

Annex H

State of the Cetacean Environment Report (SOCER) 2020

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INTRODUCTION

Several resolutions of the International Whaling Commission, including Resolutions 1997-7 (IWC, 1998) and 1998-5 (IWC, 1999), directed the Scientific Committee to provide regular updates on environmental matters that affect cetaceans. Resolution 2000-7 (IWC, 2001) welcomed the concept of the State of the Cetacean Environment Report (SOCER) and requested the annual submission of this report to the Commission. The first full SOCER (Stachowitsch *et al.*, 2003) was presented in 2003 and subsequent editions initiated and continued a cycle of focusing on the following regions: Atlantic Ocean, Pacific Ocean, Arctic and Antarctic Oceans, Indian Ocean and Mediterranean and Black Seas. Each SOCER also includes a Global section addressing the newest information that applies generally to the cetacean environment. The 2020 SOCER features the **Atlantic Ocean**, summarising key papers and articles published from *ca.* 2018 through 2020 to date. This year's regional SOCER represents the initial year of the next cycle (see first SOCER five-year compendium at <https://iwc.int/socer-report>), which will be combined in a second five-year compendium (2020: Atlantic Ocean through 2024: Mediterranean and Black Seas) to present to the Commissioners at IWC/70.

ATLANTIC OCEAN

General

COMPREHENSIVE OVERVIEW OF MARINE POLLUTION IN THE CARIBBEAN

The Caribbean is home to six species of baleen whales and 24 species of toothed whales and for many of these species, waters of the region serve as primary habitat for critical activities such as feeding, mating and calving. In five chapters, seven annexes and dozens of figures, tables and boxes, this overview of the marine pollution problems facing the Wider Caribbean Region deals with a full range of issues, from oil pollution to marine debris and invasive species. It emphasises assessment, marine pollution policy frameworks, and the impacts and threats to the blue economy. Notably, 15 Caribbean countries have now banned plastic bags and Styrofoam. With 37 distinct geopolitical entities, this region has the potential to serve as a case study for addressing the major difficulties in controlling pollution in seas bordered by multiple countries.

(SOURCE: Diez, S.M., Patil, P.G., Morton, J., Rodriguez, D.J., Vanzella, A., Robin, D.V., Maes, T. and Corbin, C. 2019. *Marine Pollution in the Caribbean: Not a Minute to Waste*. Washington, D.C., World Bank Group, 100pp. <https://www.researchgate.net/publication/333237096>).

CRUISE SHIP WASTE AND SEISMIC NOISE IN THE CARIBBEAN

Beyond the marine pollution problems facing the Wider Caribbean Region (WCR) outlined in Diez *et al.* (2019), other publications have noted that this region has, for example, one of the highest numbers of cruise routes and cruise ship ports worldwide. The number of vessels and the amount of waste produced have increased substantially over the last two decades (e.g. a middle-sized ship produces an estimated 8 tons of solid waste within a week). Most port facilities do not have sufficient capacity to receive garbage, and while discharging of solid waste at sea is prohibited through MARPOL, enforcement is often lacking. With regard to noise, 12 marine areas in Latin America are under exploration for oil and gas reserves and therefore subject to seismic surveys: 11 such blocks are located in the Caribbean. As an example for scale, this is equivalent to approximately 34 million ha or 10% of the Colombian seascape. Increasing energy demands are expected to intensify the use of seismic surveying, and this activity is currently poorly regulated. The authors provide detailed lists of appropriate mitigation standards that should be adopted and implemented.

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(SOURCES: Acosta, A., Niño-Rodríguez, N., Yepes, M. C. and Boisseau, O. 2017. Mitigation provisions to be implemented for marine seismic surveying in Latin America: A review based on fish and cetaceans. *Aquat. Biol.* 26: 199-216; Dowling, R. and Weeden, C. (ed). 2017. *Cruise Ship Tourism*. 2nd Edition. University of Brighton, U.K.; Sanches, V.M.L., Aguiar, M.R.d.C.M., de Freitas, M.A.V. and Pacheco, E.B.A.V. 2020. Management of cruise ship-generated solid waste: A review. *Mar. Pollut. Bull.* 151: 110785. <https://doi.org/10.1016/j.marpolbul.2019.110785>).

Habitat degradation

Fisheries interactions

PROACTIVE CONSERVATION IS NEEDED AND EFFECTIVE FOR THE NORTH ATLANTIC RIGHT WHALE

Of 17 documented North Atlantic right whales killed in 2017, 12 died in the Gulf of St Lawrence, Canada, and five in the USA, extending south to the state of Virginia (<https://www.fisheries.noaa.gov/national/marine-life-distress/2017-2020-north-atlantic-right-whale-unusual-mortality-event>). Nine died from entanglement in fishing gear ($n=4$) or ship strike ($n=5$); the others died of unknown causes. These mortalities were deemed an unusual mortality event (UME). Three more carcasses were found in US waters in 2018 - all died from entanglement (Sharp *et al.*, 2019). Davies and Brillant (2019) maintain that the UME in Canada was the result of relative inaction by government agencies nominally working to protect this species from these threats. The tendency to protect economic sectors at the expense of conservation efforts can lead, as it did here, to a crisis where emergency action could be more damaging to economic interests than measured proactive responses. The authors believe that '[m]onitoring...and proportionate action in response to evidence in years prior to 2017 almost certainly would have lessened the mass mortality of right whales'. They conclude that conservation '[a]ctions must be done proportionate to the evidence, and based on science, but also be adaptive and precautionary'. Importantly, strict federal regulations in Canada in 2018, enacted in response to the UME, led to zero whale deaths attributable to entanglement in Canadian waters, while allowing a successful fishery in areas of high whale density. Thus acting *before* a crisis can be effective in reducing wildlife losses. The authors thus advocate for proactive plans, with strong follow-through, to allow consistent right whale recovery. Right whale deaths in Canada resumed in 2019, with the primary cause of death attributable to ship strikes in at least three of the nine documented cases (see URL above). Final causes of death are still pending for the remaining cases. Two additional right whale deaths occurred in the USA as well, one each in 2019 and 2020.

Partly in response to the UME, a consortium of researchers, fishing industry representatives, manufacturers, conservationists and regulators is working to develop 'ropeless' fishing gear (Myers *et al.*, 2019). Fishing traps on the seafloor connected to buoys at the surface by vertical ropes are commonly used in right whale habitat, who become entangled easily as they skim feed at the surface. They then may drag the gear for weeks or months before succumbing to infection or injury as the rope cuts into the flesh and blubber. The development of ropeless traps would be an important innovation, directly relevant to the goal of avoiding future UMEs. This gear is not yet ready to be used widely, but is the type of 'adaptive' gear innovation recommended by Davies and Brillant (2019). The consortium notes that '[r]opeless fishing needs to advance quickly to help avert the existing [North Atlantic right whale] entanglement crisis and address the immediate need to reduce wildlife entanglements off the U.S. West Coast while keeping the fishing industry viable'.

(SOURCES: Davies, K.T.A. and Sean W. Brillant, S.W. 2019. Mass human-caused mortality spurs federal action to protect endangered North Atlantic right whales in Canada. *Mar. Pol.* 104: 157-162; Sharp, S.M., McLellan, W.A., Rotstein, D.S., Costidis, A.M., Barco, S.G., Durham, K., Pitchford, T.D., Jackson, K.A. *et al.* 2019. Gross and histopathologic diagnoses from North Atlantic right whale *Eubalaena glacialis* mortalities between 2003 and 2018. *Dis. Aquat. Org.* 135: 1-31, <https://doi.org/10.3354/dao03376>; Myers, H.J., Moore, M.J., Baumgartner, M.F., Brillant, S.W., Katona, S.K., Knowlton, A.R., Morissette, L., Pettis, H.M. *et al.* 2019. Ropeless fishing to prevent large whale entanglements: Ropeless Consortium report. *Mar. Pol.* 107: 103587, <https://doi.org/10.1016/j.marpol.2019.103587>).

BYCATCH OF HARBOUR PORPOISES EXCEEDS SUSTAINABLE ANTHROPOGENIC REMOVAL LEVELS

Bycatch in fisheries is one of the major threats to marine mammal populations worldwide. The number of bycaught harbour porpoises, one of the most common cetaceans in northern Europe, in gillnet fishing operations is high. An observer programme in the Swedish Skagerrak and Kattegat Seas recorded a total of 21 porpoises bycaught during 10,174 km²h of fishing effort. This is 2.6% of the population abundance, i.e. above the maximum sustainable total anthropogenic removal (1.7%). Net soak time, string length and water depth were positively related to bycatch occurrence. Such results provide guidance for bycatch mitigation measures in terms of adjusting fishing operations (restricting soak time and string length), improving gear, and establishing separate management units for area-specific conservation measures.

(SOURCE: Nui, J. 2019. *Factors Affecting Harbour Porpoise Bycatch Occurrence in the Swedish Skagerrak and Kattegat Seas*. MSc Thesis, Uppsala University, 1-40. <http://www.diva-portal.org/smash/get/diva2:1367052/FULLTEXT01.pdf>).

DRIFT OF STRANDED BYCAUGHT DOLPHINS IN HIGH NE ATLANTIC MAY HELP IDENTIFY FISHERIES INVOLVED

A new method (reverse drift modelling) calculated that 3690 common dolphins died in fishing gear within the Bay of Biscay in 2017, based on 793 stranded cetaceans (84% of which were common dolphins) along the French Atlantic coasts during two months in that year. There was a positive correlation between the origin of stranded bycaught dolphins and the fishing

effort distribution of French midwater pair trawlers, Spanish otter bottom trawlers and French Danish seiners. The common feature of these fisheries is that they target predatory fishes (sea bass and hake) in winter and use high vertical opening gear. The authors call for continued monitoring of strandings to help explain the unusual stranding events recorded in the Bay of Biscay since the late 1980s.

(SOURCE: Peltier, H., Authier, M., Dabin, W., Dars, C., Demaret, F., Doremus, G., Van Canneyt, O., Laran, S. et al. 2020. Can modelling the drift of bycaught dolphin stranded carcasses help identify involved fisheries? An exploratory study. *Global Ecol. Conserv.* 21: e00843. <https://doi.org/10.1016/j.gecco.2019.e00843>).

Marine debris

DEEP-FEEDING PYGMY SPERM WHALES INGEST MARINE DEBRIS

A pygmy sperm whale stranded on the coast of Brazil showed evidence of interaction with fishing nets. Its stomach also contained four plastic items (packaging and bags) measuring 70×92cm; 47×31cm; 30×45cm; and 30×45cm; these occupied a considerable proportion of the stomach. These findings supported earlier reports that this species ingests plastics, and the fact that it feeds at depths between 600 and 1,200m underlines that even deep-feeding cetaceans are threatened by marine debris. As experts do not yet agree on an explanation for such ingestion, the authors call for further monitoring of stranded marine mammals to detect it.

(SOURCE: Brentano, R. and Petry, M.V. 2020. Marine debris ingestion and human impacts on the Pygmy sperm whale (*Kogia breviceps*) in southern Brazil. *Mar. Pollut. Bull.* 150: 110595. <https://doi.org/10.1016/j.marpolbul.2019.110595>).

INTERACTIONS BETWEEN MARINE LITTER AND MEGAFUNA

Charismatic megafauna can serve as flagship species for marine conservation. In addition to sea turtles, sea birds, seals and certain large fish species, this paper presented case studies on interactions between litter and eight cetacean species in the Atlantic Ocean. All these case studies reveal the need to improve guidelines and protocols, as well as standardise monitoring efforts regarding entanglement and ingestion. The improved information would better highlight the diversity and scale of impacts being felt by marine species. This goes beyond marine debris to include other anthropogenic pressures (e.g. bycatch, ship strikes). As charismatic megafauna, cetaceans can help communicate the health of ecosystems, an important step in developing management plans for the conservation of ecosystems and biodiversity.

