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State of the Cetacean Environment Report (SOCER) 2022

Editors: M. Stachowitsch, N.A. Rose and E.C.M. Parsons

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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 2022 SOCER features the **Arctic and Antarctic Oceans**, summarising key papers and articles published from ca. 2020 through 2022 to date. This year's regional SOCER represents the third year of the current cycle, which will be combined in a second 5-year compendium (2020: Atlantic Ocean through 2024: Mediterranean and Black Seas; see first 5-year compendium at *https://iwc.int/socer-report*) to present to the Commissioners at IWC/70.

ARCTIC AND ANTARCTIC OCEANS

General

Most Recent Ocean Health Index Includes Arctic Countries But Omits Antarctic Region

The OHI provides quantitative assessments of progress towards healthy and sustainable oceans on a scale from 0–100. It is based on 10 goals encompassing current status, trend, external pressures and resilience measures. The average score of the 2020 OHI was 72 out of 100. The Index is currently available for 220 regions (coastal nations and territories). Although the average OHI scores have not dramatically changed over eight years, some individual goals and regions have changed significantly. The Arctic is not listed separately, but based on the OHI's country/territory approach, certain countries bordering Arctic waters are at or above the average global value (Greenland 86, Norway 83, Finland 79, Iceland 78, Canada, 76, Russia 71). Antarctica, although listed, is evaluated throughout with 'NA', meaning that many of the OHI goals do not apply to Antarctica and that it has therefore been excluded in recent assessments. Longo *et al.* (2017) provided the most recent OHI-based assessment of the Southern Ocean.

(SOURCES: Anonymous. Ocean Health Index. 2020, http://ohi-science.org/ohi-global/scores.html; Longo, C.S., Frazier, M., Doney, S.C., Rheuban, J.E., Humberstone, J.M. and Halpern, B.S. 2017. Using the Ocean Health Index to identify opportunities and challenges to improving Southern Ocean ecosystem health. Front. Mar. Sci. 4: 20, https://doi.org/10.3389/fmars.2017.00020)

Cetacean Distribution Shifting in the Arctic

Spatial trends were examined in Svalbard for three Arctic endemic cetacean species (white whales, narwhals and bowhead whales), sperm whales, white-beaked dolphins and four summer-resident baleen whales (blue whales, fin whales, humpback whales and common minke whales). The authors compared earlier (2005–2019) and more recent periods (2015–2019) to identify potential shifts in distribution in this area, which is experiencing rapid warming and concomitant sea-ice losses. The summer residents shifted their distributions from the continental shelf break west of Spitsbergen during the earlier period into fjords and coastal areas during the recent period. These changes coincided

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with increased inflows of warmer, nutrient- and plankton-rich Atlantic Water into the fjords and troughs around this high-Arctic archipelago. Two of the three Arctic endemic species increased in number north of Svalbard and decreased in coastal areas and fjords, reflecting the retreating sea-ice edge, with which they are associated. There was also an increase in the number of Atlantic species, which may indicate an uncertain future for endemic Arctic species.

(SOURCE: Bengtsson, O., Lydersen, C. and Kovacs, K.M. 2022. Cetacean spatial trends from 2005 to 2019 in Svalbard, Norway. Polar Res. 41: 7773, https://doi.org/10.33265/polar.v41.7773)

WHITE WHALES IN ST LAWRENCE ESTUARY SUBJECT TO MULTIPLE STRESSORS

Endangered St Lawrence Estuary white whales have failed to recover from overharvest (population size reduction by ~ 90% by 1979), despite combined management measures. This has been attributed to the sub-lethal effects of noise, toxic contaminants and prey reduction (with rare lethal ship strikes and entanglement in fishing gear). Chion *et al.* (2021) used a model to simulate the effect of vessel underwater noise. They concluded that the projected ship traffic increase in the Saguenay River will negate the role of this river as a quiet zone or acoustic refuge in critical habitat for females and calves. Williams *et al.* (2021) conducted a population viability analysis and concluded that the predicted effects of climate change could determine the future of this population more than other threats. This "population is unlikely to recover to pre-exploitation levels or meet interim recovery targets, even under our most optimistic scenarios, because the reproductive capacity has been reduced both by sublethal threats and by climate changes since cessation of harvest". This population is thus a case study for the cumulative effects of multiple stressors, as well as for polar species at the southernmost limits of their distribution, where climate change exacerbates the mix of other threats. Finally, Ménard *et al*. (2022) reported on an effort to mitigate acoustic disturbance of these whales based on using different marine spatial planning-based approaches in the Saguenay-St Lawrence Marine Park. These approaches included preserving the area as an acoustic refuge by not diverting ship traffic into an already quiet sector of critical habitat and restricting the growth of commercial whale watching activities.

*(SOURCES: Chion, C., Bonnell, T.R., Lagrois, D., Michaud, R., Lesage, V., Dupuch, A., McQuinn, I.H. and Turgeon, S. 2021. Agent-based modelling reveals a disproportionate exposure of females and calves to a local increase in shipping and associated noise in an endangered beluga population. Mar. Pollut. Bull. 173: 112977, https://doi.org/10.1016/j.marpolbul.2021.112977; Williams, R., Lacy, R.C., Ashe, E., Hall, A., Plourde, S. McQuinn, I.H. and Lesage, V. 2021. Climate change complicates efforts to ensure survival and recovery of St. Lawrence Estuary beluga. Mar. Pollut. Bull. 173: 113096, https://doi.org/10.1016/j.marpolbul.2021.113096; Ménard, N., Turgeon, S., Conversano, M. and Martins, C.C.A. 2022. Sharing the waters: Application of a marine spatial planning approach to conserve and restore the acoustic habitat of endangered beluga whales (*Delphinapterus leucas*) in and around the Saguenay-St. Lawrence Marine Park. Mar. Pollut. Bull. 175: 113325, https://doi.org/10.1016/marpolbul.2022.113325)*

MOST ANTARCTIC BIOTAS ARE EXPOSED TO MULTIPLE STRESSORS AND CONSIDERED VULNERABLE TO ENVIRONMENTAL CHANGE

A literature survey by 26 international experts provided 10 key messages regarding the impact of environmental change on biological processes in the Antarctic. Life in the Southern Ocean and Antarctica is highly sensitive to environmental changes, and these experts concluded that climate change was the greatest anthropogenic threat. In contrast, the IPBES Global Assessment considered exploitation to present the greatest risk to global marine and terrestrial ecosystems. This difference reflects the currently low economic importance of exploitable Antarctic resources. Pollution in Antarctic habitats has recently attracted particular attention, especially microplastics. Antarctic concerns include multiple stressors, biotas vulnerable to environmental change due to narrow tolerance ranges, rapid change, projected circumpolar impacts, low potential for timely genetic adaptation and migration barriers. The authors noted that the Southern Ocean makes a remarkable contribution to global biodiversity and ecosystem services and that conservation strategies should consider Antarctic biotas and their functioning to be more connected to the rest of the world than previously understood.

(SOURCE: Gutt, J., Isla, E., Xavier. J.C., Adams, B.J., Ahn, I.-Y., Cheng, C.-H.C., Colesic, C., Cummings, V.J. et al. 2021. Antarctic ecosystems in transition—life between stresses and opportunities. Biol. Rev. 96: 798–821, https://doi.org/10.1111/brv.12679)

KRILL AS A FOUNDATION OF THE SOUTHERN OCEAN FOOD CHAIN IN THE FRAMEWORK OF ECOSYSTEM-BASED MANAGEMENT

Krill is a key dietary item for whales, seals, seabirds and fish. Its biomass is the largest of any multicellular species of wildlife on the planet. Seventy percent of the krill population inhabits the Southwest Atlantic sector of the Southern Ocean and is the target of a valuable commercial fishery managed by CCAMLR. Based on the restricted distribution of successfully spawning krill and the high inter-annual variability in its biomass, Meyer *et al*. (2020) argued that the risk of direct fishery impacts might be higher than previously thought. They contended that improved knowledge and remaining mindful of uncertainties about krill ecology would benefit management decisions by enabling improved models to be used in a more holistic approach to ecosystem change. This would promote the overall goal of conservation of the Antarctic ecosystem as a whole. One such ecosystem model (Karakuş *et al*. [2021]) incorporated krill as large zooplankton. The model's results showed that these crustaceans and their metabolic products actually support a stable phytoplankton population and that this has implications for the transfer of carbon to the deep ocean. A projected decline of krill or a shift to a salp-dominated ecosystem could weaken this role.

