *Aquat. Mamm.* 35: 452-472; Filadelfo, R., Mintz, J., Michlovich, E., D'Amico, A.D., Tyack, P.L. and Ketten, D.R. 2009. Correlating military sonar use with beaked whale strandings: what do the historical data show? *Aquat. Mamm.* 35: 435-444; Filadelfo, R., Pinelis, Y.K., Davis, S., Chase, R., Mintz, J., Wolfganger, J., Tyack, P.L., Ketten, D.R. and D'Amico, A.D. 2009. Correlating whale strandings with navy exercises off Southern California. *Aquat. Mamm.* 35: 445-451)

Beaked whales more likely vulnerable to nitrogen-related pathologies than other species

A model based on known physiological data was used to predict nitrogen levels in blood and tissues in three beaked whale species (Blainville's and Cuvier's beaked whales, and northern bottlenose whales). Dive length and diving lung volume had a large effect on nitrogen levels at the end of a dive; these

species may generally have high levels of dissolved nitrogen in their tissues, making them vulnerable to decompression sickness, or the bends. Thus, nitrogen levels in tissues may end beaked whale dives before a lack of oxygen does. Moreover, the diving behaviour of Cuvier's beaked whales resulted in higher nitrogen levels, potentially explaining why this species in particular has been associated with strandings coincident with military exercises. Another paper examined the hypothesis that high levels of dissolved nitrogen (*i.e.*, supersaturation) in cetacean blood leads to gas emboli or 'bubble lesion' formation when ascending into shallow waters. A trained common bottlenose dolphin performed 10-12 serial dives in a row with one minute gaps between dives, to depths of 30, 50, 70 and 100 m, with the dolphin staying at each depth for 90 seconds. Blood samples and ultrasounds of blood vessels revealed no significant change. The results "*do not support the hypothesis that [nitrogen] supersaturation during repetitive dives contributes to [gas emboli] formation in the dolphin*", at least for bottlenose dolphins during normal diving behaviour. In the case of beaked whale strandings and cetaceans caught in nets, however, a rapid ascent may be one cause of bubble lesions.

(SOURCES: Hooker, S.K., Baird, R.W. and Fahlman, A. 2009. Could beaked whales get the bends? Effect of diving behaviour and physiology on modelled gas exchange for three species: *Ziphius cavirostris*, *Mesoplodon densirostris* and *Hyperoodon ampullatus. Respir. Phys. Neurobiol*. 167: 235-246; Houser, D.S., Dankiewicz-Talmadge, L.A., Stockard, T.K. and Ponganis, P.J. 2010. Investigation of the potential for vascular bubble formation in a repetitively diving dolphin. *J. Exp. Biol.* 213: 52-62)

Temporary threshold shifts from sonar exposure in a captive common bottlenose dolphin

A study using actual recordings of mid-frequency sonar sound resulted in TTS lasting 20-40 minutes in a trained, captive common bottlenose dolphin at a SPL of 203 dB (rms) or a SEL of 214 dB re: 1 μPa^2 s. Considering the source level of standard mid-frequency sonar systems, this animal would had to have been 40 m from the sound source for approximately 2 minutes for TTS to be induced. If the animal was closer, then TTS would have been induced within a shorter period, and conversely if further away a proportionately longer sound exposure would have been required. It was concluded that "*mid-frequency sonar can induce at least temporary physiological hearing loss in odontocete cetaceans, although repeated exposures are necessary to generate effects*". However, the authors note "[*t*]*he results do not preclude other noise or sonar-induced effects on marine mammals, which may occur at lower sound levels*".

(SOURCE: Mooney, T.A., Nachtigall, P.E. and Vlachos, S. 2009. Sonar-induced temporary hearing loss in dolphins. *Biol. Lett.* 5: 565–567)

Offshore wind farms

Harbour porpoises likely displaced beyond 20 km from wind farm construction site

The possible acoustic impacts of wind farms were assessed with regard to pile-driving during turbine construction. Acoustic recording devices (T-PODs) were placed at 7 and 20 km from the construction site. During pile driving, acoustic detections of harbour porpoises decreased. There was no significant difference in the detection rates at 7 versus 20 km. The "*size of the zone of responsiveness could not be inferred as no grading in response was observed with distance from the pile driving site but must have exceeded 21km*". Porpoises were detected within the wind farm area during pile driving (although detection rates of porpoises within the farm were much lower than outside, whether pile driving was occurring or not). This suggested habituated/noise-tolerant harbour porpoises within the wind farm area.

(SOURCE**:** Tougaard, J., Carstensen, J., Teilmann, J., Skiv, H. and Rasmussen, P. 2009. Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (*Phocoena phocoena* (L.)). *J. Acoust. Soc. Am.* 126: 11-14)

Impacts of wind turbine noise probably minimal

A study measuring the noise from three types of offshore wind turbines concluded that noise from rotating turbine blades would not adversely impact marine mammals, including harbour porpoises, because virtually all of the in-air noise would reflect off the ocean's surface. However, vibrations generated by machinery would likely be transmitted via the seabed and out into the water. Ambient noise masked most of the sound so generated, except for frequencies below 500 Hz (with SPLs of 109-127 dB re 1µPa rms at a distance of 14-20 m from the turbines' foundations). Harbour porpoise audiograms indicate that wind turbine sounds would be audible at 20-70 m (potentially several kilometres for harbour seals). It was concluded that acoustic masking would be unlikely and that sound levels would not be high

enough to cause significant acoustic impact (*e.g.*, TTS), although behavioural changes might occur close to the turbines.