(SOURCE: Claro, F., Fossi, M.C., Ioakeimidis, C., Baini, M., Lusher, A.L., Mc Fee, W., McIntosh, R.R., Pelamatti, T. et al. 2019. Tools and constraints in monitoring interactions between marine litter and megafauna: Insights from case studies around the world. *Mar. Pollut. Bull.* 141: 147-160. <https://doi.org/10.1016/j.marpolbul.2019.01.018>).

MICROPLASTICS MAY BE OMNIPRESENT IN ATLANTIC SMALL CETACEANS

Although microplastics are a major topic in recent marine debris literature, researchers have only recently begun to examine their presence in the digestive tract of cetaceans. One study examined the stomach contents of 35 stranded common dolphins in northwest Spain. Microplastics were identified in all the samples, with an average of 12 items per stomach (mostly fibres). The authors consider the fact that all stomachs analysed contained microplastics to be a cause for concern. A second study in the waters of the Republic of Ireland supported these results and conclusions. It examined four species of stranded and bycaught small cetaceans (common bottlenose dolphin, striped dolphin, harbour porpoise, common dolphin) and reported that, of the 21 individuals assessed using a novel method for identifying microplastics, all contained this material (84% fibres, 16% fragments).

(SOURCES: Hernandez-Gonzalez, A., Saavedra, C., Gago, J., Covelo, P., Santos, M.B. and Pierce, G.J. 2018. Microplastics in the stomach contents of common dolphin (*Delphinus delphis*) stranded on the Galician coasts (NW Spain, 2005-2010). *Mar. Pollut. Bull.* 137: 526-532. <https://doi.org/10.1016/j.marpolbul.2018.10.026>; Lusher, A.L., Hernandez-Milian, G., Berrow, S., Rogan, E. and O'Connor, I. 2018. Incidence of marine debris in cetaceans stranded and bycaught in Ireland: recent findings and a review of historical knowledge. *Environ. Pollut.* 232: 467-476. <https://doi.org/10.1016/j.envpol.2017.09.070>).

THE UK'S 'FISHING FOR LITTER' SCHEME - A PROMISING APPROACH TO REDUCING MARINE DEBRIS?

A voluntary clean-up scheme, Fishing for Litter (FFL), in which marine debris is collected as part of routine fishing operations, may be a promising approach to addressing this problem. A survey of fishers and stakeholders showed an overall positive evaluation. FFL fishers showed less environmentally harmful waste management behaviours, both out at sea and in other contexts, than did non-FFL fishers. Thus, as well as directly helping to remove litter, this clean-up scheme indirectly helps address the underlying causes of marine pollution. The authors conclude that FFL is an exemplary scheme that makes use of people in the right place at the right time, builds on best practise and social norms, and empowers fishers to do something about a problem that directly affects them.

(SOURCE: Wyles, K.J., Pahl, S., Carroll, L. and Thompson, R.C. 2019. An evaluation of the Fishing For Litter (FFL) scheme in the UK in terms of attitudes, behavior, barriers and opportunities. *Mar. Pollut. Bull.* 144: 48-60. <https://doi.org/10.1016/j.marpolbul.2019.04.035>).

Ship strikes

WHALES STRUCK BY SHIPS PRESENT FAT EMBOLI IN LUNG TISSUE

An estimated 60% of sperm whale deaths in the Canary Islands are due to ship strikes. When carcasses are relatively fresh, injuries providing evidence that strikes occurred before death (i.e. ante mortem) (rather than a ship striking a floating carcass) are easy to detect, but this is more difficult in decomposed carcasses. A study on 35 sperm whale carcasses (collected between 2000 and 2017) sought to identify diagnostic signs of ante mortem ship strikes. Lung samples were taken from 24 whales; 16 had evidence of ship strikes. Seventy percent of samples were autolysed (i.e. in a state of decomposition). Of these, 83% presented fat emboli in blood vessels. Emboli were found in only 25% of the lung samples from whales not struck by ships. Bone fractures were also significantly more common in ship struck animals. Moreover, sperm whale calves (62%) were significantly more likely to be struck by ships; only 12.5% of ship-struck whales were adults. The study concluded that 81% of the sperm whales with signs of ship strike were alive at the moment of being struck and died subsequently. Fat emboli may be a good diagnostic tool to identify ship strike mortality cases, even in heavily decomposed carcasses.

(SOURCE: Arregui, M., Bernaldo de Quirós, Y., Saavedra, P., Sierra, E., Suárez-Santana, C.M., Arbelo, M., Díaz-Delgado, J., Puig-Lozano et al. 2019. Fat embolism and sperm whale ship strikes. *Front. Mar. Sci.* 6: 379. <https://doi.org/10.3389/fmars.2019.00379>).

HIGH SHIP STRIKE RISK FOR HUMPBACK WHALES IN CHESAPEAKE BAY

In winter, humpback whales forage in the mouth of Chesapeake Bay, USA. In addition to hosting a naval base, this area has substantial recreational and fishing boat traffic and has the nation's sixth busiest container port. From December 2015 to February 2017, 35 whales were tagged; nearly all were found in, or next to, shipping channels during the study. In addition, of 106 photo-identified humpback whales, 8.5% displayed injury suggestive of propeller strikes. One tagged whale was later found dead from a ship strike. This region therefore poses a relatively high risk of ship strike injury and mortality to humpbacks.

(SOURCE: Aschettino, J.M., Engelhaupt D.T., Engelhaupt, A.G., DiMatteo, A., Pusser, T., Richlen, M.F. and Bell, J.T. 2020 Satellite telemetry reveals spatial overlap between vessel high-traffic areas and humpback whales (*Megaptera novaeangliae*) near the mouth of the Chesapeake Bay. *Front. Mar. Sci.* 7: 121. <https://doi.org/10.3389/fmars.2020.00121>).

HIGH SHIP STRIKE RISK FOR HUMPBACK WHALES IN THE NEW YORK BIGHT

The New York Bight, including New York Harbour, is an area with a high density of shipping traffic, but it is also frequented by increasing numbers of humpback whales. Opportunistic sightings from 2011 to 2016 were analysed and compared to shipping data (collected via AIS vessel position data). By 2016, 95% of humpback whale sightings were located within 100m of the path of at least one vessel. Passenger vessels showed the highest likelihood of encounters with whales (81%), followed closely by tug or towing vessels (76%). There is therefore a high, and increasing, threat of vessel collision with whales in this region.

(SOURCE: Brown, D., Sieswerda, P.L. and Parsons, E.C.M. 2019. Potential encounters between humpback whales (*Megaptera novaeangliae*) and vessels in the apex of the New York Bight, USA. *Mar. Pol.* 107: art. 103527 (1-8)).

MODELLING EXERCISE IMPLIES SPEED RESTRICTION REDUCES RIGHT WHALE MORTALITY

A modelling framework based on encounter theory was used to estimate the risk of North Atlantic right whale ship strikes. Ship locations were obtained using AIS data and spatial changes in right whale abundance from surveys, with adjustments to account for the likelihood of whale sightings being missed. These data were then used to compare potential mortality before and after the implementation of a vessel speed rule on the south Atlantic US coast. After the rule was implemented, the expected seasonal mortality rate decreased by 22% on average. Unsurprisingly, risk of ship strikes was greatest when both whale and ship densities were simultaneously high, and the speed restriction had greatest effect at these times and areas. This analysis took account of several factors incorporated in other studies, i.e. the effects of vessel size, speed, transit distance, as well as whale abundance and behaviour when encountering ships. This method could possibly be used to model other anthropogenic risks, such as offshore wind farms. This study did not ascertain the ship strike risk from vessels that are less than 20 m in length, nor military or other government vessels, which are not subject to the speed restriction.

(SOURCE: Crum, N., Gowan, T., Krzystan, A. and Martin, J. 2019. Quantifying risk of whale-vessel collisions across space, time, and management policies. *Ecosphere* 10: e02713 (1-15)).

SHIP STRIKES ON HUMPBACK WHALES IN THE GULF OF MAINE MAY BE UNDERREPORTED

Although there are regulations protecting humpback whales from whale-watching traffic, there are no regulations for other types of shipping. To gauge the extent of shipping interactions, 210,733 photographs of 624 individuals taken between 2004 and 2013 in the southern Gulf of Maine were analysed by multiple reviewers for five types of ship-strike related injury. This review showed 14.7% had injuries consistent with one or more vessel strikes. It was noted that this analysis would not detect internal blunt force trauma injuries. The authors conclude that 'vessel strikes are underreported' and they call for a management strategy to minimise ship strikes in the region.

(SOURCE: Hill, A.N., Karniski, C., Robbins, J., Pitchford, T., Todd, S. and Asmutis-Silvia, R. 2017. Vessel collision injuries on live humpback whales, *Megaptera novaeangliae*, in the southern Gulf of Maine. *Mar. Mamm. Sci.* 33: 558-573).

HIGH NUMBERS OF SHIP STRIKES FOR LARGE WHALES ON THE FRENCH COAST

Stranding records of large whales in French waters between 1972 and 2017 were reviewed, with 51 ship strike incidents identified. Seven instances were reported in the first decade of this period, increasing to 22 animals in the last dozen years. One in five whales stranded on the Mediterranean coast showed evidence of ship strike. The authors note that this high number of ship strikes may prevent France from meeting its obligations within the European Marine Strategy Framework Directive.

(SOURCE: Peltier, H., Beaufils, A., Cesarini, C., Dabin, W., Dars, C., Demaret, F., Dhermain, F., Doremus, G. et al. 2019. Monitoring of marine mammal strandings along French coasts reveals the importance of ship strikes on large cetaceans: A challenge for the European Marine Strategy Framework Directive. *Front. Mar. Sci.* 6: 486. <https://doi.org/10.3389/fmars.2019.00486>).

IMPACTS OF SHIPPING ON BOTTLENOSE DOLPHIN BEHAVIOUR

Land-based observations of common bottlenose dolphin behaviour were made with a digital theodolite in the Galveston Ship Channel, in Texas, USA. This constrained waterway has a high level of dolphin-watching, fishing and commercial shipping traffic. Dolphins regularly used the channel to forage (57% of their time) and socialise (27%) and rarely used the channel to travel to other sites (5%). When boats were present, the proportion of time dolphins spent socialising and foraging was significantly lower. Swimming speed significantly increased in the presence of small recreational boats, dolphin-watching vessels and shrimp trawlers. Direction changes also increased significantly in the presence of tourism boats and shrimp trawlers. Because of the impact on foraging, and the likely resulting energetic cost this poses to dolphins, the author warns of 'potential long-term consequences to health and survivorship' of the dolphin population.

(SOURCE: Piwetz, S. 2019 Common bottlenose dolphin (*Tursiops truncatus*) behavior in an active narrow seaport. *PLoS ONE* 14: e0211971 (1-23)).

Chemical pollution

MODERATE TO HIGH HG LEVELS IN COLOMBIAN DELPHINIDS

The La Guajira region in the northern portion of the Colombian Caribbean is a transit zone for dolphins and could be an important feeding area, due to upwelling events and productive local marine ecosystems. The region is affected by local ports and coal mining, leading to potential heavy metal pollution. Measurements of skin Hg content for four delphinid species show that all were influenced by Hg contamination, with moderate to high values. The mean THg ranged from 2,481ng/g for common dolphins to 16,817ng/g for rough-toothed dolphins. These values are similar or higher than reported in skin samples of delphinid species in Europe.

(SOURCE: Barragán-Barrera, D. C., Fariás-Curtidor, N., Luna-Acosta, A., Bustamante, P., Ayala, R. and Caballero, S. 2019. Evidence of mercury bioaccumulation in skin samples of wild delphinids in La Guajira, Colombian Caribbean. Poster presented at SETAC Latin America 13th Biennial Meeting. September 15-18, 2019. Cartagena, Colombia).