(SOURCES: Meyer, B., Atkinson,A., Bernard, K.S., Brierley, A.S., Driscoll, R., Hill, S.L., Marschoff, E., Maschette, D., Perry, F.A., Reiss, C.S., Rombolá, E., Tarling, G.A., Thorpe, S.E., Trathan, P.N., Guoping, Z. and Kawaguchi, S. 2020. Successful ecosystem-based management of Antarctic krill should address uncertainties in krill recruitment, behaviour and ecological adaptation. Commun. Earth Environ. 1: 28, https://doi.org/10.1038/s43247-020-00026-1; Karakuş, O., Völker, C., Iversen, M., Hagen, W., Wolf-Gladrow, D., Fach, B. and Hauck, J. 2021. Modeling the impact of macrozooplankton on carbon export production in the Southern Ocean. J. Geophys. Res-Oceans 126 e2021JC017315, https://doi.org/10.1029/2021JC017315)

AQUATIC CRITICAL ZONES: FJORDS ARE PARTICULARLY SENSITIVE TO THREATS

Fjords, many in subarctic and Arctic regions and frequented by cetaceans, have been classified as Aquatic Critical Zones (ACZs). This reflects their "high vulnerability to anthropogenic pressure and increasing evidence of Holocene climate fluctuations". The authors predicted shipping to increase considerably in the Arctic Ocean and subarctic, a reflection of climate change and declining sea ice cover. This increase would be associated with higher levels of vessel-related contaminants, including antifouling paints, metals and airborne articles (PAHs), as well as pharmaceuticals and sanitary wastes (e.g. PPCPs). The authors also predicted shipping accidents to increase. They called for intensified monitoring and research, e.g. into whether the toxicity of pollutants might be different in cold-water organisms or in species that have previously hardly encountered pollution, focusing particularly on emerging pollutants of concern. Additional threats to these ACZs include considerably expanding mariculture and waste disposal, including suggestions to use deep anoxic fjord basins as dumping grounds for fresh forestry waste to help reduce the quantity of CO_2 released to the atmosphere. Glaciated high-latitude fjords are the 'canary in the coalmine', i.e. particularly vulnerable to climate change because the rate of warming is three times faster in the Arctic than the global average. The authors concluded by stating that "Climate change affecting rainfall and river discharge into fjords will impact the thickness and extent of the low-salinity layer in the upper reaches of the fjord, slowing the rate of the overturning circulation and deep-water renewal—thereby impacting bottom water oxygen concentrations".

(SOURCE: Svavarsson, J., Guls, H.D., Sham, R.C., Leung, K.M.Y. and Halldórsson, H.P. 2021. Pollutants from shipping—new environmental challenges in the subarctic and the Arctic Ocean. Mar. Pollut. Bull. 164: 112004, https://doi.org/10.1016/j.marpolbul.2021.112004)

Habitat degradation

General

INCREASING CARBON DIOXIDE, TRACE ELEMENT AND NUTRIENT LEVELS IN ARCTIC OCEAN WATERS

Due to melting Arctic sea ice, more ocean surface water is being exposed to the atmosphere, which in turn leads to greater absorption of carbon dioxide in polar waters (Ouyang *et al.* 2020). As the uptake of carbon dioxide is actually greater in colder water, this has elevated the rates of carbon dioxide uptake in the region. Some of this increased carbon uptake may lead to increase biological productivity in some areas; however, it may also lead to an increase in ocean acidification in the Arctic environment. Melting sea ice also increases the levels of freshwater runoff (Charette *et al.* 2020), bringing higher levels of trace elements into Arctic waters. Because this runoff is bound to organic matter from the land surface and rivers, it is allowing carbon and trace elements to be transported over 1000 km from their source into the central Arctic Ocean. Some of these trace elements, such as Fe, are a limiting nutrient in the ocean, and elevated levels lead to an increase in ocean productivity and algal growth. However, some trace elements, such as Hg, are toxic to marine ecosystems. In addition, as permafrost melts, the flow of water will change, from melting ice at the surface flowing into the oceans to a groundwater-dominated system (Rawlins *et al.* 2019). Deeper water will flow through newly thawed soils, bringing more nutrients to coastal waters and altering food webs and ecosystems. These increases in carbon, acidification and trace elements could have major impacts on Arctic ecosystems.

(SOURCES: Ouyang, Z., Qi, D., Chen, L., Takahashi, T., Zhong, W., DeGrandpre, M.P., Chen, B., Gao, Z., Nishino, S., Murata, A., Sun, H., Robbins, L.L., Jin, M. and Cai, W.-J. 2020. Sea-ice loss amplifies summertime decadal CO_2 increase in the western Arctic Ocean. Nat. Clim. Change 10: 678–684, https://doi.org/10.1038/s41558-020-0784-2; Charette, M.A., Kipp, L.E., Jensen, L.T. et al. 2020. The transpolar drift as a source of riverine and shelf-derived trace elements to the central Arctic Ocean. J. Geophys. Res-Oceans 125: e2019JC015920, https://doi.org/10.1029/2019JC015920; Rawlins, M.A., Cai, L., Stuefer, S.L. and Nicolsk, D. 2019. Changing characteristics of runoff and freshwater export from watersheds draining northern Alaska. Cryosphere 13: 3337–3352, https://doi.org/10.5194/tc-13-3337-2019)

Fisheries interactions

FISHERIES INTERACTIONS WITH ALASKAN KILLER WHALES

Between 2001 and 2016, Alaskan fisheries observer records were examined for instances of killer whale injuries and mortalities associated with fishing operations. The highest number of incidents occurred in the southeast Bering Sea and most incidents were when killer whales fed on caught fish or discarded catches, or fishermen used whale deterrent measures (96% of 3245 interactions). Longline fisheries accounted for 87% of incidents. A total of 27 mortalities were reported (3 of which were mammal eaters and the rest fish eaters), but the actual number was assumed to be higher. At least 12 animals were entangled and/or killed in fishing gear and 9 were killed by propeller injuries. This level of mortality could have major impacts on relatively small killer whale populations.

*(SOURCE: Dahlheim, M.E., Cahalan, J. and Breiwick, J.M. 2022. Interactions, injuries, and mortalities of killer whales (*Orcinus orca*) observed during fishing operations in Alaska. Fish. Bull. 120: 79–94)*

Marine Debris

IS A PREDICTED FUTURE INCREASE IN PLASTIC INGESTION BY SEABIRDS ALSO VALID FOR CETACEANS?

In the Canadian Arctic, 72% of northern fulmars and 15% of black-legged kittiwakes ingested plastics (two other seabird species did not). The authors concluded that, with increased shipping activities and as climate change releases plastics frozen in sea ice, "seabirds may be increasingly susceptible to plastic ingestion in the Arctic". The ingestion threat posed by plastics introduced by these two mechanisms would no doubt be equally applicable to cetaceans.

(SOURCE: Baak, J.E., Provencher, J.F. and Mallory, M.L. 2020. Plastic ingestion by four seabird species in the Canadian Arctic: Comparisons across species and time. Mar. Pollut. Bull. 158: 112386, https://doi.org/10.1016/j.marpolbul.2021.111386)

LOW LEVELS OF SEABED LITTER IN THE SIBERIAN ARCTIC STEM MOSTLY FROM THE FISHING INDUSTRY

In the first study of its kind in this region, 174 bottom trawl hauls in the Chukchi, East Siberian, Laptev and Kara Seas yielded seabed litter only in the Chukchi and Kara Seas, with the values being highest in the latter. Plastic was the most common type of debris. The main source was fisheries related (e.g. net pieces, rope fragments), followed by solid municipal wastes (e.g. textiles, wrappings, packaging). Navigation on this Northern Sea Route is limited by time of year, but the amount of cargo transported is expected to double between 2024 and 2035. Much of the litter that enters the Kara Sea is from fishing fleets in the Barents Sea, with long-range transport via currents and, to some degree, by ice. The geography is such that large amounts of garbage accumulate on beaches. Four species of cetaceans occur regularly in the Kara Sea, with three more as vagrants in the ice-free season. Such studies are important because much of the marine debris in the oceans is thought to ultimately sink to the sea floor and thus escape detection.

(SOURCES: Benzik, A.N., Orlov, A.M. and Novikov, M.A. 2021. Marine seabed litter in Siberian Arctic: A first attempt to assess. Mar. Pollut. Bull. 172: 112836, https://doi.org/10.1016/j.marpolbul.2021.112836; https://www.pame.is/images/03_Projects/EA/LMEs/Factsheets/6_Kara_Sea_LME.pdf)

MICROPLASTICS IN ARCTIC FJORD PROBABLY TRANSPORTED LONG-RANGE BY WEST SPITSBERGEN CURRENT

The abundance of microplastics in the sediments of two fjords in Svalbard was high, 721 and 783 pieces/kg, respectively. Polyethylene and polypropylene were the most common polymers and fibres the most common shape. The Krossfjord-Kongsfjord system is thus heavily polluted by microplastics, despite its low population density and remote location. The authors identified long-range transport by the west Spitsbergen current, sea ice, glacial melt and atmospheric transport by wind as possible sources of these microplastics. Moreover, the contribution of local sources such as wastewater effluents, packaging material and fishing gear is increasing, because anthropogenic activities have expanded in recent years due to a reduction in sea ice.

(SOURCE: Choudhary, S., Neelavanan, K. and Saalim, S.M. 2022. Microplastics in the surface sediments of Krossfjord-Kongsfjord system, Svalbard, Arctic. Mar. Pollut. Bull. 176: 113452, https://doi.org/10.1016/j.marpolbul.2022.113452)

ANTARCTIC SPECIALLY PROTECTED AREA STATUS INSUFFICIENT TO PREVENT ANTHROPOGENIC DEBRIS

Antarctica is typically considered to be one of the most pristine environments on Earth. Nevertheless, even the highest form of environmental protection here—the status as an Antarctic Specially Protected Area—is insufficient to ensure protection from anthropogenic debris. A study on Nelson Island, South Shetland Islands, revealed a wide range of debris from local terrestrial sources and marine transportation. The authors outlined the threats that this poses to wildlife and stated "an international treaty for the conservation and sustainable use of the high seas could decrease the release of debris in these remote areas by enforcing the already existing regulations (e.g. MARPOL 73/78 Annex V)".