(SOURCE: Tougaard, J., Henriksen, O.D. and Miller, L.A. 2009. Underwater noise from three types of offshore wind turbines: Estimation of impact zones for harbor porpoises and harbor seals. *J. Acoust. Soc. Am.* 125: 3766-3773)

Masking

Humpback whales in noisy environments change behaviour

If ambient noise increased (in this example, due to increasing wind speeds), humpback whales in Australia adopted more surface active behaviour. It was suggested that this behaviour (*e.g.*, breaching) allowed communication in noisier environments. This has implications with regard to anthropogenic noise – humpback whales might adopt more surface active behaviour during breeding, which could have an energetic cost.

(SOURCE: Dunlop, R.A., Cato, D.H. and Noad, M.J. 2009.Your attention please: increasing ambient noise levels elicits a change in communication behaviour in humpback whales (*Megaptera novaeangliae*). *Proc. Royal. Soc. B*: in press)

Varying levels of noise along right whale migration route could affect breeding success

'Pop up' acoustic recorders monitored ambient noise levels and calls of North Atlantic right whales in three areas along the whale's migration route: the Bay of Fundy, Cape Cod, and Georgia. When whales produced louder calls, it was related more to peak noise levels than to the average ambient noise level in an area. Ambient levels were over 105 dB re 1µPa in the frequency range of right whale calls (i.e., 50-350 Hz) 20-30% of the time in Georgia (winter) and 53-63% of the time in Cape Cod, with the loudest location, the Bay of Fundy, having this level 85-95% of the time (summer). This high level in summer might affect reproduction by masking communication calls.

(SOURCE: Parks, S.E., Urazghildiiev, I. and Clark, C.W. 2009. Variability in ambient noise levels and call parameters of North Atlantic right whales in three habitat areas. *J. Acoust. Soc. Am.* 125: 1230-1239)

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Appendix 1

GLOSSARY

Species glossary

Atlantic white-sided dolphin	*Lagenorhynchus acutus*
Beluga (aka white) whale	*Delphinapterus leucas*
Blainville's beaked whale	*Mesoplodon densirostris*
Bowhead whale	*Balaena mysticetus*
Common bottlenose dolphin	*Tursiops truncatus*
Common dolphin, short-beaked	*Delphinus delphis*
Cuvier's beaked whale	*Ziphius cavirostris*
Fin whale	*Balaenoptera physalus*
Gervais' beaked whale	*Mesoplodon europaeus*
Gray whale	*Eschrichtius robustus*
Harbour porpoise	*Phocoena phocoena*
Humpback whale	*Megaptera novaeangliae*
Killer whale	*Orcinus orca*
Narwhal	*Monodon monoceros*
North Atlantic right whale	*Eubalaena glacialis*
Northern bottlenose whale	*Hyperoodon ampullatus*
Pilot whale, short-finned	*Globicephala macrorhynchus*
Sperm whale	*Physeter macrocephalus*
Grey seal	*Halichoerus grypus*
Harbour seal	*Phoca vitulina*
Harp seal	*Pagophilus groenlandicus*
Steller sea lion	*Eumetopias jubatus*
Northern fulmar	*Fulmarus glacialis*
Polar cod	*Boreogadus saida*

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.

Biogenic: Resulting from biological activity or living organisms.

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

Biota: The plant and animal life of a region.

Brucella: Various species of bacteria that cause the disease brucellosis.

Calcareous: Mostly or partly composed of calcium carbonate.

Carrying capacity: The maximum population number of a species that an ecosystem can sustain indefinitely.

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

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

Delphinid: Of the family Delphinidae (dolphins).

Diatom: Common type of phytoplankton, a one-celled alga encased in a silica cell wall.

Emboli: Plural of embolus, a clot (of blood or other material) in a blood vessel leading to circulation blockage.

Endemic: Found only in a particular geographic region.

Hg: Mercury.

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

Lobomycosis: A chronic fungal infection of the skin affecting humans in South America and two species of dolphins.

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.

Morbillivirus: A family of viruses that are typically highly infectious and pathogenic – the family includes measles, dog distemper and dolphin morbillivirus. A number of mass mortality events have been associated with viruses from this family.

MPA: A marine protected area.

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.

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

Papillomavirus: A family of viruses that can cause warts and may be a causative factor in some cancers.

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.

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

Picoplankton: Very small phytoplankton (less than 2 μm in diameter).

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

ppm: Parts per million.

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

Temporary threshold shift: Temporary hearing loss.

Toxoplasma gondii: A parasitic one-celled organism that causes the disease toxoplasmosis.

Zoonotic: Capable of zoonosis. Zoonoses are infectious diseases that can be transmitted from vertebrate animals to humans or in the reverse direction.