POTENTIAL HEALTH RISK FROM HG IN ENDANGERED PANAMANIAN BOTTLENOSE DOLPHIN POPULATION

Hg levels were generally low in the small and genetically isolated common bottlenose dolphin population that resides year-round in the Bocas del Toro Archipelago along the northwest Caribbean coast of Panama, as well as in 11 of its prey species. Nonetheless, biomagnification revealed a marginal health risk for adult dolphins, and a potential major health threat to calves. This is important in light of other threats facing this endangered population, such as overfishing, pollution, sedimentation and, above all, significant pressure due to boat traffic. The authors call for monitoring the exposure of these dolphins, in particular the transfer of pollutants from mother to calf, and argue for monitoring the temporal trends in Hg concentrations in sentinel species as a proxy for ecosystem health.

(Concentration range on dry weight basis: 113-4,627ng/g for THg).

(SOURCE: Barragán-Barrera, D.C., Luna-Acosta, A., May-Collado, L.J., Polo-Silvag, C.J., Riet-Saprizza, F.G., Bustamante, P., Hernández-Ávila, M.P., Vélez, N. et al. 2019. Foraging habits and levels of mercury in a resident population of bottlenose dolphins (*Tursiops truncatus*) in Bocas del Toro Archipelago, Caribbean Sea, Panama. *Mar. Pollut. Bull.* 145: 325-333. <https://doi.org/10.1016/j.marpolbul.2019.05.076>).

LEAD LEVELS DECREASING IN ST LAWRENCE BELUGA WHALES

Analysis of liver and kidney samples from male ($n=3$) and female ($n=7$) beluga whales stranded along the St Lawrence River in 2006 and 2007 showed Pb levels had decreased from levels reported in the 1980s. Comparative data such as this can be used to help establish timelines of how long heavy metals take to make their way through ecosystems into the tissues of top predators such as cetaceans, and to demonstrate the impacts of environmental protective measures on persistent pollutants.

(SOURCE: Belanger, M. and Wittnich, C. 2018. Evidence of stabilizing lead concentrations in livers and kidneys of St. Lawrence beluga (*Delphinapterus leucas*) from 1982 to 2007. *J. Mar. Anim. Ecol.* 10: 6-10).

UNUSUAL HEAVY METAL IN SOUTH ATLANTIC FALSE KILLER WHALES

The concentrations of Ag, a biologically non-essential metal, in the liver and kidney of five mass-stranded false killer whales in the Strait of Magellan, Chile, exceeded the cetacean toxic thresholds proposed as 'unhealthy concentrations' and 'critically dangerous'. The main exposure route for Ag is likely through ingestion of contaminated prey items. In general, values were higher than those reported in odontocetes from other marine areas of South America, and concentrations varied within the ranges measured in species worldwide (aside from the high values in beluga whales). Importantly, however, the values exceeded the new proposed toxicological levels in odontocetes for hepatic, renal, muscle and lung tissues. In view of the numerous stressors that this species faces, which may lead to stranding events, the authors call for continuously monitoring these animals: toxic metal levels can help to determine the degree of overall species contamination and inform future conservation plans.

(Concentration ranges on dry weight basis: 6.62-10.78µg/g in liver; 0.008-7.41µg/g in spleen; 0.004-5.71µg/g in testis; 0.757-1.69µg/g in kidney; 0.011-0.078µg/g in lung; <0.01-0.038µg/g in muscle).

*(SOURCE: Cáceres-Saez, I., Haro, D., Blank, O., Aguayo-Lobo, A., Dougnac, C., Arredondo, C., Luis Cappozzo, H. and Ribeiro Guevara, S. 2019. Stranded false killer whales, *Pseudorca crassidens*, in Southern South America reveal potentially dangerous silver concentrations. *Mar. Pollut. Bull.* 145: 325-333. <https://doi.org/10.1016/j.marpolbul.2019.05.045>).*

LONG-BANNED ORGANOCHLORINE INSECTICIDE STILL PRESENT IN CARIBBEAN CETACEANS

The insecticide chlordecone can induce a wide range of pathologies in birds and mammals (e.g. reproductive impairment, neurotoxicity). It is carcinogenic, causing hepatic tumours in laboratory rats and mice and prostate cancer in humans. Despite having been banned since 1993 in the French West Indies and prohibited by the Stockholm Convention in 2009, chlordecone was found in the blubber of four cetacean species (Fraser's dolphin, Pantropical spotted dolphin, sperm whale, false killer whale) in Guadeloupe. Although the values were low, this underlines: (1) the long-term presence of persistent toxic chemicals that show biomagnification and bioaccumulation; and (2) that such compounds have reached deep-sea food webs in areas with deep waters close to shore.

(Concentration range on lipid weight basis: 1-329ng/g).

*(SOURCE: Méndez-Fernandez, P., Kiszka, J.J., Heithaus, M.R., Beal, A., Vandersarren, G., Caurant, F., Spitz, J., Taniguchi, S. et al. 2018. From banana fields to the deep blue: Assessment of chlordecone contamination of oceanic cetaceans in the eastern Caribbean. *Mar. Pollut. Bull.* 137: 56-60. <https://doi.org/10.1016/j.marpolbul.2018.10.012>).*

HIGH CONCENTRATIONS OF POPs IN STRANDED KILLER WHALES IN IRELAND

The concentrations of 16 PCBs, 7 PBDEs, 1 PBB and 19 OCs were measured in blubber samples from four killer whales stranded in Ireland between 2010 and 2017. The levels of these POPs were high, with the value in one female exceeding the suggested toxicity threshold of 17mg/kg. This confirms that bioaccumulation continues to be a major concern for marine apex predators such as killer whales.

(Concentration ranges on lipid weight basis: 1.5-49.3mg/kg and 0.04-1.2mg/kg for Σ16PCBs and Σ7PBDEs respectively. Concentrations in one male killer whale on lipid weight basis: 49.4mg/kg for Σ19OCs)

*(SOURCE: Schlingermann, M., Berrow, S., Craig, D., McHugh, B., Marrinan, M., O'Brien, J., O'Connor, I., Mudzatsi, E. et al. 2020. High concentrations of persistent organic pollutants in adult killer whales (*Orcinus orca*) and a fetus stranded in Ireland. *Mar. Pollut. Bull.* 151: 110699. <https://doi.org/10.1016/j.marpolbul.2019.110699>).*

ORGANOHALOGENS MAY IMPACT SEVERAL BIOLOGICAL FUNCTIONS IN BELUGA AND MINKE WHALES

Concentrations of POPs and emerging HFRs are elevated in the tissues of beluga whales in the St Lawrence Estuary (Canada), as well as of minke whales visiting that feeding area. This study examined the linkages between blubber concentrations of these compounds and the transcription of genes involved in regulating thyroid and steroid function in belugas: concentrations of PCBs, OCs and HBB were positively correlated with the transcription of thyroid- and/or steroid-related genes, while Dec-604 CB concentrations were negatively associated with the transcription of glucocorticoid and thyroid genes. In minke whales, PBDE concentrations changed positively with *Esrβ* transcript levels and HBB concentrations negatively with *Nr3c1* transcripts. Nonetheless, demonstrating cause-effect linkages between organohalogen exposure and endocrine disruption will require more closely examining other potentially confounding variables (e.g. age, nutritional status, other unmeasured contaminants), other markers (e.g. hormone titres) and degradation products of certain POPs - efforts hampered by difficulties in collecting sufficient tissue to conduct the required multiple analyses. This beluga population - at risk of extinction under the Canadian Species at Risk Act - has been declining approximately 1% per year since the year 2000, from contaminant and noise exposure, disturbance, algal toxins, food scarcity and climate change.

*(SOURCE: Simond, A.E., Houde, M., Lesage, V., Michaud, R., Zbinden, D. and Verreault, J. 2019. Associations between organohalogen exposure and thyroid- and steroid-related gene responses in St. Lawrence Estuary belugas and minke whales. *Mar. Pollut. Bull.* 145: 174-184. <https://doi.org/10.1016/j.marpolbul.2019.05.029>).*

Disease and mortality events

Disease

MORBILLIVIRUS MAY HAVE SPREAD VIA COASTAL BOTTLENOSE POPULATIONS

An outbreak of dolphin morbillivirus in the western North Atlantic (2013-2015) resulted in the stranding of over 1,600 common bottlenose dolphins. A study was conducted to investigate the spread of this outbreak between the five coastal and 10 bay/estuarine bottlenose dolphin stocks along the Atlantic coast of the USA via a combination of antibody testing and satellite tagging. Antibody rates were higher in coastal dolphins (from the South Carolina-Georgia stock) than in bay/estuarine dolphins (southern Georgia estuarine system), i.e. the spread and occurrence may have been primarily via coastal dolphins. It was noted, however, that the small sizes of bay/estuarine stocks, in addition to possible pollutant impacts, may make these populations more vulnerable to disease, especially morbillivirus outbreaks.

(SOURCE: Balmer, B., Zolman, E., Rowles, T., Smith, C., Townsend, F., Fauquier, D., George, C., Goldstein, T. et al. 2018. Ranging patterns, spatial overlap, and association with dolphin morbillivirus exposure in common bottlenose dolphins (*Tursiops truncatus*) along the Georgia, USA coast. *Ecol. Evol.* 8: 12,890-12,904).

ANTHROPOGENIC MORTALITIES IN CETACEANS FROM THE CANARY ISLANDS

Of 234 stranded cetaceans in the Canary Islands, 34% were in a good nutritional state and 23.5% were in a poor nutritional state. Anthropogenic causes of death included vessel collisions (11.5%), fishery interactions (4.8%) and foreign body ingestion (2.4%). Natural causes of death included probable aggression and injury by, within or between cetaceans (17.8%) and likely birth complications (6.2%). In total, 19% of mortalities had an identified anthropogenic cause.

(SOURCE: Diaz-Delgado, J., Fernandez, A., Sierra, E., Sacchini, S. andrada, M., Vela, A.I., Quesada-Canales, O., Paz, Y. et al. 2018. Pathologic findings and causes of death in stranded cetaceans in the Canary Islands (2006-2012). *PLoS One* 13: e0204444 (1-33)).

MASS MORTALITY OF GUIANA DOLPHINS FROM MORBILLIVIRUS IN BRAZIL

From November 2017 to March 2018, a cetacean morbillivirus outbreak caused an unprecedented mass mortality among Guiana dolphins; at least 263 individuals died in Sepetiba and Grande Bays, from a total population of 739-2,196). Boat surveys were undertaken to observe the behaviour and clinical signs presented by diseased dolphins. At least five dolphins were observed having difficulties maintaining their course, orientation and buoyancy, and three of these were assumed to have died (one stranded). A further 40 dolphins were observed emaciated, and 10 photo-identified dolphins had skin lesions (including orange patches and ulcerated lesions). Dolphins were also heard with laboured breathing, suggestive of pneumonia. High levels of organochlorine contaminants have been found in this species, which may have been an exacerbating factor. The authors conclude that anthropogenic pressures, with the simultaneous threat posed by morbillivirus infection, 'is of concern for the survival of the Guiana dolphin population' in Sepetiba Bay, Brazil.

(SOURCE: Flach, L., Alonso, M.B., Marinho, T., Van Waerebeek, K. and Van Bresse, M.F. 2019. Clinical signs in free-ranging Guiana dolphins *Sotalia guianensis* during a morbillivirus epidemic: case study in Sepetiba Bay, Brazil. *Dis. Aquat. Org.* 133: 175-180).

HIGH LEVEL OF TOXOPLASMA INFECTION IN ST LAWRENCE ESTUARY BELUGA WHALES

Samples from 34 stranded belugas in the St Lawrence Estuary, Quebec, Canada, were analysed for the protozoan parasite *Toxoplasma gondii*, using PCR for *Toxoplasma* DNA. Forty-four percent were positive, with more neonates and juveniles being infected than adults, and males having a higher level of infection than females. However, while there was a high prevalence of *T. gondii* infection, very few deaths have been attributed to toxoplasmosis (the disease resulting from the parasite). This population of belugas is listed as 'endangered' under the Canadian Species at Risk Act and the high prevalence of *T. gondii* infection is another issue to monitor for the health of this population.