(SOURCE: Grohman Finger, J.V., Corá, D.H., Covey, P., Santa Cruz, F., Petry, M.V. and Krüger, L. 2021. Anthropogenic debris in an Antarctic Specially protected Area in the maritime Antarctic. Mar. Pollut. Bull. 172: 112921, https://doi.org/10.1016/j.marpolbul.2021.112921)

ANTARCTIC SEA ICE IS A RESERVOIR FOR MICROPLASTIC DEBRIS

A core taken in coastal land-fast sea ice in the East Antarctic yielded ca. 12 microplastic particles/litre. The most common polymers were polyethylene, polypropylene and polyamide, corresponding to most studies on marine microplastics. Based on the literature and polymer composition, the authors considered that one source is fishing debris. They also noted that "western Antarctica may experience higher levels of [microplastics] pollution due to the presence of more scientific research stations, heavier marine traffic and the majority of Antarctic tourism operations". Importantly, the authors concluded that sea ice serves as a potential reservoir for microplastics debris, which "may have consequences for Southern Ocean food webs".

(SOURCE: Kelly, A., Lannuzel, D., Rodemann, T., Meiners, K.M. and Auman, H.J. 2020. Microplastic contamination in east Antarctic sea ice. Mar. Pollut. Bull. 154: 111130, https://doi.org/10.1016/j.marpolbul.2020.111130)

POTENTIAL COMBINED EFFECTS OF NANOPLASTICS, THE SMALLEST MARINE DEBRIS, AND OCEAN ACIDIFICATION

Marine debris is ubiquitous in the world's oceans. Although not yet documented in the Southern Ocean, the smallest category, nanoplastics, is expected to be as pervasive as the larger categories. For example, Arctic krill can fragment microplastics down to nanoplastic size. In a laboratory study, polystyrene nanoparticles compromised the ability of sub-Antarctic pteropods to counteract the stress of ocean acidification, which hampers shell formation and thus survival. Nanoplankton on and in both pteropods and krill can potentially pose a threat because pteropods are an important link between phytoplankton and higher trophic levels, including whales. This is a good example of the potential combined effects of more than one stressor or threat. The authors highlighted the importance of studying plastic pollution in the context of climate change.

(SOURCE: Manno, C., Peck, L.V., Corsi, I. and Bergami, E.L. 2022. Under pressure: Nanoplastics as a further stressor for sub-Antarctic pteropods already tackling ocean acidification. Mar. Pollut. Bull. 174: 113176, https://doi.org/10.1016/j.marpolbul.2021.113176)

MARINE DEBRIS IN ARCTIC SEAS ORIGINATES PRIMARILY IN THE ATLANTIC

Pogojeva *et al.* (2021) found that the average density of large items of marine debris floating on the surface of Russian Arctic seas was a comparatively low 0.92 items/km². The eastern part of the study area—the Kara, Laptev and East Siberian seas—was practically free of such litter. The authors believed North Atlantic surface water, which flows along the Norwegian coastline and enters through the Norwegian and Barents seas, to be primarily responsible for introducing floating plastic litter to the study area, with little input from Siberian rivers, at least during the autumn study period. These results serve as a baseline and can help to prioritise efforts to manage Arctic marine litter. Hänninen *et al.* (2021) also reported relatively small amounts of plastic debris in the Arctic Ocean. The mean particle size was 2.7 mm; the most abundant polymer was polyethylene. Although the drifting times of particles could not be determined, long-range drifting was likely. Accordingly, the Atlantic Ocean, via the Fram Strait, was again the main source of marine debris in the Arctic Ocean. The authors discussed the Greenland gyre and a potential accumulation somewhere, "whether in surface waters, the water column, the sea ice, in deep-sea sediments or in the biota".

(SOURCES: Pogojeva, M., Zhdanov, I., Berezina, A., Lapenkov, A., Kosmatch, D., Osadchiev, A., Hanke, G., Semiletov, I. and Yakushev, E. 2021. Distribution of floating marine macro-litter in relation to oceanographic characteristics in the Russian Arctic Seas. Mar. Pollut. Bull. 166: 112201, https://doi.org/10.1016/j.marpolbul.2021.112201; Hänninen, J., Weckström, M., Pawlowska, J., Szymanska, N., Uurasjärvi, E., Zajaczkowski, M., Hartikainen, S. and Vuoinen, I. 2021. Plastic debris composition and concentration on the Arctic Ocean, the North Sea and the Baltic Sea. Mar. Pollut. Bull. 166: 112150, https://doi.org/10.1016/j.j.marpolbul.2021.112150)

MICROPLASTICS POLLUTION VERY HIGH IN THE ARCTIC REGION

Despite its remoteness, the Arctic region has amongst the highest microplastics concentrations worldwide. Based on sampling at four depths (near-surface, ∼300 m, ∼1000 m, above seafloor), Tekman *et al.* (2020) reported water column values between 0 and 1287 items/m^3 and sediment values from 239 to 13,331 items/kg. Polyamide (39%) and ethylene-propylene-diene rubber (23%) were the most abundant polymers within the water column, while polyethylene-chlorinated (31%) was most abundant in the sediments. The authors concluded that biological processes in the water interact with microplastics and found support for the hypotheses that "the Arctic is an accumulation area for [microplastics] particles transported (i) from the North Atlantic via the thermohaline circulation, ii) from the north of the Fram Strait entrained in sea ice and released during melting, (iii) from the Barents Sea, (iv) via local emissions from increasing shipping activities, (v) from different directions through the atmosphere and precipitation, and (vi) from the discharge of rivers". In a later review, Bergmann *et al.* (2022) noted that, even if plastics emissions were halted today, fragmentation of legacy plastics would lead to an increasing microplastics burden in Arctic ecosystems.

(SOURCE: Tekman, M.B., Wekerle, C., Lorenz, C., Primpke, S., Hasemann, C., Gerdts, G. and Bergmann, M. 2020. Tying up loose ends of microplastic pollution in the Arctic: Distribution from the sea surface through the water column to deep-sea sediments at the HAUSGARTEN Observatory. Environ. Sci. Technol. 54: 4079–4090, https://doi.org/10.1021/acs.est.9b06981; Bergmann, M., Collard, F., Fabres, J. Gabrielsen, G.W., Provencher, J.F., Rochman, C.M., van Sebille, E. and Tekman, M.B. 2022. Plastic pollution in the Arctic. Nat. Rev. Earth Environ., https://doi.org/10.1038/s43017-022-00279-8)

MARINE DEBRIS ON THE SHORES OF NOVAYA ZEMLYA, BARENTS SEA

The density of beach litter on four shores of an uninhabited island of the Novaya Zemlya archipelago (Russian Federation) was 1.5 x 10³ items/km². Eighty-five percent of the 375 items collected (>2.5 cm) were plastic. This density is relatively low compared to other remote and uninhabited areas. The Barents-Kara region is the most developed in the Russian Arctic sector and features significant industrial fishing and pressure by marine traffic due to industrial development. The authors found support for the hypothesis that marine litter is mainly transported here by oceanic currents from more populated areas and is connected to the fisheries in the Barents Sea.

(SOURCE: Vesman, A., Moulin, E., Egorova, A. and Zaikov, K. 2020. Marine litter pollution on the Northern Island of the Novaya Zemlya archipelago. Mar. Pollut. Bull. 150: 110671, https://doi.org/10.1016/j.marpolbul.2019.110671)

NORTHERN DVINA RIVER A MAIN SOURCE OF MICROPLASTICS POLLUTION FOR THE WHITE AND BARENTS SEAS

The Northern Dvina River, one of the largest rivers in the European Arctic flowing into the White Sea, passes through populated regions with developed industry. The microplastics export rate was highest during the spring flood period in May (58 items/s) and lowest in September (9 items/s). The calculated loads of microplastics and total plastics in May reached 250 mg/s for microplastics and 800 mg/s for total plastics. As in other studies, the main polymers were polyethylene and polypropylene. Although the Northern Dvina River is less polluted by about 1–2 orders of magnitude when compared with other rivers, the average weight concentration was higher than in the Barents Sea and several times higher than in the Eurasian Arctic on average. These results indicate that the Northern Dvina River is one of the main sources of microplastics pollution for the White and Barents seas.

(SOURCE: Zhdanov, I., Lokhov. A., Belesov, A., Kozhevnikov, A., Pakhomova, S., Berezina, A., Frolova, N., Kotova, E., Leshchev. A., Wang, X., Zavialov, P. and Yakushev, E. 2022. Assessment of seasonal variability of input of microplastics from the Northern Dvina River to the Arctic Ocean. Mar. Pollut. Bull. 175: 113370, https://doi.org/10.1016/j.marpolbul.2022.113370)

Ship Strikes

POTENTIAL INCREASED SHIP STRIKE RISK FOR ARCTIC BALEEN WHALES

The IUCN Cetacean Specialist Group examined trans-Arctic shipping via the Northern Sea Route (NSR) and determined that shipping there increased from 10.7 million tons in 2017 to 32 million tons in 2020. With continued loss of sea ice due to global warming, commercial shipping will increase in terms of both rates of passage and season length. The first-ever voyages of liquid natural gas tankers along the NSR took place in January 2021. All shipping routes here converge in the narrow and shallow Bering Strait, "making these waters especially perilous for large whales that migrate through and feed in the area". This was particularly relevant for sub-arctic species, including gray, humpback, fin and common minke whales, which are now common in the Bering Strait region during the summer. The report pointed to the Arctic Marine Shipping Assessment of the Arctic Council PAME Working Group as the most relevant international effort to mitigate risks to baleen whales from ship strike. It also highlighted the cooperation with the Conservation and Scientific Committees of the IWC. The report argued for introducing multi-faceted ship strike mitigation efforts to the Bering Strait gateway as soon as possible.