(SOURCE: Iqbal, A., Measures, L., Lair, S. and Dixon, B. 2018. *Toxoplasma gondii* infection in stranded St. Lawrence Estuary beluga *Delphinapterus leucas* in Quebec, Canada. *Dis. Aquat. Org.* 130: 165-175).

THE SPREAD OF MORBILLIVIRUS

There have been multiple morbillivirus outbreaks in cetaceans and pinnipeds, leading to mass mortality events. To investigate the nature of morbillivirus, wild viruses were sequenced from cetacean tissues from multiple species and locations. Closely related strains of the virus found in the Gulf of Mexico, the Mediterranean Sea, both coasts of the North Atlantic Ocean and the North Sea demonstrated the wide trans-ocean pattern of the virus spread. One strain was more basal and likely diverged from the other cetacean morbillivirus strains a few hundred years ago. Moreover, the virus strain in the Mediterranean outbreak in 1990-1992 was more basal to strains that have emerged in subsequent years, including the outbreak in 2006-2008, suggesting rapid divergence and spread. However, the virus was likely endemic in an as-yet-unidentified cetacean species in the North Atlantic from the 1970s, because a strain more basal than the 1990-1992 Mediterranean strain was found in North Sea Atlantic white-sided dolphins. The authors suggest pilot whales and melon-headed whales might be vectors spreading the virus between populations. The virus appears to need little change, if any, to jump between cetacean species, which means that the virus is a particular threat to endangered cetacean populations, as it could be readily contracted from other more robust cetacean species.

(SOURCE: Jo, W.K., Kruppa, J., Habierski, A., van de Bild, M., Mazzariol, S., Di Guardo, G., Siebert, U., Kuiken, T. et al. 2018. Evolutionary evidence for multi-host transmission of cetacean morbillivirus. *Emerg. Microbes Infect.* 7: 1-15).

HIGH PREVALENCE OF PNEUMONIA IN RIVERINE CETACEANS

Lung tissue examined in Amazon River dolphins ($n=24$) and tucuxi ($n=28$) were found to have an extremely high prevalence of pneumonia (85%). Of these cases, one quarter were the result of the nematode worm *Halocercus brasiliensis* (a lungworm) and one quarter were bacterial pneumonia. This high prevalence of lung infection could potentially have population-level effects on these riverine cetaceans.

(SOURCE: Rodrigues, T.C.S., Díaz-Delgado, J., Catão-Dias, J.L., da Luz Carvalho, J. and Marmontel, M. 2018. Retrospective pathological survey of pulmonary disease in free-ranging Amazon River dolphin *Inia geoffrensis* and tucuxi *Sotalia fluviatilis*. *Dis. Aquat. Org.* 131: 1-11).

HIGH PREVALENCE OF BRUCELLA INFECTION IN BY-CAUGHT AND STRANDED SMALL CETACEANS IN BRAZIL

One hundred twenty-four stranded or by-caught cetaceans from Brazil were tested for the pathogen *Brucella*; there was 'a relatively high occurrence of Brucella-positivity' (10.1%). Animals infected included pygmy killer whale ($n=1$); short-finned pilot whales ($n=3$); melon-headed whales ($n=2$); franciscana ($n=1$); Guiana dolphin ($n=1$); Clymene dolphins ($n=3$); spinner dolphin ($n=1$); and common bottlenose dolphin ($n=1$). Two of the *Brucella*-infected cetaceans were also infected with cetacean morbillivirus; *Edwardsiella tarda* (see Lee *et al.* [2018] below) and *Proteus mirabilis* were also detected. Lesions observed in infected animals included chronic meningoencephalitis and meningitis, chronic gastritis and enterocolitis, hepatitis, pneumonia, lymphoid hyperplasia and lymphoid depletion. Three of the animals were newborns, suggesting that infection may have occurred *in utero*. This is the first record of *Brucella* infection in the franciscana, Guiana dolphin and spinner dolphin.

(SOURCE: Sánchez-Sarmiento, A.M., Carvalho, V.L., Díaz-Delgado, J., Ressio, R.A., Fernandes, N.C., Guerra, J.M., Sacristán, C., Groch, K.R. *et al.* 2019. Molecular, serological, pathological, immunohistochemical and microbiological investigation of *Brucella* spp. in marine mammals of Brazil reveals new cetacean hosts. *Transbound Emerg. Dis.* 66: 1674-1692).

Harmful Algal Blooms (HABs)

ALZHEIMER-LIKE CHANGES SEEN IN THE BRAINS OF DOLPHINS EXPOSED TO HAB TOXIN

Dolphins stranding in Florida and Massachusetts, USA, were examined to determine whether cyanobacteria toxins (i.e. from a HAB) could be identified; specifically, the bioaccumulating and biomagnifying neurotoxin BMAA. High levels of BMAA (20-748 μ g/g) were found in the brains of 13 of 14 dolphins examined. Microscopic examination of these brains showed abnormal, Alzheimer-like nerve cell changes. The presence of BMAA suggests that dolphins provide an excellent sentinel species for such toxin exposure in the marine environment and may have long-term implications for cetacean health.

(SOURCE: Davis, D.A., Mondo, K., Stern, E., Annor, A.K., Murch, S.J., Coyne, T.M., Brand, L.E., Niemeyer, M.E. *et al.* 2019. Cyanobacterial neurotoxin BMAA and brain pathology in stranded dolphins. *PLoS ONE* 14: e0213346 (1-18). <https://doi.org/10.1371/journal.pone.0213346>).

Oil spills

OIL SPILL IN SOUTHERN ATLANTIC THREATENS COASTAL MARINE BIODIVERSITY

Since late August/early September 2019, nearly 400 localities spanning approximately 3000km of the northern and southeast Brazilian coast (> 980 beaches) have been exposed to hundreds of tons of crude oil from an as yet undetected source. Magris and Giarrizzo (2020) identify three most-affected habitats (estuaries, mangroves, seagrass meadows) and 27 potentially most-affected threatened coastal species, including the Guiana dolphin. These authors expect the mysterious oil slicks to have significant and long-lasting socioeconomic impacts, in particular for local tourism and small-scale fisheries. de Oliveira Soares *et al.* (2020) consider this oil spill to be the most extensive and severe environmental disaster ever recorded in Brazilian history, in the South Atlantic basin and in tropical coastal regions worldwide.

(SOURCES: Magris, R.A. and Giarrizzo, T. 2020. Mysterious oil spill in the Atlantic Ocean threatens marine biodiversity and local people in Brazil. *Mar. Pollut. Bull.* 153: 110961. <https://doi.org/10.1016/j.marpolbul.2020.110961>; de Oliveira Soares, M., Teixeira, C.E.P., Bezerra, L.E.A., Paiva, S.V., Tavares, T.C.L., Garcia, Z.M., de Araújo, J.T., Campos, C.C. *et al.* 2020. Oil spill in South Atlantic (Brazil): Environmental and governmental disaster. *Mar. Pol.* 115: 103879. <https://doi.org/10.1016/j.marpol.2020.103879>).

TEN YEARS AFTER THE DEEPWATER HORIZON OIL SPILL

The Deepwater Horizon oil spill occurred on 20 April 2010, spilling an estimated 210 million gallons of oil into the Gulf of Mexico. Ten years later, 55% of common bottlenose dolphins in affected areas have worsening lung disease, 43% exhibit abnormal stress responses, 25% are underweight and 19% anaemic. Successful birth rates are less than a quarter of normal levels for the species. However, dolphins born after the spill do not exhibit symptoms of as many maladies as those that were exposed to the spill. An estimated 17% of the Gulf's unique population of Bryde's whales died as a result of the spill, and reproductive failures are predicted for surviving individuals. Despite increased legislation on oil platform safety, the US Coast Guard reports that an additional 13,187 oil spills have occurred in the Gulf of Mexico in the past decade. In addition, other marine megafaunal species, such as turtles, and fish stocks suffered impacts. In a separate analysis, a model assessed

the impacts of the oil spill on the growth and mortality rates of fish stocks and fisheries closures. The model estimated that biomass of large reef fish decreased by 25-50% in areas most affected by the spill and of large demersal fish by 40-70%. The model also showed that, while high-turnover populations of fish have mostly recovered in the 10 years since the oil spill, some slower-growing fish populations could take more than 30 years to recover from exposure.

(SOURCES: National Wildlife Federation. 2020. *10 Species, 10 Years Later: A Look at Gulf Restoration after the Deepwater Horizon Disaster*, https://restorethegulf.nwf.org/?_ga=2.48848998.116792924.1587758800-395230847.1587758800; Ainsworth, C.H., Paris C.B., Perlin, N., Dornberger, L.N., Patterson, W.F., Chancellor, E., Murawski, S., Hollander, D. et al. 2018. *Impacts of the Deepwater Horizon oil spill evaluated using an end-to-end ecosystem model*. *PLoS ONE* 13: e0190840 (1-21). <https://doi.org/10.1371/journal.pone.0190840>).

Climate change

PREY SPECIES OF NORTH ATLANTIC BALEEN WHALES RESPONDING TO ECOSYSTEMS ALTERED BY CLIMATE CHANGE

Oceanographically, three sectors in the North Atlantic present contrasting habitats to baleen whales: (i) a broad-deep-strait and deep-shelf inflow system in the Northeast Atlantic; (ii) a combination of inflow and outflow systems north of Iceland in the central North Atlantic; and (iii) an outflow shelf and basin in the Northwest Atlantic. Sea ice loss, ocean warming and regional increases in primary productivity are causing rapid transformation, with effects across the entire food chain. Humpback, fin, common minke, sei and blue whales occupy the diverse habitats here. These species all exhibit flexible diets, mostly krill and forage fishes (e.g. capelin, herring, sand eel), which are now responding to ecosystems altered by climate change. Baleen whale distribution, phenology, body condition and diet can provide data for ecosystem models, underlining the potential sentinel capability these cetaceans offer to improve our understanding of ocean habitats.

(SOURCE: Moore, S.E., Haug, T., Vikingsson, G.A. and Stenson, G.B. 2019. *Baleen whale ecology in arctic and subarctic seas in an era of rapid habitat alteration*. *Prog. Oceanography* 176: 102188. <https://doi.org/10.1016/j.pocean.2019.05.010>).

Noise impacts

ACOUSTIC DETERRENT DEVICES HAVE POTENTIAL ADVERSE EFFECTS ON BOTH TARGET AND NON-TARGET SPECIES

Acoustic deterrent devices (ADDs) are designed to, for example, reduce pinniped depredation on finfish aquaculture sites by emitting loud and pervasive noise. This study shows that ADD detections have steadily increased from 2006 to 2016 on the Scottish west coast (mainly in relation to Atlantic salmon facilities). This represents a significant and chronic source of underwater noise here. This has potential adverse impacts on target (pinniped) and non-target (e.g. cetacean) species. The authors call for further study and improved monitoring and regulatory strategies to assess the wider environmental impact of the aquaculture industry.

(SOURCE: Findlay, C.R., Ripple H.D., Coomber F., Froud, K., Harries, O., van Geel, N.C.F., Calderan, S.V., Benjamins, S. et al. 2018. *Mapping widespread and increasing underwater noise pollution from acoustic deterrent devices*. *Mar. Pollut. Bull.* 135: 1,042-1,050. <https://doi.org/10.1016/j.marpolbul.2018.08.042>).

GUIANA DOLPHIN ACOUSTIC BEHAVIOR AFFECTED BY UNDERWATER NOISE

An investigation of the effects of underwater noise (0.43-35.8 kHz) on the Guiana dolphin in Pipa, Brazil, found that recreational tourism motorboats caused a significant alteration in several dolphin whistle and call patterns. The sound of an underwater water pump was associated with a significant decrease in dolphin click duration. It was suggested that the changes were the result of dolphins trying to compensate for the anthropogenic noise. The Guiana dolphin in northeast Brazil has already demonstrated a decrease in residence time and reduced number of individuals occurring when recreational vessels were present; therefore, the authors suggest that regulations to manage boat traffic need to be put in place, alongside an outreach program to boat operators, tourists, and the general public.

(SOURCE: Leão Martins, D.T., Rossi-Santos, M.R. and de Lima Silva, F.J. 2018. *Effects of anthropogenic noise on the acoustic behaviour of Sotalia guianensis (Van Bénédén, 1864) in Pipa, North-eastern Brazil*. *J. Mar. Biol. Assoc. UK* 98: 215-222).

UNDERWATER NOISE POLLUTION IN THE NORTHEAST ATLANTIC

Impulsive noise activity (e.g. explosions, seismic air guns, percussive pile driving) in the Northeast Atlantic was reported from 2015-2017 to the first international impulsive noise register (INR), established in 2016 under the OSPAR Convention. Seismic air gun surveys were the dominant noise source (67%-83% of annual activity) and declined by 38% during the study period. Reported pile driving activity increased 46%. Explosions and sonar/acoustic deterrent devices showed overall increases in activity. Such noise can affect marine fauna through mortality, physical injury, auditory damage, physiological stress, acoustic masking and behavioural responses. The authors argue for using and improving noise registries to develop 'noise budgets' within regional seas, which, if exceeded, would necessitate measures to limit noise emissions at sensitive times and locations, and/or require the application of noise abatement measures.

(SOURCE: Merchant, N.D., Andersson, M.H., Box, T., Le Courtois, F., Cronin, D., Holdsworth, N., Kinneging, N., Mendes, S. et al. 2020. *Impulsive noise pollution in the Northeast Atlantic: Reported activity during 2015-2017*. *Mar. Pollut. Bull.* 152: 110951. <https://doi.org/10.1016/j.marpolbul.2020.110951>).

GLOBAL

General

SEX RATIOS OF MIGRATING WHALES: A NOVEL INDICATOR OF ECOSYSTEM HEALTH

Based on a 1:1 birth ratio, the relative migratory sex ratios of southern humpback whales could serve as an indirect measure of relative, inter-annual whale fecundity. Accordingly, the lower the female component of the migration, the lower their reproductive health: females that have been unable to accumulate sufficient energy reserves do not participate in the migration. As an example, the migrating population was more highly male skewed in years with poor feeding conditions (e.g. extreme La Niña event). This is also reflected in the adiposity (blubber thickness) of the population as a whole. The authors argue for including such sex ratios as a new non-lethal tool for the study of population health, which in turn is a function of ecosystem productivity and reflects ecosystem health.

(SOURCE: Druskat, A., Ghosh, R., Castrillon, J. and Bengtson Nash, S.M. 2019. Sex ratios of migrating southern hemisphere humpback whales: A new sentinel parameter of ecosystem health. *Mar. Environ. Res.* 151: 104749. <https://doi.org/10.1016/j.marenvres.2019.104749>).

REBUILDING THE WORLD'S MARINE ECOSYSTEMS BY 2050

In a review of successful conservation interventions, it was suggested that 'substantial recovery of the abundance, structure and function of marine life could be achieved by 2050'. There have been some gains in marine conservation over the past 20 years. For example, levels of many marine pollutants (such as DDTs) have declined. The proportion of marine species threatened with extinction was 18% in 2000, and had declined to 11.4% by 2019. For marine mammals, 47% of the 124 well-assessed populations showed a significant increase in population size over the past 20 years, with only 13% decreasing, with the recovery of humpback whale populations being a particular success story. In 2000, only 0.9% of the ocean was protected; today, fully implemented MPAs now encompass 5.3% of the ocean. However, greater protection is required for substantial recovery. In addition to greater action on mitigating the effects of climate change, the proportion of the oceans that would need protection would have to be increased by approximately 50%. This would cost US\$10-20 billion per year to achieve, although it is also estimated that the economic dividends will eventually outweigh the expenditure by a factor of 10. The authors conclude that 'meeting this challenge requires immediate action to reduce relevant pressures, including climate change, safeguarding places of remaining abundance, and recovering depleted populations, habitats and ecosystems elsewhere. This will require sustained perseverance and substantial commitment of financial resources', but they note that if this is done, the economic benefits could be immense.

(SOURCE: Duarte, C.M., Agusti, S., Barbier, E., Britten, G.L., Castilla, J.C., Gattuso, J.P., Fulweiler, R.W., Hughes, T.P. et al. 2020. Rebuilding marine life. *Nature* 580: 39-51).

Habitat degradation

General

NEW POTENTIAL IMPACT OF OFFSHORE WIND FARMS

Wind farms have been identified as potential threats to cetaceans as physical barriers and as sources of noise and vibrations related to construction, operation, servicing and decommissioning. Another potential threat comes from impacts due to corrosion protection systems, i.e. the leaching of toxic metals, organic and other compounds from protective paints, coatings and galvanic anodes. As of 2017, Europe had 4,149 grid-connected wind turbines in 92 offshore wind farms across 11 countries. Based on the observed effects of anti-fouling paints on boat hulls and other structures, and on the expected future increase of wind farms here and elsewhere, the authors argue for collecting more information as part of efforts to reduce the environmental footprint of such facilities.

(SOURCE: Kirchgeorg, T., Weinberg, I., Hörnig, M., Baier, R., Schmid, M.J. and Brockmeyer, B. 2018. Emissions from corrosion protection systems of offshore wind farms: Evaluation of the potential impact on the marine environment. *Mar. Pollut. Bull.* 136: 257-268. <https://doi.org/10.1016/j.marpolbul.2018.08.058>).

Fisheries interactions

PROSPECTS FOR CRITICALLY ENDANGERED SMALL CETACEANS GRIM UNLESS BYCATCH PROBLEM IS RESOLVED

The conservation status of small cetaceans has significantly worsened since the 1980s. Thirteen species, subspecies, or populations (units-to-serve or units) of small cetaceans are listed as Critically Endangered (IUCN Red List). Bycatch is the main threat to 11 of these units. The long-term solution is the development of efficient, inexpensive, alternative fishing gear that can replace gillnets. Good fisheries governance and the direct involvement of fishing communities are essential to the successful conservation of most threatened populations of small cetaceans. Among others, the authors highlight the Baltic harbour porpoise, the Yangtze finless porpoise, and the Atlantic humpback dolphin. Adequately sized conservation zones (gillnet use forbidden) will have to be coupled with strict enforcement.

(SOURCE: Brownell Jr., R.L., Reeves, R.R., Read, A.J., Smith, B.D., Thomas, P.O., Ralls, K., Amano, M., Berggren, P. et al. 2019. Bycatch in gillnet fisheries threatens Critically Endangered small cetaceans and other aquatic megafauna. *Endang. Spec. Res.* 40: 285-296. <https://doi.org/10.3354/esr00994>).

SEEKING GLOBAL TRENDS IN, AND SOLUTIONS TO, GHOST FISHING GEAR

Abandoned, lost or discarded fishing gear (ALDFG) comprises a significant amount of global marine debris, with diverse impacts to marine environments, wildlife (including cetaceans) and the fishing industry. This paper summarises a technical session of ALDFG leaders. The Global Ghost Gear Initiative (GGGI) calls for raising awareness of and developing solutions for ALDFG. In this pursuit, the authors highlight: (1) case studies that feature innovative approaches to ALDFG data collection and retrieval; (2) examples of opportunities to fill data gaps and improve our understanding of wildlife ingestion and entanglement; and (3) awareness-raising by developing a publicly accessible global ALDFG database.

(SOURCE: Richardson, K., Asmutis-Silvia, R., Drinkwin, J., Gilardi, K.V.K., Giskes, I., Jones, G., O'Brien, K., Pragnell-Raasch, H. et al. 2019. Building evidence around ghost gear: Global trends and analysis for sustainable solutions at scale. *Mar. Pollut. Bull.* 138: 222-229. <https://doi.org/10.1016/j.marpolbul.2018.11.031>).

ELECTROFISHING A THREAT TO FRESHWATER CETACEANS

Electrofishing has been banned in most countries due to its damaging impacts on fish stocks and non-target species, including several endangered and threatened cetacean species (e.g. Yangtze river dolphin, Yangtze finless porpoise, Irrawaddy dolphins). Due to the potential for death and injury of threatened freshwater cetaceans, there is a need to identify lesions and injuries caused by electrofishing, the range of impacts caused by this fishing method, and the extent and scale of the practise. The threats that this fishing method poses to endangered cetaceans (and ecosystems) lead the authors to suggest that 'high priority should be given to enforcing electrofishing bans in the freshwater habitat of dolphins and finless porpoises'.

(SOURCE: Thomas, P.O., Gulland, F.M.D., Reeves, R.R., Krebs, D., Wang, D., Smith, W.B., Malik, M.I., Ryan, G.E. et al. 2019. Electrofishing as a potential threat to freshwater cetaceans. *Endang. Spec. Res.* 39: 207-220).

Marine debris

GLOBAL IMPACT OF MARINE PLASTIC ENCOMPASSES MARINE MAMMALS

A literature review of 1191 data points examined the global ecological, social and economic impacts of marine plastic pollution and determined that there is global evidence of impact with medium to high frequency on all the major marine groups and social factors, with a medium to high degree of irreversibility. In the case of marine mammals, on a score range from +9 (positive effect) to -9 (lethal or sublethal effect that is global, highly irreversible and occurring at a high frequency), the score was poor: -7 regarding entanglement and -7 regarding ingestion. The authors conclude that, overall, this is accompanied by a reduction in ecosystem services with implications for human health and wellbeing, linked particularly to fisheries, charismatic species, and recreation.

(SOURCE: Beaumont, N.J., Aanesen, M., Austen, M.C., Börger, T., Clark, J.R., Cole, M., Hooper, T., Lindeque, P.K. et al. 2019. Global ecological, social and economic impacts of marine plastic. *Mar. Pollut. Bull.* 14: 189-195. <https://doi.org/10.1016/j.marpolbul.2019.03.022>).

MICROPLASTICS GAIN RELEVANCE FOR CETACEANS

Beyond the entanglement and direct ingestion threat posed by larger marine debris, researchers are increasingly examining the potential impact of microplastics on cetaceans. The uptake for two large whale species was inferred by determining their prey species and examining the latter species' microplastics load. High levels of microplastic contamination were reported for fish from the family Scombridae in the Atlantic (a prey of sei whales) and anchovy in the northwest Pacific (a prey of minke whales). Other fish species and invertebrates (e.g. copepods) had lower values. Species-specific prey preferences and feeding strategies (minke whales are 'gulpers', whereas sei whales are 'surface skimmers') imply that different cetaceans have varied potential for diet-related microplastics ingestion, even if they feed in similar geographic areas. Importantly, the authors stress that microplastics may also be ingested incidentally and directly from the water; for example, while grazing for copepods. Unravelling the effects of microplastics on cetaceans is imperative because the influx of plastics into the oceans is expected to increase, and 29% of the 89 cetacean species are currently listed as critically endangered, endangered, vulnerable or near threatened.

(SOURCE: Burkhardt-Holm, P. and N'Guyen, A. 2019. Ingestion of microplastics by fish and other prey organisms of cetaceans, exemplified for two large baleen whale species. *Mar. Pollut. Bull.* 145: 224-234. <https://doi.org/10.1016/j.marpolbul.2019.04.068>).