(SOURCE: https://iucn-csg.org/baleen-whales-in-the-cross-hairs-potential-for-increased-ship-strike-risk-in-and-near-bering-strait)

Chemical Pollution

MERCURY LEVELS IN THE EAST SIBERIAN SEA ARE MODERATE BUT EXPECTED TO INCREASE DUE TO WARMING

Hg accumulation in the sediments of the East Siberian Sea have increased over the past 150 years, reflecting global carbon emissions. The current values, however, are deemed to be slight to moderate and are comparable to other Arctic sediments. Nonetheless, the authors predicted that ongoing and future increases would be partly governed by biological factors affected by global warming, namely the influx of Pacific water with its higher productivity and new plankton species (e.g. diatoms) that accumulate Hg. Thus, beyond releasing toxic substances currently accumulated in ice (see Kannan *et al*. [2022] and Pouch *et al*. [2021]), climate change could also promote an increase in Hg in Arctic waters by altering biological productivity.

(SOURCE: Aksentov, K.I., Astakhov, A.S., Ivanov, M.V., Shi, X., Hu, L., Alatortsev, A.V., Sattarova, V.V., Mariash, A.A. and Melgunov, M.S. 2021. Assessment of mercury levels in modern sediments of the East Siberian Sea. Mar. Pollut. Bull. 168: 112426, https://doi.org/10.1016/j.j.marpolbul.2021.112426)

FIRST RESULTS ON MERCURY LEVELS IN SOUTHERN OCEAN HUMPBACK WHALES

Hg is a toxic heavy metal that biomagnifies along the food chain and is therefore a priority focus in most ecotoxicological investigations on marine organisms and seafood. In the Arctic and Antarctic, Hg enters the ocean via Atmospheric Mercury Depletion Events. Due to their relatively high trophic position, humpback whales were considered to be ideal biomonitoring species for Hg and other persistent elements and compounds. Among the seven megafauna species examined, humpback whales had the lowest Hg levels in blubber and skin, with values similar to those of its chief prey, Antarctic krill. The values were 5 times lower than from an earlier study on Antarctic minke whales from this area, pointing to potential niche partitioning between the two species. Interestingly, however, the second highest values were recorded in the muscle tissue of a stranded humpback whale. The authors therefore called for more detailed studies on how Hg accumulates in different tissues, to improve routine biopsy-based humpback whale Hg monitoring.

(SOURCE: Bengtson Nash, S.M., Casa, M.V., Kawaguchi, S., Staniland, I. and Bjerregaard. 2021. Mercury levels in humpback whales and other Southern Ocean marine megafauna. Mar. Pollut. Bull. 173: 113096, https://doi.org/10.1016/j.marpolbul.2021.112774)

Decreasing Levels of Persistent Organic Pollutants in Alaskan Bowhead Whales

The concentrations of POPs in blubber and muscle from Western Arctic bowhead whales were measured from 2006–2015. While the levels of PCBs and HCB did not decrease significantly during the 10-year study period, they were lower than corresponding values from the 1990s. The authors concluded that the POPs in whale tissues are declining at rates comparable to those of other Arctic biota, with current levels in the examined whale tissues being one-half to one-quarter what they had been in the 1990s. They attributed this to international agreements (e.g. Stockholm Convention) restricting the use and production of many POPs, which have apparently outweighed current climate change-related drivers of potential POP increases (e.g. melting ice, transport by migratory species).

*(SOURCE: Bolton, J.L., Ylitalo, G.M., Chittaro, P., George, J. C., Suydam, R., Person, B.T., Gates, J.B., Baugh, K.A., Sformo, T. and Stimmelmayr, R. 2020. Multi-year assessment (2006–2015) of persistent organic pollutant concentrations in blubber and muscle from Western Arctic bowhead whales (*Balaena mysticetus*), North Slope, Alaska. Mar. Pollut. Bull. 151: 110857, https://doi.org/10.1016/j.marpolbul.2019.110857)*

Mercury Levels and Toxicological Risk in Arctic Cetaceans

Levels of Hg tended to be higher in marine mammals than in terrestrial mammals in the Arctic. Long-finned pilot whales and killer whales from the Faeroe Islands and white whales in the Southern Beaufort Sea were the most contaminated cetaceans. For adult pilot whales, 18.4% were considered to be at moderate risk from Hg effects, 19.6% were at high risk and 27.4% were at severe risk. In addition, 20% of sub-adults were at severe risk. For adult killer whales, 33% were at high risk and 33% at severe risk. For adult narwhals, 7% were at moderate risk, 13% were at high risk and 7% were at severe risk. For adult white whales, 5.1% were at moderate risk, 3.9% at high risk and 1.2% at severe risk. Sub-adult white whales were at 4% and 1.3% moderate and high risk, respectively. Harbour porpoises had lower Hg levels in comparison, with only one adult male porpoise from the Danish straits being at moderate risk and one at high risk.
(Maximum liver mercury levels, $\mu g.g^{-1}$ wet wt: harbour porpoise, 92; white whale, 143.7; narwhal, 132; Long-finned pilot whale, 574; killer whale, 199.8)

(SOURCE: Dietz, R., Letcher, R.J., Aars, J. et al. 2022. A risk assessment review of mercury exposure in Arctic marine and terrestrial mammals. Sci. Total. Environ. 829: 154445, https://doi.org/10.1016/j.scitotenv.2022.154445)

Melting Glaciers Are an Important Source of Toxic Organic Compounds in the High Arctic

Kannan *et al.* (2022) found that the concentrations of highly toxic PCDFs and DL-PCBs in the sediment of selected fjords of the Svalbard archipelago, Norway, were higher than those reported for other polar regions. Such compounds reach the Arctic primarily through long-range atmospheric transport and local sources such as tourism activities. The authors also noted that "[a]n increase in glacial melt has released trapped PCDD/Fs, contributing to their introduction to the Arctic Sea". Pouch *et al*. (2021) examined another set of pollutants in seawater of the same archipelago and determined that most are combustion products transported to the Arctic by the atmosphere. The seawater levels are seen as "background and good", except for toxic levels associated with a few suspended particulate matter samples. With regard to PAHs and HCBs, the authors pointed to melting glaciers as "additional, important suppliers of pollutants to Arctic fjords". Finally, Zaborska *et al.* (2020) reported extremely high Cd values in a fjord in Spitsbergen. The highest concentrations of Pb, Zn and Cu were recorded in late June, when snow cover melts. The authors concluded that the most important sources of heavy metals in summer are glacier meltwater and surface run-off discharges. The middle of the water column is influenced by heavy metals from glacial meltwaters and possible transport from the Atlantic. This means that the remobilisation and accumulation of a large variety of toxic compounds must also be seen in relation to climate change.

(SOURCES: Kannan, V.M., Gopikrishna, V.G., Saritha, V.K., Krishnan, K.P. and Mohan, M. 2022. PCDD/Fs, dioxin-like, and non-dioxin like PCBs in the sediments of high Arctic fjords, Svalbard. Mar. Pollut. Bull. 172: 113277, https://doi.org/10.1016/j.marpolbul.2021.113277; Pouch, A., Zaborska, A., Mazurkiewicz, M., Winogradow, A. and Pazdro, K. 2021. PCBs, HCB, and PAHs in the seawater of Arctic fjords—Distribution, sources and risk assessments. Mar. Pollut. Bull. 164: 111980, https://doi.org/10.1016/j.marpolbul.2021.111980; Zaborska, A., Strzelewicz, A. Rudnicka, P. and Moskalik, M. 2020. Processes driving heavy metal distribution in the seawater of an Arctic fjord (Hornsund, southern Spitsbergen). Mar. Pollut. Bull. 161: 111719, https://doi.org/10.1016/j.marpolbul.2020.111719)

Persistent Organic Pollutants In The Tissues Of Antarctic Marine Mammals

Persistent organic pollutants were evaluated in the blubber of Ross Sea killer whales (Type C) and compared with seals (Weddell, Ross and crabeater seals) collected from the Southern Ocean, Antarctica. DDTs, PCBs and chlordanes were the most abundant POPs, with killer whales displaying levels of pollutants several times greater than seals, except for PBDEs. Levels of the emerging contaminant Dechlorane plus (DP) were also detected in the killer whale blubber.