PERVASIVE INGESTION OF MARINE DEBRIS BY MARINE MEGAFUNA

In a summary of 747 studies with marine debris entanglement and ingestion records for marine birds, mammals, turtles, fish and invertebrate species, 914 species were found entangled in, and/or had ingested, marine debris. Ingestion was recorded for 701 species, entanglement for 354 species. Less than 30% of individual seabirds, 4.4% of mammals and 32% of turtles had debris in their stomachs. Cetacean species overall seemed to suffer more from marine debris ingestion (60.5% of species) than entanglement (25.6%). Within species, a substantial proportion of individual baleen whales (16.7%) were found to have ingested marine debris; for toothed whales, it was 9.4%, a strong difference between these taxa. Amongst toothed whale taxa, while less than 10% of dolphins and porpoises ingested marine debris, approximately a quarter of all

beaked, pygmy and dwarf sperm, and sperm whales, as well as the franciscana, did so. The actual occurrence of marine debris ingestion is probably underestimated in many studies due to methodological differences. In harbour porpoises, for example, one study showed that using a plastic-dedicated protocol increased the detection of affected individuals from 6% to 15%. The authors conclude that ingestion rates are reason for serious concern for certain species and call for using standardised methods in future studies to generate datasets that allow higher-level ecosystem analyses.

(SOURCES: Kühn, S. and van Franeker, J.A. 2020. Quantitative overview of marine debris ingested by marine megafauna. *Mar. Pollut. Bull.* 151: 110858. <https://doi.org/10.1016/j.marpolbul.2019.110858>; Van Franeker, J.A., Bravo Rebolledo, E.L., Hesse, E., IJsseldijk, L.L., Kühn, S., Leopold, M. and Mielke, L. 2018. Plastic ingestion by harbour porpoises *Phocoena phocoena* in the Netherlands: Establishing a standardised method. *Ambio* 47: 387-397. <https://doi.org/10.1007/s13280-017-1002-y>).

FEEDING STRATEGY PROBABLY MORE IMPORTANT THAN POSITION IN WATER COLUMN FOR MARINE DEBRIS INGESTION

One approach to understanding the effect of marine debris on cetaceans and other larger organisms is to determine the factors that govern ingestion. One hypothesis (tested on four fish and two dolphin species) involves whether the position of predators in the water column affects the probability of ingestion. Accordingly, those species living closer to the bottom (demersal) should be more exposed (because debris availability is high and associated mainly with the seabed at this study site). The hypothesis was not supported: while the ‘pelagic demersal’ feeding franciscana showed the highest frequency of debris ingestion, the values for the boto (pelagic) and the fish species (both pelagic and demersal representatives) were lower and similar. The authors conclude that prey-capture strategies (or feeding behaviour) rather than preferred feeding site (depth) determine the probability of ingestion, regardless of debris availability (a conclusion also supported by Burkhardt-Holm and N’Guyen (2019), above).

(SOURCE: Madeira Di Benedetto, A.P. and da Silva Oliveira, A. 2019. Debris ingestion by carnivorous consumers: Does the position in the water column truly matter? *Mar. Pollut. Bull.* 145: 134-139. <https://doi.org/10.1016/j.marpolbul.2019.04.074>).

WHAT HAPPENS WITH COLLECTED MARINE DEBRIS?

Beyond the direct impact of entanglement and ingestion, marine debris poses multiple other threats to marine species and their environment. This has prompted numerous schemes to collect this material, but there is little or no information about how this waste is treated or used post-collection. A review of 103 studies and 29 projects outside academia on collection efforts found over 250,000 tons of litter have already been removed, but much is from wealthy countries that do not primarily contribute to the problem. Given this is only a tiny fraction of the amount entering the world’s oceans every year, and that little information is available on waste treatment of collected material, the authors call for boosting collection efforts and a ‘full system quantitative assessment from the impact of litter collections on the marine environment all the way to reuse and recycling options ... to help policy makers and waste treatment companies identify the collection and treatment pathways of marine litter that are most environmentally friendly and minimize undesired side effects’.

(SOURCE: Schneider, F., Parsons, S., Clift, S., Stolte, A. and McManus, M.C. 2018. Collected marine litter - A growing waste challenge. *Mar. Pollut. Bull.* 128: 162174. <https://doi.org/10.1016/j.marpolbul.2018.01.011>).

Ship strikes

MITIGATION SHOULD ACCOUNT FOR NIGHT-TIME WHALE LOCATIONS, WHEN SHIP STRIKE RISK IS HIGHEST

Blue, fin, and humpback whales are known to feed in areas of high ship traffic along the US west coast. Tagging research indicated that, while dive profiles varied, all three species spent a high proportion of their time closer to the surface at night, when they might be more vulnerable to ship strikes. In particular, night time vulnerability of blue whales to ship strike was twice as high as in daytime. In addition, due to the whales following prey, there were different patterns of overlap with shipping lanes during the night versus the day. As risk for whales from shipping is assessed using daytime visual survey data, this difference is critical. The authors state that ‘[ship strike mitigation] methods based on visual sightings of whales or other approaches requiring daylight would not be very effective since they would not address the primary period of whale vulnerability’.

(SOURCE: Calambokidis, J., Fahlbusch, J.A., Szesciorka, A.R., Southall, B.L., Cade, D.E., Friedlaender, A.S. and Goldbogen, J.A. 2019. Differential vulnerability to ship strikes between day and night for blue, fin, and humpback whales based on dive and movement data from medium duration archival tags. *Front. Mar. Sci.* 6: 543. <https://doi.org/10.3389/fmars.2019.00543>).

A ‘ROAD ECOLOGY’ APPROACH TO MITIGATING SHIPPING IMPACTS

A ‘road ecology’ framework (similar to methods used in terrestrial species, treating shipping lanes as marine roads) was used to review the threat to cetaceans and other megafauna from ship strikes. Large body size, long migrations and time spent at the surface makes cetaceans especially vulnerable to ship strike. Shipping also causes chemical and noise pollution and fragments habitats. In addition to shifting shipping lanes to avoid high concentrations of cetaceans, the authors recommend ‘transition zones’ (i.e. buffer areas around shipping lanes where the impacts of threats, such as noise, diminish) to mitigate impacts. Minimising the creation of new shipping channels and having ‘no go’ zones where shipping traffic is prohibited (e.g. in the Arctic) may also help to mitigate shipping impacts. New technologies (e.g. advanced methods for tracking

whales) may identify possible collisions before they occur and prevent them from happening. The authors conclude that '[r]oad ecology indicates that the expansion of marine roads has potential risks that may be unforeseen through existing approaches'.

(SOURCE: Pirotta, V., Grech, A., Jonsen, I.D., Laurance, W.F. and Harcourt, R.G. 2019. Consequences of global shipping traffic for marine giants. *Front. Ecol. Environ.* 17: 39-47).

Chemical pollution

HG CONTAMINATION TRENDS IN CETACEANS

A review on Hg contamination in cetaceans found there was no trend in levels between 1975 and 2010. However, despite a decline in global emissions of Hg, levels continued to bioaccumulate in cetaceans. Of all monitored cetacean populations, Mediterranean species displayed the highest levels (in liver tissues). Toxic effects resulting from Hg contamination in cetaceans have been reported for neurological systems, immune systems, and kidney and liver tissues. The element Se is often found in conjunction with Hg and may play a detoxifying effect in cetacean tissues. The authors recommend that Se levels in tissues should also be determined when trying to estimate the impacts of Hg contamination in cetaceans. The population-level effects of Hg contamination are still unknown and the authors state that 'Estimating direct and indirect risk thresholds of mercury exposure is a priority'.

(SOURCE: Kershaw, J.L. and Hall, A. 2019. Mercury in cetaceans: Exposure, bioaccumulation and toxicity. *Sci. Total Environ.* 694. <https://doi.org/10.1016/j.scitotenv.2019.133683>).

SILVER NANOPARTICLES IMPACT CETACEAN IMMUNE SYSTEMS

Ag nanoparticles (AgNPs) are raising increasing concern as a widespread marine contaminant (they are used in numerous products for their anti-microbial properties). A study investigated the impact of these nanoparticles on cetacean immune systems, specifically on white blood cells *in vitro*. At high concentrations of 20nm AgNPs (10 and 50µg/ml), cell death occurred in cetacean leukocytes, lymphocytes and monocytes. Lower doses (0.1 and 1µg/ml) negatively affect the ability of these types of white blood cells to perform their functions of engulfing or killing pathogens infecting an organism. The authors conclude that their results 'suggest that the immune function of cetaceans may have been compromised by AgNPs and/or Ag, and the immunotoxic effects of AgNPs in marine mammals should not be overlooked'. See also Cáceres-Saez *et al.* (2019) above.

(SOURCE: Li, W.T., Chang, H.W., Yang, W.C., Lo, C., Wang, L.Y., Pang, V.P., Chen, M.H. and Jeng, C.R. 2018. Immunotoxicity of silver nanoparticles (AgNPs) on the leukocytes of common bottlenose dolphins (*Tursiops truncatus*). *Sci. Rep.* 8: 5593 (1-12). <https://doi.org/10.1038/s41598-018-23737-0>).

Disease and mortality events

Disease

GENETIC ANALYSIS OF MORBILLIVIRUS SUSCEPTIBILITY

Cetacean morbillivirus is highly contagious and has caused the death of tens of thousands of cetaceans in several locations around the world, including the northwest Atlantic. A genetic analysis of non-survivors and living animals (putative survivors) from the most infected population ($n=38$) sought to identify genes associated with morbillivirus resistance and susceptibility. There were significant differences in the genetic make-up of victims and survivors, in particular five candidate genes associated with stress, pain and immune responses. The authors note that 'These results could also possibly aid in the advancement of vaccines against morbilliviruses', as well as help to genetically identify susceptible populations.

(SOURCE: Batley, K.C., Sandoval-Castillo, J., Kemper, C.M., Attard, C.R.M., Zanardo, N., Tomo, I., Beheregaray, L.B. and Möller, L.M. 2019. Genome-wide association study of an unusual dolphin mortality event reveals candidate genes for susceptibility and resistance to cetacean morbillivirus. *Evolut. Applic.* 12: 718-732).

VIRULENCE AND GENOME OF THE PATHOGEN *EDWARDSIELLA TARDA*

The bacterial pathogen *Edwardsiella tarda* has been reported in several marine mammal species and is one of the main causes of septicaemia in captive marine mammals. The genome of an *E. tarda* strain isolated from a false killer whale by-caught in South Korea was similar to strains that are pathogenic in humans, and distinct from other *Edwardsiella* species. Several virulence-related genes (genes that increase the ability for a pathogen to infect or injure a host) were present in the genome, although some genes that are responsible for virulence in other *Edwardsiella* species were not. The authors conclude that 'These results provide important insights into the *E. tarda* infecting marine mammals and give valuable information on potential virulence factors in this pathogen'. Moreover, the analysis determined that this cetacean *E. tarda* strain is a 'potentially virulent strain' that could spread quickly through cetacean populations and possibly cause zoonotic infections (infections that pass from animals to humans) if encountered during stranding events or if consumed (i.e. through eating cetacean meat).

(SOURCE: Lee, K., Kim, H.K., Park, S-Y., Sohn, H., Cho, Y., Choi, Y.-M., Jeong, D.G. and Kim, D.G. 2018. First report of the occurrence and whole genome characterization of *Edwardsiella tarda* in the false killer whale (*Pseudorca crassidens*). *J. Vet. Med. Sci.* 80: 1,041-1,046).

Harmful Algal Blooms (HABs)

EXPANSION IN RANGE AND FREQUENCY OF HABs IN RESPONSE TO CLIMATE CHANGE AND OTHER FACTORS

The impacts of HABs have increased in recent decades and, in coastal waters, are associated with other threats. This trend is attributed partly to the effects of ocean warming, marine heatwaves, oxygen loss, eutrophication and pollution. This highlights the combined effects of perturbations in the marine environment. The authors report that the United Nations' Intergovernmental Panel on Climate Change's (IPCC) Special Report (approved September 2019) on the Ocean and Cryosphere in a Changing Climate was the first IPCC report to directly link HABs to climate change. Two other threats - acidification and deoxygenation - are also noted as being related to progressive warming. Non-climatic drivers such as increased nutrient input from rivers, which leads to eutrophication, also promote HABs. Eutrophication also promotes the oxygen crises that can lead to mass mortalities of organisms and collapses of entire marine ecosystems ('dead zones'). The authors call for addressing the gaps in our understanding of HABs as a climate change co-stressor in order to develop management plans that adequately protect fisheries, aquaculture, aquatic ecosystems and human health.