(Maximum values, $\mu g.g^{-1}$ lipid wt: DDTs 4.6, PCBs 1.6, HCB 1.42, Chlordanes 1.7, Heptachlors 0.065, PBDEs 0.017 (Khairy *et al.* 2021))

(Maximum values, $\mu g.g^{-1}$ lipid wt: DDTs 3.55, PCBs 3.97, HCB 0.2, HCHs 0.056, PBDEs 0.138; $ng.g^{-1}$ lipid wt: DP 0.074 (Panti *et al.* 2022))

(SOURCES: Khairy, M., Brault, E., Dickhut, R., Harding, K.C., Harkonen, T., Karlsson, O., Lehnert, K., Teilmann, J. and Lohmann, R. 2021. Bioaccumulation of PCBs, OCPs and PBDEs in marine mammals from West Antarctica. Front. Mar. Sci. 8: 768715, https://doi.org/10.3389/fmars.2021.768715; Panti C., Muñoz-Arnanz, J., Marsili, L., Panigada, S., Baini, M., Jiménez, B., Fossi, M.C. and Lauriano, G. 2022. Ecotoxicological characterization of Type C killer whales from Terra Nova Bay (Ross Sea, Antarctica): Molecular biomarkers, legacy, and emerging persistent organic contaminants. Front. Mar. Sci. 9: 818370, https://doi.org/10.3389/fmars.2022.818370)

POLAR REGIONS A SINK FOR ORGANOPHOSPHATE ESTERS

Eleven OPEs were documented in the air and seawater from the northwest Pacific to the Arctic Ocean. Temperature is apparently a driving factor for the long-range atmospheric transport of these compounds northward. The Arctic Ocean and the Bering Strait are considered to be a global sink for OPEs. The authors expected global warming to remobilise OPEs, deposited in sinks such as snow and ice, into the atmosphere and ocean water.

(SOURCE: Na, G., Hou, C., Li, R., Gao, H., Jin, S., Gao, Y., Jiao, L. and Cai, Y. 2020. Occurrence, distribution, air-seawater exchange and atmospheric deposition or organophosphate esters (OPEs) from the Northwestern Pacific to the Arctic Ocean. Mar. Pollut. Bull. 157: 111243, https://doi.org/10.1016/j.marpolbul.2020.111243)

PREDICTED SHIPPING INCREASE IN THE ARCTIC OCEAN CALLS FOR MONITORING PROGRAMMES AND RESEARCH ON CONTAMINANTS

The authors predicted shipping to increase considerably in the Arctic Ocean and subarctic, a reflection of climate change and declining sea ice cover. This increase would be associated with higher levels of vessel-related contaminants, including antifouling paints, metals and airborne articles (PAHs), as well as pharmaceuticals and sanitary wastes. The authors also predicted shipping accidents to increase. They called for intensified monitoring and research, e.g. into whether the toxicity of pollutants might be different in cold-water organisms or on species that have previously hardly encountered pollution. They noted that one focus should be on emerging pollutants of concern.

(SOURCE: Svavarsson, J., Guls, H.D., Sham, R.C., Leung, K.M.Y. and Halldórsson, H.P. 2021. Pollutants from shipping—new environmental challenges in the subarctic and the Arctic Ocean. Mar. Pollut. Bull. 164: 112004, https://doi.org/10.1016/j.marpolbul.2021.112004)

Disease and mortality events

Disease

ARCTIC SEA ICE REDUCTION MAY PROMOTE VIRAL INFECTIONS IN MARINE MAMMALS

Climate change in the Arctic is predicted to affect marine ecosystems in many ways. The authors questioned whether reductions in sea ice could increase contact between Arctic and sub-arctic marine mammals, in turn leading to viral transmission. Based on positive cases of phocine distemper virus (PDV) in North Pacific sea otters, Steller sea lions, northern fur seals and ice-associated seals—after extensive mortalities in Atlantic harbour seals—the authors pointed to viral exchanges among such diverse North Pacific marine mammals as potentially being linked to changes in the extent of Arctic sea ice. Coupled with rapid long-distance movements of many marine mammals, they suggested that the opportunities for PDV and other pathogens to cross between North Atlantic and North Pacific marine mammal populations along open water routes through Arctic sea ice may become more common in “this new normal in the Arctic,” with as yet unknown health impacts, including to cetacean populations.

(SOURCE: VanWormer, E., Mazet, J.A.K., Hall, A., Gill, V.A., Boveng, P.L., London, J.M, Gelatt, T., Fadely, B.S., Lander, M.E., Sterling, J., Burkanov, V.N., Ream, R.R., Brock, P.M., Rea, L.D., Smith, B.R., Jeffers, A., Henstock, M., Rehberg, M.J., Burek-Huntington, K.A. Cosby S. L., Hammond J. A. and Goldstein, T. 2019. Viral emergence in marine mammals in the North Pacific may be linked to Arctic sea ice reduction. Sci. Rep. 9: 15569, https://doi.org/10.1038/s41598-019-51699-4)

Harmful Algal Blooms (HABs)

GLOBAL WARMING COULD CAUSE AN INCREASE IN TOXIC ALGAL BLOOMS IN THE ARCTIC

A warming climate could lead to increasing numbers of HABs of the alga *Alexandrium catenella* in the northern Bering, Chukchi and Beaufort seas. The authors mapped the life cycle of the alga and examined the factors affecting this life cycle. *A. catenella* lies dormant on the seabed as a seed-like organism for most of the year, coming to the surface and reproducing when certain nutrient levels and temperatures are reached. Warming Arctic waters will increase the frequency of this process, leading to more blooms, and consequently more algal toxins, in surface waters, potentially affecting cetaceans and their prey species.

(*SOURCE: Anderson, D.M., Fachon, E, Pickart, R.S. and Fukai, Y. 2021. Evidence for massive and recurrent toxic blooms of* Alexandrium catenella *in the Alaskan Arctic. Proc. Natl. Acad. Sci. 118: e2107387118: 1-11, https://doi.org/10.1073/pnas.2107387118)*

Oil spills

OIL SPILLS IN THE ARCTIC: RISK ASSESSMENTS AND RESPONSE OPTIONS

Oil spills in polar waters are of special concern due to the threat to pristine environments, the poor accessibility of accident sites and the behaviour of oil in cold water and ice. The Arctic, for example, is increasingly vulnerable to oil spills involving commercial vessels utilising newly open shipping lanes. Lubetkin (2020) used three case studies near and on Arctic seas—drilling on the Alaskan Coastal Plain, the Pebble Mine project and Arctic offshore drilling—to criticise the process of environmental impact statements (EIS) and their evaluation. This includes the used spill risk models, the grey literature in which they are often cited and the potential for scientific results to be overridden by political concerns. Better peer review of EIS documents would be a good first step to improving the process. In recognition of the potential threat of oil spills in Arctic waters, a number of additional authors modelled risk, considering 42 risk factors (Sajid *et al*. 2020); described the degradation and behaviour of oil in relation to sea ice (Lofthus *et al*. 2020; Nordam *et al*. 2020; Singsaas *et al*. 2020; de Aguiar *et al*. 2022); and discussed strategies to select appropriate response measures to ongoing oil spills, depending on oil type and conditions (Hu *et al*. 2020).

(SOURCES: Lubetkin, S.C. 2020. The tip of the iceberg: Three case studies of spill risk assessments used in environmental impact statements. Mar. Pollut. Bull. 152: 110613, https://doi.org/10.1016/j.marpolbul.2019.110613; Sajid, Z., Khan, F-. and Veitch, B. 2020. Dynamic ecological risk modelling of hydrocarbon release scenarios in Arctic waters. Mar. Pollut. Bull. 153: 110100, https://doi.org/10.1016/j.marpolbul.2020.110001; Lofthus, S., Bakke, I., Trembley, J., Greer, C.W. and Brakstad, O.G. 2020. Biodegradation of weathered crude oil in seawater with frazil ice. Mar. Pollut. Bull. 154: 111090, https://doi.org/10.1016/j.marpolbul.2020.111090; Nordam, T., Litzler, E., Skancke, J., Singsaas, I., Leirvik, F. and Johansen, Ø. 2020. Modelling of oil thickness in the presence of an ice edge. Mar. Pollut. Bull. 156: 111229, https://doi.org/10.1016/j.marpolbul.2020.111229; Singsaas, I., Leirvik, F., Daling, P.S., Guénette, C. and Sørheim, K.R.. 2020. Fate and behaviour of weathered oil drifting into sea ice, using a novel wave and current flume. Mar. Pollut. Bull. 159: 111485, https://doi.org/10.1016/j.marpolbul.2020.111485; de Aguiar, V., Dagestad, K.-F., Hole, L.R. and Barthel, K. 2022. Quantitative assessment of two oil-in-ice surface drift algorithms. Mar. Pollut. Bull. 175: 113393, https://doi.org/10.1016/j.marpolbul.2022.113393; Hu, G., Mohammadiun, S., Gharahbagh, A.A., Li, J., Hewage, K. and Sadiq, R. 2020. Selection of oil spill response method in Arctic offshore waters: A fuzzy decision tree based framework. Mar. Pollut. Bull. 161(A): 111705, https://doi.org/10.1016/j.marpolbul.2020.111705)

Climate change

RECORD MELTING OF ANTARCTICA'S GEORGE VI ICE SHELF

During the 2019–2020 summer season, record melting was observed in the Antarctic's George VI Ice Shelf when compared with the previous three decades. The George VI Ice Shelf is the second largest on the Antarctic Peninsula. This extreme melting period also coincided with record periods of time when surface air temperatures were at, or above, freezing. The authors utilised satellite observations of 'ponds' and 'lakes' of meltwater on top of the ice. Meltwater ponds were observed covering 23% of the ice shelf surface. These meltwater ponds and lakes can cause ice sheets to fracture and hasten the rate of ice shelf collapse. Moreover, the George VI Ice Shelf acts as a dam for the largest volume of ice on the Antarctic Peninsula, and, should this ice shelf completely break off, this additional volume of land-based ice would flow into the ocean, adding considerably to sea level rise.