(SOURCES: Griffith, A.W. and Gobler, C.J. 2019. Harmful algal blooms: A climate change co-stressor in marine and freshwater ecosystems. *Harmful Algae* 91: 101590. <https://doi.org/10.1016/j.hal.2019.03.008>; Gobler, C.J. 2020. Climate change and harmful algal blooms: Insights and perspective. *Harmful Algae* 91: 101731. <https://doi.org/10.1016/j.hal.2019.101731>).

Oil spills

OIL READILY WASHES OFF OF BALEEN PLATES

There has been concern that baleen whales encountering oil might undergo clogging of the baleen plates as they filter-feed in oil-contaminated waters. An investigation of the effects of oil on bowhead, fin, humpback and North Atlantic right whale baleen demonstrated that it was hydrophilic (water-attracting) and oleophobic (oil-repelling). Six petroleum-based oils and two fish oils were tested. There was no difference amongst oil types or species; baleen readily repelled oil, and oil easily rinsed off of the baleen plates. Thus, coating of baleen plates by these types of oil is not a threat. However, the potential risks of ingestion of oil by the whales remains.

(SOURCE: Werth, A.J., Blakeney, S.M. and Cothren, A.I. 2019. Oil adsorption does not structurally or functionally alter whale baleen. *R. Soc. Open Sci.* 6: 182194. <http://dx.doi.org/10.1098/rsos.182194>).

Climate change

PREDICTING MARINE MAMMAL VULNERABILITY TO CLIMATE CHANGE

A trait-based approach to assess the vulnerability of marine mammals to climate change used 15 traits in five categories (feeding, habitat, reproduction, social behaviour and biology) for 123 marine mammal species. Traits that made species vulnerable (e.g. restricted range) or might allow species to adapt to a changing climate were especially noted. Vulnerability to climate change was then ranked on a 4-point scale. This was compared to the predicted change in temperature for the respective habitats under a high and low greenhouse gas emission scenario for the middle and end of the 21st century. The results showed that the North Pacific Ocean, the Greenland Sea and the Barents Sea had species that were most vulnerable to global warming. The most vulnerable included some that are currently quite abundant, such as the Pacific white-sided dolphin, or data deficient (e.g. northern bottlenose whale and Stejneger's beaked whale), but several currently threatened marine mammals were also amongst the most vulnerable, such as the North Pacific right whale and narrow-ridged finless porpoise.

(SOURCE: Albouy, C., Delattre, V., Donati, G., Frölicher, T.L., Albouy-Boyer, S., Rufino, M., Pellissier, L., Mouillot, D.F. et al. 2020. Global vulnerability of marine mammals to global warming. *Sci.Rep.* 10: 548. <https://doi.org/10.1038/s41598-019-57280-3>).

MODELLING THE EFFECTS OF INCREASING OCEAN TEMPERATURES ON CETACEAN DISTRIBUTION

Sightings and environmental data from 1991-2009 were modelled for eight cetacean species found in the California Current system. These models were then used to predict cetacean abundance and distribution in 2014, a year with unusually warm ocean temperatures (average sea surface temperature was 18.4°C, versus the average of 16.7°C over the previous period). The predicted cetacean distributions matched well with the observed distributions for that year, indicating an effective model. As water warmed, cool water species such as northern right whale dolphins, Pacific white-sided dolphins and Dall's porpoises generally shifted northward into cooler waters, or their range contracted. Warm water species such as short-beaked common and striped dolphins also moved northward as these waters warmed. In warm conditions, blue whale abundance decreased (except in offshore areas of Monterey Bay and the coast of the Southern California Bight), while fin and humpback whale abundance increased. The model accurately predicted particular humpback increases in the Monterey Bay and San Francisco area. This exercise showed that climate models can accurately predict cetacean distributions as ocean temperatures rise.

(SOURCE: Becker, E.A., Forney, K.A., Redfern, J.V., Barlow, J., Jacox, M.G., Roberts, J.J. and Palacios, D.M. 2019. Predicting cetacean abundance and distribution in a changing climate. *Divers. Distrib.* 25: 626-643).

DIRE PREDICTIONS FOR WHALE POPULATIONS WHEN CLIMATE CHANGE FACTORED INTO MODEL

A model linking whale and krill population dynamics with changes in ocean temperatures, primary productivity and sea ice coverage predicted negative impacts on whale populations and their prey species from climate change. The model predicted population declines and even extirpation for Pacific populations of blue, fin and southern right whales, and Atlantic and Indian Ocean fin and humpback whales. Whale populations that fed in mid-latitudes appeared to suffer more negative impacts by prey changes than whale populations in the Southern Ocean and southern Atlantic/Pacific. If whales could adapt their migratory routes to account for changes in Antarctic sea ice, the model predicted that some of the impacts might be mitigated for Antarctic minke and blue whales with feeding habitats associated with the ice edge. The model showed a much lower rate of population increase, post-whaling, than other population models that do not consider climate change (a third of the rate of some models). It also predicted population crashes not predicted by whale population models not factoring in climate change. In short, accounting for climate change led to more pessimistic predictions for whale population growth. Greenhouse gas emissions are currently matching scenarios with higher warming effects and there is a predicted expansion of krill fisheries. Therefore, dramatic reductions in greenhouse gas emissions, coupled with major decreases in whale mortality (e.g. from bycatch and ship strikes), may be needed to prevent extirpation of whale populations, even of those currently recovering.

(SOURCE: Tulloch, V.J.D., Plagányi, É.E., Brown, C., Richardson, A.J. and Matear, R. 2019. Future recovery of baleen whales is imperilled by climate change. *Glob. Change Biol.* 25: 1,263-1,281).

Noise impacts

SOCIAL INTERACTIONS BETWEEN HUMPBACK WHALES MORE AFFECTED BY NOISE THAN PREVIOUSLY RECOGNISED

In an examination of the responses (reduced likelihood of socially interacting) of migrating humpback whales to vessels towing seismic air gun arrays, whale groups were significantly less likely to interact in the presence of a vessel, regardless of whether or not the air guns were active. Thus, potentially detrimental behavioural changes occur at much greater ranges, and much lower received sound levels, than previously thought or are being used for current mitigation recommendations. Accordingly, while current regulations and practices are likely to prevent direct hearing impacts of seismic surveys (for a small number of individuals very close to the air guns), they do not prevent all impacts such as changes in behaviour, which affects a much larger number of whales.

(SOURCE: Dunlop, R.A., McCauley, R.D. and Noad, M.J. 2020. Ships and air guns reduce social interactions in humpback whales at greater ranges than other behavioral impacts. *Mar. Pollut. Bull.* 154: 1110721072. <https://doi.org/10.1016/j.marpolbul.2020.111072>).

AIRPLANE NOISE IDENTIFIED AS POTENTIAL THREAT TO MARINE MAMMALS

Airplane noise may be more audible underwater than commonly expected, especially when runways are built near a coast, on reclaimed land, or extend into the ocean. The coastal underwater soundscape caused by commercial passenger airplanes at two locations (Indonesia and Australia) exhibited broadband received levels of 84-132 dB re 1 μ Pa rms. The levels were similar to those of cargo and container ships transiting at ranges of 1-3 km, although the airplane noise passed much faster. Power spectral density levels of airplane noise underwater exceeded ambient levels between 12 Hz and 2 or 10 kHz by up to 36 dB. While most of the acoustic energy was below 300 Hz, other frequencies are relevant to marine mammals such as pinnipeds, sirenians, baleen whales, and odontocetes. With many of the world's airports lying close to the coast, airplane noise may affect at-risk species in small, confined habitats. In this respect the authors also point to cetaceans near Hong Kong, belugas in Cook Inlet, southern resident killer whales, western grey whales and bottlenose dolphins.

(SOURCE: Erbe, C., Williams, R., Parsons, M., Parsons, S.K., Hendrawan, I.G. and Dewantama, I.M.I. 2018. Underwater noise from airplanes: An overlooked source of ocean noise. *Mar. Pollut. Bull.* 137: 656-661. <https://doi.org/10.1016/j.marpolbul.2018.10.064>).

NOISE LEVELS ALONE DO NOT DETERMINE IMPACT ON CETACEANS

A review of 370 papers on the effects of noise on cetaceans in the wild found that the severity of the behavioural response was better explained by the sound source type (e.g. continuous, sonar, seismic/explosion) and functional hearing group (different species have different sensitivities), rather than the received level of sound that the cetacean encountered (i.e. more severe responses were not necessarily caused by higher received levels of sound). Continuous sources (such as shipping) elicited less severe behavioural responses from odontocetes with best hearing in mid-frequencies, whereas seismic or explosive sound sources elicited substantially greater behavioural responses in mysticetes with best hearing at low frequencies. Behavioural responses were reported at RL from 110 dB re 1 μ Pa, but a severe behavioural response was just as likely as a low or moderate one at this RL. The authors warn that monitoring and regulation of noise-producing activities should not be based on generic RL thresholds for multiple species. Regulations based primarily on RLs are unlikely to effectively mitigate the impacts of underwater noise. Accordingly, the absence of a behavioural response to a sound source does not necessarily mean there was no impact, and a severe behavioural response does not necessarily mean a severe population-level impact. Finally, the authors suggest that monitoring the impact of noise upon cetaceans should be based on variables associated with biologically important behaviours - such as foraging, socialising, reproduction and/or survival - rather than simply degree of behavioural response.

(SOURCE: Gomez, C., Lawson, J.W., Wright, A.J., Buren, A.D., Tollit, D. and Lesage, V. 2016. A systematic review on the behavioural responses of wild marine mammals to noise: the disparity between science and policy. *Can. J. Zool.* 94: 801-819).

RESPONSE OF BEAKED WHALES TO MILITARY SONAR

Seven tagged Blainville's beaked whales were monitored for their response to exposure to mid-frequency naval sonar (at 3-8 kHz) in the Bahamas. Five of the seven whales were displaced from 28 to 68km by this exposure, returning 2 to 4 days after the sonar-using exercise had ended. The RL of sound was initially 145-172 dB re 1 μ Pa, dropping to 70-150 dB re 1 μ Pa after the whales moved away. Although the whales took dives that were assumed to be for foraging, the length of these dives was reduced by the sonar exposure. These 'lost' foraging dives may translate to a loss of energy for the whales, which should be considered, in addition to the displacement from habitat, in terms of population-level impacts.

(SOURCE: Joyce, T.W., Durban, J.W., Claridge, D.E., Dunn, C.A., Hickmott, L.S., Fearnbach, H., Dolan, K. and Moretti, D. 2020. Behavioral responses of satellite tracked Blainville's beaked whales (*Mesoplodon densirostris*) to mid-frequency active sonar. *Mar. Mamm. Sci.* 36: 29-46).

HARBOUR PORPOISES SHOW SIGNIFICANT BEHAVIOURAL CHANGES WHEN EXPOSED TO NAVAL SONAR

Two harbour porpoises were exposed to mid-frequency naval sonar in a 12x8x2 m pool with background ambient noise equivalent to Beaufort 6 weather conditions. At a source SPL of 117 dB re 1 μ Pa, there was no noticeable response; however, both porpoises demonstrated a significant change in behaviour (i.e. surfacing rates) at 122 dB re 1 μ Pa. The decibel scale is logarithmic, meaning the latter SPL is multiple times louder.

(SOURCE: Kastelein, R.A., Ainslie, M.A. and van Kester, R. 2019. Behavioral responses of harbor porpoises (*Phocoena phocoena*) to U.S. Navy 53C sonar signals in noise. *Aquat. Mamm.* 45: 359-366).

MASS STRANDINGS OF BEAKED WHALES DURING NAVAL SONAR EXERCISES IN THE MARIANAS ISLANDS

Two Cuvier's beaked whales stranded on the northern Marianas Islands (western Pacific) on 22-23 August 2011, after mid-frequency active sonar was detected from hydrophones. Subsequently, patterns of beaked whales stranding were compared to naval exercises. Between June 2006 and January 2019, eight stranding events (with 1-3 animals) occurred, with half happening within six days of a US naval exercise (a statistically significant relationship). The authors note that due to the difficulties of observing beaked whales at sea, passive acoustic monitoring for beaked whales is especially important as a mitigation measure.

(SOURCE: Simonis, A.E., Brownell Jr, R.L., Thayre, B.J., Trickey, J.S., Oleson, E.M., Huntington, R. and Baumann-Pickering, S. 2020. Co-occurrence of beaked whale strandings and naval sonar in the Mariana Islands, Western Pacific. *Proc. Roy. Soc. B* 287: 20200070 (1-10).

RESPONSES OF BLUE WHALES TO MILITARY SONAR EXPOSURE

The behavioural responses of 42 tagged blue whales when exposed to mid-frequency active sonar (3-8 kHz; maximum SL 210 dB re 1 μ Pa @ 1m) was recorded off the California coast. The animals included both shallow feeding (<30m; n=7) and deep water feeding whales (>50m; n=21), as well as non-feeding whales (n=5). Observers subjectively graded responses to sonar exposure on a severity scale of 0 to 9. More than 50% of the deep feeding blue whales responded to the sonar exposure (scores ranging from 3-7 at RLs of 97-155 dB re 1 μ Pa²), but no responses were observed in shallow feeding whales. Two of the non-feeding whales scored a 7 in their response at RLs of 108-123 dB re 1 μ Pa². The authors conclude that '[w]ith increased energetic demands and needs for high-density prey, even the cessation of feeding for a short time could have consequences for the fitness of these large animals...If [these consequences] are chronic, they could manifest as population level effects'.

(SOURCE: Southall, B.L., DeRuiter, S.L., Friedlaender, A., Stimpert, A.K., Goldbogen, J.A., Hazen, E., Casey, C., Fregosi, S. et al. 2019. Behavioral responses of individual blue whales (*Balaenoptera musculus*) to mid-frequency military sonar. *J. Exp. Biol.* 222: jeb190637, 1-15. <https://doi.org/10.1242/jeb.190637>).

PASSING SHIP CAUSED HUMPBACK WHALES TO STOP SINGING

Humpback whales ceased singing when a twin propeller passenger-cargo liner (57x12m; 453 tons), producing noise at a SL of 157 dB rms re 1 μ Pa at 54 Hz, approached and passed by. The primary vocal frequency range of the humpback whales in this study was 100-800 Hz. One whale ceased singing when the ship was approaching and 235m away, whereas other whales stopped singing when the boat had passed the whales, and was at a distance of 500-1,200m. The estimated RL of shipping sound at the whales that ceased singing was 95-105 dB rms re 1 μ Pa. Nine of 12 whales stopped singing and did not restart singing until at least 30 minutes after the liner had passed by the test area (and was approximately 17-20km away).

(SOURCE: Tsujii, K., Akamatsu, T., Okamoto, R., Mori, K., Mitani, Y. and Umeda, N. 2018. Change in singing behavior of humpback whales caused by shipping noise. *PLoS ONE* 13: e0204112).

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Appendix 1

GLOSSARY

Glossary of terms

- ADD:** Acoustic deterrent device, typically used to keep predators away from mariculture facilities.
- AIS:** Automatic identification system, for logging the location of ships.
- Bioaccumulation:** Increase in concentration of a pollutant within an organism compared to background levels in its diet. Pollutant levels are highest in older individuals.
- Biomagnification:** Increase in concentration of a contaminant from one link in a food chain to another. Pollutant levels are highest in top predators.
- BMAA:** β -methylamino-L-alanine, a neurotoxin associated with some harmful algal blooms.
- Brucella:** Various species of bacteria that cause the disease brucellosis.
- Chlordecone (also known as Kepone or CLD):** An organochlorine insecticide once used worldwide to control banana weevil infestations in banana plantations.
- dB:** Decibel - a logarithmic measure of sound pressure level.
- DDT:** The organochlorine pesticide dichlorodiphenyltrichloroethane, which tends to accumulate in the ecosystem and in the blubber and certain internal organs of cetaceans.
- Dec-604 CB:** Dechlorane 604 Component B, a halogenated flame retardant.
- Demersal:** Living in the water body just above the sea floor (see also pelagic).
- Ecosystem services:** The many and varied direct and indirect benefits to human well-being provided by the natural environment and its inhabitants.
- Edwardsiella tarda:** Anaerobic bacterium that causes the disease Edwardsiella septicaemia in marine animals.
- Emboli:** Plural of embolus, a clot (of blood or other material) in a blood vessel leading to circulation blockage.
- Endocrine disruption:** When an outside substance (chemical) interferes with an organism's endocrine system, a system of ductless glands producing hormones that control and moderate metabolic processes in the body.
- Esr β :** Estrogen [oestrogen] receptor B gene.
- Eutrophication:** Input of nutrients into an aquatic system, typically associated with excessive plant growth and oxygen depletion.
- Fecundity:** The potential reproductive capacity of an organism or population.
- Glucocorticoid:** A type of natural, corticosteroid hormone that is very effective at reducing inflammation and suppressing the immune system.
- ha:** Hectare.
- HBB:** Hexabromobenzene, a halogenated flame retardant.

Hz: Hertz, a measure of sound frequency (pitch), in wave cycles per second (kHz=1,000 Hz).

HFRs: Halogenated flame retardants.

Immunotoxic: Toxic to the immune system of an organism.

In vitro: Latin for 'in glass', meaning outside a living organism/in a laboratory.

IUCN: International Union for Conservation of Nature.

Km*h: Kilometres of fishing net multiplied by hours of soak time

µg: Microgram, one thousandths of a gram.

µPa: Micropascal, a unit of pressure.

Microplastics: Plastic particles 0.3-5mm in diameter, often the result of larger plastic pieces breaking down over time.

MPA: Marine protected area.

ng: Nanogram, one billionth of a gram.

nm: Nanometre, one billionth of a metre.

Nr3c1: Nuclear receptor subfamily 3 group C member 1, a glucocorticoid receptor gene.

OC: Organochlorine compound.

OSPAR: Convention for the Protection of the Marine Environment of the North-East Atlantic.

PBB: Polybrominated biphenyl.

PBDE: Polybrominated diphenyl ether.

PCB: Polychlorinated biphenyl.

PCR: Polymerase chain reaction, a method for making many copies of small sections of genetic material.

Pelagic: Living in the open water (see also demersal).

Phenology: The study of cyclic and seasonal natural phenomena, especially in relation to climate and plant and animal life.

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

Proteus mirabilis: Anaerobic bacterium that causes urinary tract infections.

RL: Received level of a sound.

rms: Root-mean-square, a measurement of sound pressure.

Septicaemia: Fatal blood poisoning.

SL: Source level of a sound.

SPL: Sound pressure level.

Stockholm Convention: International environmental convention on Persistent Organic Pollutants, signed in 2001 and effective from May 2004, designed to help eliminate or restrict the production and use of persistent organic pollutants.

THg: Total mercury.

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

Transcript: In the context of genetics, a transcript is the first product of gene expression, usually a strand of RNA made from a strand of DNA.

Water column: A conceptual column of water extending from the sea surface down to the seafloor.

Species glossary

| | |
|---------------------------------|--|
| Amazon River dolphin or boto | <i>Inia geoffrensis</i> |
| Antarctic minke whale | <i>Balaenoptera bonaerensis</i> |
| Atlantic humpback dolphin | <i>Souza teuszii</i> |
| Atlantic white-sided dolphin | <i>Lagenorhynchus acutus</i> |
| Beluga whale | <i>Delphinapterus leucas</i> |
| Blainville's beaked whale | <i>Mesoplodon densirostris</i> |
| Blue whale | <i>Balaenoptera musculus</i> |
| Bowhead whale | <i>Balaena mysticetus</i> |
| Bryde's whale (Gulf of Mexico) | <i>Balaenoptera edeni</i> |
| Common bottlenose dolphin | <i>Tursiops truncatus</i> |
| Common dolphin (short-beaked) | <i>Delphinus delphis</i> |
| Common minke whale | <i>Balaenoptera acutorostrata</i> |
| Cuvier's beaked whale | <i>Ziphius cavirostris</i> |
| Dall's porpoise | <i>Phocoenoides dalli</i> |
| Fin whale | <i>Balaenoptera physalus</i> |
| False killer whale | <i>Pseudorca crassidens</i> |
| Franciscana | <i>Pontoporia blainvillei</i> |
| Fraser's dolphin | <i>Lagenodelphis hosei</i> |
| Grey whale | <i>Eschrichtius robustus</i> |
| Guiana dolphin or costero | <i>Sotalia guianensis</i> |
| Harbour porpoise | <i>Phocoena phocoena</i> |
| Humpback whale | <i>Megaptera novaeangliae</i> |
| Indo-Pacific bottlenose dolphin | <i>Tursiops aduncus</i> |
| Irrawaddy dolphin | <i>Orcaella brevirostris</i> |
| Killer whale | <i>Orcinus orca</i> |
| Melon-headed whale | <i>Peponocephala electra</i> |
| Narrow-ridged finless porpoise | <i>Neophocaena asiaeorientalis</i> |
| North Atlantic right whale | <i>Eubalaena glacialis</i> |
| North Pacific right whale | <i>Eubalaena japonica</i> |
| Northern bottlenose whale | <i>Hyperoodon ampullatus</i> |
| Northern right whale dolphin | <i>Lissodelphis borealis</i> |
| Pacific white-sided dolphin | <i>Lagenorhynchus obliquidens</i> |
| Pantropical spotted dolphin | <i>Stenella attenuata</i> |
| Pygmy killer whale | <i>Feresa attenuata</i> |
| Pygmy sperm whale | <i>Kogia breviceps</i> |
| Rough-toothed dolphin | <i>Steno bredanensis</i> |
| Sei whale | <i>Balaenoptera borealis</i> |
| Short-finned pilot whale | <i>Globicephala macrorhynchus</i> |
| Southern right whale | <i>Eubalaena australis</i> |
| Sperm whale | <i>Physeter macrocephalus</i> |
| Spinner dolphin | <i>Stenella longirostris</i> |
| Stejneger's beaked whale | <i>Mesoplodon stejnegeri</i> |
| Striped dolphin | <i>Stenella coeruleoalba</i> |
| Tucuxi | <i>Sotalia fluviatilis</i> |
| Yangtze finless porpoise | <i>Neophocaena asiaeorientalis asiaeorientalis</i> |
| Yangtze river dolphin | <i>Lipotes vexillifer</i> |
| | |
| Anchovy | Family <i>Engraulidae</i> |
| Atlantic salmon | <i>Salmo salar</i> |
| Capelin | <i>Malotus villosus</i> |
| Hake (European) | <i>Merluccius</i> spp. |
| Herring | <i>Clupea haerengus</i> |
| Mackerels, tunas, bonitos | Family <i>Scombridae</i> |
| Sand eel | <i>Ammodytes</i> spp. |
| Sea bass (European) | <i>Dicentrarchus</i> spp. |
| Krill | Family <i>Euphausiidae</i> (euphausiids) |
| | |
| <i>Heavy metals</i> | |
| Ag | Silver |
| Hg | Mercury |
| Pb | Lead |
| Se | Selenium |