(SOURCE: Banwell, A.F., Datta, R.T. and Dell, R.L. 2021. The 32-year record-high surface melt in 2019/2020 on the northern George VI Ice Shelf, Antarctic Peninsula. Cryosphere 15: 909–925, https://doi.org/10.5194/tc-15-909-2021)

WHY THE ARCTIC IS WARMING SO FAST

A new theory, aided by computer simulations and observations, was published to explain why the Arctic is warming so much faster than other regions. Due to the unique oceanography of the Arctic Ocean, the surface is usually covered with ice, with cold, low salinity water at the surface and warmer water at depth. These deeper waters are fed by the relatively warm Pacific and Atlantic oceans. Heat flows upward from the warmer water to the colder water at the surface. Because of climate change, deeper water is getting even warmer, but near surface water remains close to freezing temperatures. The increasing temperature difference is leading to a greater upwards flow of heat. The authors estimated that this oceanographic effect is responsible for 20% of the amplification of warming impacts in the Arctic.

(SOURCE: Beer, E. Eisenman, I. and Wagner, T.J.W. 2020. Polar amplification due to enhanced heat flux across the halocline. J. Geophys. Res-Lett. 47: e2019GL086706, https://doi.org/10.1029/2019GL086706)

GREENLAND ICE SHEET ON BRINK OF NO RETURN

A new analysis (Boers and Rypdal 2021), based on a 140-year record of ice-sheet height and melting rates, warned that Jakobshavn Basin, one of the five biggest ice-filled basins in Greenland and the fastest-melting, is reaching a tipping point. Accelerated melting would become inevitable, even if global warming was halted, should this point be passed. The authors stated that ice equivalent to 1–2 m of sea level rise is probably already doomed to melt. The increase in melting was attributed to a positive feedback loop, in which melting reduces the height of the ice sheet, exposing it to the warmer air found at lower altitudes, which causes further melting. In addition, melting might be accelerated by thinning of coastal glaciers, allowing more ice to flow into the sea, and reduced snowfall, leading to greater exposure of the darker surface of the ice sheet, which would then absorb more heat from the sun. Due to the level of uncertainty in the data, this 'tipping point' may already have passed, or it could pass within a matter of decades. It is also possible that, although the majority of the ice sheet would likely melt, a stable, but much smaller ice sheet could result. The current and near future melting of the ice sheet is irreversible, and to restore the original height of the Greenland ice sheet would require temperatures to be driven down to pre-industrial levels. The melting of the Greenland ice sheet could also stop the flow of the Gulf Stream, leading to major changes in oceanography and climate. Added to these concerns, Maier *et al.* (2019) noted that loss of ice in Greenland is accelerated by ice sliding over underlying bedrock much faster than previously predicted. It had been assumed that ice would flow fastest over underlying soft sediments, like mud, but in fact rates of sliding over bedrock were high. Thus, ice is moving faster to the coasts, or to lower, warmer altitudes, and melting.

(SOURCES: Boers, N. and Rypdal, M. 2021. Critical slowing down suggests that the western Greenland Ice Sheet is close to a tipping point. Proc. Nat. Acad. Sci. 118: e2024192118, https://doi.org/10.1073/pnas.2024192118; Maier, N., Humphrey, N., Harper, J. and Meierbachtol, T. 2019. Sliding dominates slow-flowing margin regions, Greenland Ice Sheet. Sci. Adv. 5(7): eaaw5406, https://www.science.org/doi/pdf/10.1126/sciadv.aaw5406)

MASSIVE ICE SHELF COLLAPSE IN EAST ANTARCTICA

An ice shelf 1200 km^2 in area, approximately the size of New York City, has collapsed in East Antarctica. The collapse was observed by satellite images and occurred on 14–16 March 2022. This part of Antarctica was thought to be relatively stable and not affected substantively by climate change; this was the first time in human history that ice in this area has collapsed. The collapse may have been due to a major heat wave in this region, where temperatures were 40° C warmer than usual. Because of this collapse, scientists are concerned that they have been been overestimating East Antarctica's stability. The shelf had been holding back ice from the Conger and Glenzer glaciers, which now may flow rapidly into the ocean, increasing Antarctic ice loss and adding to sea level rises.

(SOURCE: Borenstein, S. 2022. Ice shelf collapses in previously stable East Antarctica. AP News, 25 March, https://apnews.com/article/climate-science-new-york-new-york-city-antarctica-4f5f1817bffd632e48e845d4638cc237)

GREENLAND WILL LOSE ICE FASTER THIS CENTURY THAN DURING THE PAST 12,000 YEARS

A new model reconstructed a 12,000 year history of Greenland's ice sheet, which has been validated by field measurements and data from proxies that have allowed the estimation of ice sheet size. The predicted ice sheet losses for the 21st century are on track to be higher than anything observed over the past 12,000 years. If dramatic reductions in greenhouse gas emissions are not made, the rate of ice loss with be four times the highest level experienced in the past 120 centuries. The authors focused on southwest Greenland; however, the rates of ice loss in this region match those seen across all of the Greenland ice sheet.

(SOURCE: Briner, J.P., Cuzzone, J.K., Badgeley, J.A. et al. 2020. Rate of mass loss from the Greenland Ice Sheet will exceed Holocene values this century. Nature 586: 70–74, https://doi.org/10.1038/s41586-020-2742-6)

ANTARCTIC WARMING AND DECLINE IN SEA ICE CONNECTED WITH DECLINE IN KEY FORAGE FISH

A study in the Southern Ocean found a correlation between warming waters, decreased sea ice and reduced abundance of Antarctic silverfish. These small fish are important prey for penguins and marine mammals. The study was conducted on the west coast of the Antarctic Peninsula, one of the fastest warming areas of the ocean. The authors warned that, with continued warming in this region, these fish could disappear from the region entirely, triggering major changes in the marine ecosystem.

(SOURCE: Corso, A.D., Steinberg, D.K., Stammerjohn, S.E. and Hilton, E.J. 2022. Climate drives long-term change in Antarctic silverfish along the western Antarctic Peninsula. Commun. Biol. 5: 104, https://doi.org/10.1038/s42003-022-03042-3)

DISTRIBUTION OF COPEPOD SPECIES SHIFTING NORTHWARDS WITH RETREATING SEA ICE

Sea ice coverage, thickness and extent are declining in the central Arctic Ocean. Based on a comparison between past (1993–1998) and recent (2007–2016) zooplankton collections and satellite-based sea ice observations, the authors found strong correlations between two species of copepods and several sea ice parameters. Accordingly, the distribution patterns of these zooplankton species are expected to shift northwards with retreating sea ice and changing climate conditions. Copepods commonly dominate the biomass of zooplankton in polar seas and serve as a link to higher trophic levels such as fish, birds and marine mammals.

(SOURCE: Ershova, E.A., Kosobokova, K.N., Banas, N.S., Ellingsen, I., Niehoff, B., Hildebrandt, N. and Hirche, H.-J. 2021. Sea ice decline drives biogeographical shifts of key Calanus *species in the central Arctic Ocean, Glob. Change Biol. 27: 2128–2143, https://doi.org/10.1111/gcb.15562)*

Recent Changes in Antarctic Sea Ice Are Unique for the 20th Century

Before satellites started gathering sea ice data, measurements were collected via direct human observations of the ice sheet edge, a small number of weather stations and ice core samples. Data were therefore limited to a restricted location or a specific season. The authors used data from a network of 30 long-term temperature and pressure observations to develop a model that reconstructed conditions throughout the 20th century, during all four seasons. They found significant decreases in sea ice in the early part of the 20th century, which were linked to increasing temperatures and wind strength, and then a significant increase in the century's latter two decades (through 2015), to levels that exceeded the greatest sea ice extent at the start of measurements in 1905. However, in 2016, Antarctic sea ice extent declined sharply, well below the average throughout the early 20th century decline, possibly part of long-term sea ice variability.

(SOURCE: Fogt, R.L., Sleinkofer, A.M., Raphael, M.N. and Handcock, M.S. 2022. A regime shift in seasonal total Antarctic sea ice extent in the twentieth century. Nat. Clim. Change 12: 54–62, https://doi.org/10.1038/s41558-021-01254-9)

Antarctic Minke Whale Ice Edge Habitat Threatened by Warming

Ship-based surveys for cetaceans are impossible in ice-covered regions, so helicopter surveys were used to estimate Antarctic minke whale abundance in relation to sea ice (2006–2013) and the data were then used to develop distribution models. The highest whale densities were at the ice edge and in medium ice concentrations. Medium densities were found up to 500 km into the ice edge. Few whales occurred in ice-free waters; thus, minke whales seem dependent upon ice edge habitat. With the loss of sea ice in Antarctica, there may already be major impacts on important minke whale habitat.

*(SOURCE: Herr, H., Kelly, N., Dorschel, B., Huntemann, M., Kock, K.-H., Lehnert, L.S., Siebert, U., Viquerat, S., Williams, R. and Scheidat, M. 2019. Aerial surveys for Antarctic minke whales (*Balaenoptera bonaerensis*) reveal sea ice dependent distribution patterns. Ecol. Evol. 9: 5664–5682, https://doi.org/10.1002/ece3.5149)*

Pine Island Glacier's Ice Sheet Disintegrating, Speeding up Glacier Flow

The Pine Island Glacier contains approximately 180 trillion tons of ice, equivalent to 0.5 m of global sea level rise if it melted. Loss of the glacier already contributes to one-sixth of a millimetre of sea-level rise each year—a rate that is expected to increase. If this and other glaciers speed up their flow into the oceans, then sea level rise could increase drastically over the next few centuries. From the 1990s to 2009, the speed of the glacier increased from 2.5 km/year to 4 km/year. The speed was relatively steady from 2009 to 2017. However, between 2017 and 2020, several large icebergs at the edge of the shelf broke off, leading to a 19 km retreat of the shelf's edge. This ice shelf had been holding back the Pine Island glacier, and this loss of the ice sheet's edge caused the speed of the glacier to increase again, by >12% over three years. The glacier's acceleration raised the concern that the ice shelf appears to be "ripping apart". The glacier has been relatively stable for millennia, and there is major concern about the rate of change being observed, and what this might mean for global sea levels.

(SOURCE: Joughin, I., Shapero, D., Smith, B., Dutrieux, P. and Barham, M. 2021. Ice-shelf retreat drives recent Pine Island Glacier speedup. Sci. Adv. 7: eabg3080, https://doi.org/10.1126/sciadv.abg3080)

A Third of Winter Arctic Ice Volume Lost over Nearly Two Decades

Over three winters (2018–2021) in the Arctic, mean April snow depth decreased by c. 2.50 cm and ice thickness by c. 0.28 m, which is equivalent to an ice volume loss of approximately 12.5%. Satellite images showed that the decrease mainly involved thick multi-year ice, which typically remains frozen through the summer, being replaced by thinner seasonal ice that forms only in the colder months. Over an 18-year satellite record, the loss of winter ice was approximately 6000 km^3, or a third of the winter ice volume.

(SOURCE: Kacimi, S. and Kwok, R. 2022. Arctic snow depth, ice thickness, and volume from ICESat-2 and CryoSat-2: 2018–2021. Geophys. Res-Lett. 49: e2021GL097448. https://doi.org/10.1029/2021GL097448)

The Arctic Is Transitioning to New Climate State

Due to warming, experts believe that the Arctic has transitioned to a new climatic state. The US National Center for Atmospheric Research has concluded that the Arctic has warmed so much that inter-annual variability has shifted beyond previous climatic ranges to a 'new Arctic' climate regime. For example, Arctic sea ice has melted to the point where even an unusually cold year will not have the same amount of summer sea ice as was observed in the mid-20th century. The authors predicted that soon, instead of snow, rain will fall for several months of the year. This has major implications for Arctic ecosystems and marine mammals.

(SOURCE: Landrum, L. and Holland, M.M. 2020. Extremes become routine in an emerging new Arctic. Nat. Clim. Chang. 10: 1108–1115, https://doi.org/10.1038/s41558-020-0892-z)*

Antarctic Core Samples Suggest that the West Antarctic Ice Sheet Could Be Even More Vulnerable to Warming

Core samples from various depths of 1.5 km of seabed sediment were used to reconstruct the evolution of Antarctic ice sheets over the past 20 million years. In the early Miocene, atmospheric concentrations of carbon dioxide were similar to those that are expected by 2100, if greenhouse gas emissions are not substantially reduced. During the warm Miocene period, sea level rose by up to 60 m. This is the sea level rise predicted if all the ice currently on the Antarctic continent melts. The authors suggested that the West Antarctic Ice Sheet contributed significantly to global sea level rises 8 million years earlier than previously known, implying that the ice sheet is more vulnerable to warming than thought. This could be due to the land mass below this ice sheet being below sea level, causing the bottom of the ice sheet to be warmed and eroded by seawater. Currently, melting of the West Antarctic Ice Sheet is contributing significantly to global sea level rise, and as temperatures rise, this contribution will increase. If this ice sheet completely melts, it could cause a 4.5 m rise in sea level, affecting coastal environments globally.

(SOURCE: Marschalek, J.W., Zurli, L., Talarico, F. et al. (2021). A large West Antarctic Ice Sheet explains early Neogene sea-level amplitude. Nature 600: 450–455, https://doi.org/10.1038/s41586-021-04148-0)

Storms Increase Ice Breakup in Arctic Through Oceanographic Processes

In 2016, a massive cyclone equivalent in force to a Category 2 hurricane was observed in the Arctic Ocean by a nearby icebreaker. During the cyclone, sea ice extent declined at a rate that was 5.7 times faster than normal, driven by cyclone-related oceanographic processes. Winds pushed low density surface water away from the ice, causing denser but warmer water to well up, warming the ice sheet. Surface winds then caused surface water turbulence; the combination of warming and turbulence helped to break up the ice more quickly. These data suggest that storms, which are likely to increase, could cause the breakup of Arctic ice faster than predicted.

(SOURCE: Peng, L., Zhang, X. Kim, J.-H., Cho, K.-H., Kim, B.-M., Wang, Z. and Tang, H. 2021. Role of intense Arctic storm in accelerating summer sea ice melt: An in situ observational study. Geophys. Res-Lett. 48: e2021GL092714:1-10, https://doi.org/10.1029/2021GL092714)

The Eastern Antarctic Ice Sheet Achieves Record Temperatures

Normally one of the coldest locations on the planet, parts of the Eastern Antarctic ice sheet recently experienced temperatures 40°C above normal for multiple days. Instead of temperatures ranging from -45°C to -51°C, they were -12°C to -18°C—still cold, but the equivalent of a massive heat wave by Antarctic standards. Vostok—808 miles from the south pole, at the centre of the eastern ice sheet and one of the coldest places in Antarctica—recorded -17.7°C in March, the warmest temperature at that time of year since recording began 65 years ago. Computer models suggested temperatures up to 50°C higher than normal may have been reached at several locations on the ice sheet.

(SOURCE: Samenow, J. and Patel, K. 2022. It's 70 degrees warmer than normal in eastern Antarctica. Scientists are flabbergasted. Washington Post, 19 March, https://www.washingtonpost.com/weather/2022/03/18/antarctica-heat-wave-climate-change/)

Climate Oscillations Can Influence Humpback Whale Migrations

Based on passive acoustic monitoring between 2011 and 2018 in the Atlantic sector of the Southern Ocean, humpback whales were present in their feeding grounds for five years, but virtually absent in two (2015, 2016). The latter two corresponded to El Niño years. Climate oscillations have large effects on sea surface temperature and local ice concentrations in the Southern Ocean. The ice concentration directly affects whale access to open water areas and indirectly affects primary productivity, which in turn drives the distribution of krill, the whale's primary prey. The authors considered that future climate change could change the overall occupancy of certain feeding areas by humpback whales or their prey resources on a hemisphere-wide spatial scale. They argue for employing acoustic detection to evaluate the sensitivity of keystone species to climate variability to help better understand the effects of climate-induced changes on the Southern Ocean ecosystem.

(SOURCE: Schall, E., Thomisch, K., Boebel, O., Gerlach, G., Woods, S.M., El-Gabbas, A. and Opzeeland, I.V. 2021. Multi-year presence of humpback whales in the Atlantic sector of the Southern Ocean but not during El Niño. Commun. Biol. 4: 790, https://doi.org/10.1038/s42003-021-02332-6)

Twhaites Glacier, West Antarctica, Melting Faster than Previously Thought

Digitised Antarctic radar data, originally recorded between 1971 and 1979 on optical film, were compared with modern data. Schroeder *et al.* (2019) calculated that the eastern ice shelf of Thwaites Glacier, West Antarctica, was shrinking faster than previously thought, between 10% and 33% during the period 1978–2009. This is consistent with other closely observed Antarctic glaciers, which have doubled their rate of ice loss in the past six years. Robel *et al.* (2019) modelled ice flow simulations with a state-of-the-art ice sheet model for Thwaites Glacier, which is thought to be unstable. The model predicted that the glacier is likely to succumb to this instability, increasing the flow of its ice into the ocean. Even if global warming were to cease, the instability of the glacier would still cause ice to flow into the sea at an accelerated rate for centuries. This high flow of ice into the ocean will lead to a higher level of sea level rise, and the researchers conclude “that the collapse of marine ice sheets makes worst-case scenarios of rapid sea-level rise more likely in future projections”.

(SOURCES: Schroeder, D.M., Dowdeswell, J.A. and Siegert, M.J. 2019. Multidecadal observations of the Antarctic ice sheet from restored analog radar records. Proc. Nat. Acad. Sci. 116: 18867–18873, https://doi.org/10.1073/pnas.1821646116; Robel, A.A., Seroussi, H. and Roe, G.H. 2019. Marine ice sheet instability amplifies and skews uncertainty in projections of future sea-level rise. Proc. Nat. Acad. Sci. 116: 14887–14892, https://doi.org/10.1073/pnas.1904822116)

Seabed Geology Has Slowed Down the Thinning of the Ross Ice Sheet, until Now

Ocean melting has thinned Antarctica’s ice shelves at an increasing rate over the past two decades, leading to loss of ice above the continent’s land area. At present, the Ross Ice Shelf is at a relatively steady state and holds back approximately 20% of Antarctica’s ice from flowing into the ocean. However, geological records suggest that it could disintegrate rapidly, freeing ice on land to flow rapidly into the ocean, which could add up to 11.6 m to global sea level rise. Surveys underneath the Ross Ice Shelf showed that the seabed’s bathymetry constrains the circulation of ocean water, which in turn reduces the amount of warm water reaching the underside of the ice sheet. In contrast, local warming of surface water near the front of the ice sheet has led to rapid ice shelf melting east of Ross Island. The reduction of the ice sheet in this area could lead to a faster loss into the ocean of land-based ice from both the Eastern and Western Antarctic ice sheets.

(SOURCE: Tinto, K.J., Padman, L., Siddoway, C.S. et al. 2019. Ross Ice Shelf response to climate driven by the tectonic imprint on seafloor bathymetry. Nat. Geosci. 12: 441–449, https://doi.org/10.1038/s41561-019-0370-2)

Climate Change Expected To Alter The Arctic’s Role In Absorbing Carbon

Certain regions of the Arctic seas (North Atlantic west and east) absorb the most anthropogenic carbon globally; the biological carbon pump contributes substantially to this absorption. As Arctic sea ice melts, this pump changes, affecting global climate and other important ocean attributes (e.g. biodiversity). The authors observed that, compared to conditions where ice was not affected, sea-ice derived meltwater stratification slowed the pump by four months, causing a shift from an export to a retention system. The details of sea ice export, distribution and melt remain to be studied in detail, but will determine the net impact of climate change on Arctic food webs, including benthic ecosystems.

(SOURCE: von Appen, W.-J., Waite, A.M., Bergmann, M., Bienhol, C., Boebel, O., Bracher, A., Cisewski, B., Hagemann, JH., Hoppema, M., Iversen, M.H. et al. 2021. Sea-ice derived meltwater stratification slows the biological carbon pump: results from continuous observations. Nat. Commun. 12: 7309, https://doi.org/10.1038/s41467-021-26943-z)

Record-High Levels of Arctic Freshwater Are Impacting the Marine Environment and Atlantic Ocean Currents

Due to melting ice, the Beaufort Sea has increased its freshwater content by 40% over the past two decades. This water tends to flow through the Canadian Archipelago to reach the Labrador Sea, rather than through the wider marine passageways that connect to seas in Northern Europe. As this water is not only less saline, but also rich in nutrients, its behaviour has implications for the Labrador Sea ecosystem and food web. In addition, greater amounts of less saline, and therefore less dense, water flowing into the Labrador Sea could have an impact on ocean circulation in the North Atlantic. If the flow into the North Atlantic should increase, the less dense, less saline water would flow over the top of the important northward flowing current in the North Atlantic, slowing down oceanic circulation in this region and also reducing heat transfer to the atmosphere. This could have major impacts on both the oceanography and climate of the North Atlantic.

(SOURCE: Zhang, J., Weijer, W., Steele, M., Cheng, W., Verma, T. and Veneziani, M. 2021. Labrador Sea freshening linked to Beaufort Gyre freshwater release. Nat. Commun. 12: 1229, https://doi.org/10.1038/s41467-021-21470-3)

Noise impacts

The Effect of Warming Oceans on Underwater Sound Speed and Propagation

Warmer oceans will cause sound underwater to travel faster and farther, which will impact many species of sound-reliant cetaceans. The authors modelled the impacts of a warming ocean on sound propagation and highlighted areas that would most be affected by changes in sound transmission. The largest effect on the underwater speed of sound can be expected east of Greenland and off Newfoundland in the Atlantic. The average speed of sound here is likely to increase by more than 1.5%, or approximately 25 m/s, from the surface to a depth of 500 m. This will occur by the end of the century if the current rate of greenhouse gas emissions continues. In addition, there will be a 1% sound speed increase, more than 15 m/s, at 50 m depth in the Barents Sea, the northwest Pacific and the Southern Ocean, as well as at 500 m depth in the Arctic Ocean, Gulf of Mexico and southern Caribbean Sea. The authors also modelled the effect of temperature change on the calls of the North Atlantic right whale, a critically endangered species that inhabits an area that would be affected, predicting that the species' calls (at 50 Hz) would travel farther in these warmer waters.

(SOURCE: Affatati, A., Scaini, C. and Salon, S. 2022. Ocean sound propagation in a changing climate: global sound speed changes and identification of acoustic hotspots. Earths Future 10: e2021EF002099, https://doi.org/10.1029/2021EF002099)

UNDERWATER NOISE IN THE CANADIAN ARCTIC INCREASING AND PREDICTED TO INCREASE FURTHER

An analysis of 30 passive acoustic datasets collected between 2014 and 2019 from 15 sites revealed that sound pressure levels in the Canadian Arctic decreased with ice cover but increased with the number of ships per day. The authors predicted that the noise levels would increase further due to two factors: 1) earlier melt and later freeze-up and 2) increased shipping in the extended ice-free months. These results provided a useful baseline for future studies, and the authors called for continued acoustic monitoring, including in the geographic gaps for which no published studies of underwater sound levels are currently available.

(SOURCE: Halliday, W.D., Barclay, D., Berkley, A.N., Cook, E., Dawson, J., Hilliard, R.C., Hussey, N.E. et al. 2021. Underwater sound levels in the Canadian Arctic, 2014–2019. Mar. Pollut. Bull. 168: 112437, https://doi.org/10.1016/j.marpolbul.2021.112437)

UNDERWATER NOISE IN THE ARCTIC OCEAN IS UNDERGOING ICE- AND TEMPERATURE-RELATED CHANGE

The Arctic Ocean is a special case with regard to underwater noise. Its acoustic properties are primarily affected by sea ice, which is a source, shield and diffuser of underwater sound. Global warming, however, is causing a decrease in sea ice coverage, thickness and duration. Sound propagation is also affected by water temperature and salinity. Lancaster *et al.* (2021) highlighted the increasing shipping in Arctic waters and its distinctive features, such as icebreaking. The authors called for "a proactive approach by Arctic coastal states that addresses key knowledge gaps about noise-sensitive species, systematically monitors underwater soundscapes and holds noise at safe levels for biodiversity". Bonnel *et al*. (2021) examined the effects of temperature and sea ice on ambient noise on the Chukchi Shelf. The Shelf shows traditional polar features, such as being quieter when the sea is ice-covered. Noise levels are also influenced by the Beaufort Duct, a recurring Pacific warm water intrusion first observed in the early 1970s. The authors reported that ambient noise dropped by up to 10 dB/Hz when the Beaufort Duct disappeared. At the same time, the Duct apparently increased acoustic propagation, which could increase the communication space of bowhead whales but also could magnify the effect of anthropogenic noise. The persistence and increasing geographic spread of the Beaufort Duct therefore has major implications for ocean noise in this region.

(SOURCES: Lancaster, M.L., Winsor, P. and Dumbrille, A. 2021. Underwater noise from shipping: A special case for the Arctic. In: Carpenter A., Johansson T.M. and Skinner J.A. (eds). Sustainability in the Maritime Domain. Strategies for Sustainability. Springer, Cham, Switzerland, https://doi.org/10.1007/978-3-030-69325-1_14; Bonnel, J., Kinda, G.B. and Zitterbart, D.P. 2021. Low-frequency ocean ambient noise on the Chukchi Shelf in the changing Arctic. J. Acoust. Soc. Am. 49: 4061–4072, https://doi.org/10.1121/10.0005135)

CETACEANS REACT TO SONAR AS THEY DO TO PREDATORS, WITH MAJOR IMPLICATIONS IN AN INCREASINGLY NOISY ARCTIC

Suction cup tags were attached to sperm, humpback, long-finned pilot and northern bottlenose whales in northern Norwegian waters, on the Arctic Circle (Miller *et al.* 2022). These tags recorded the whales' behaviour when exposed to three types of sounds: sonar similar to naval sonar (1–4 kHz) and fish-eating and marine mammal-eating killer whale clicks. Three species reduced their foraging activity by 50–97% when exposed to navy sonar or mammal-eating killer whale sounds, while northern bottlenose whales showed the strongest reaction, completely ceasing feeding behaviour. The authors concluded that the cetaceans react to sonar as a major threat, akin to a killer whale attack. They warned that with more shipping, oil and gas exploration and naval activity in an increasingly ice-free Arctic, the reactions of naïve populations to anthropogenic noise could lead to negative impacts on populations. Confirming these concerns, Ladegaard *et al.* (2021) recorded underwater sound around Greenland from 2011 to 2020. Ice-covered waters were roughly 20 dB quieter than open ocean waters, and rapidly melting ice can increase sound levels by 20 dB. Noise levels in Melville Bay, Baffin Bay and the Greenland Sea peaked in the late summer and autumn, correlating with open water periods. Seismic surveys conducted by the oil and gas industry raised sound levels by a constant 2–8 dB, with reverberation raising sound levels even between seismic pulses. A decrease in ice cover coupled with an increase in anthropogenic activity is likely to increase the sound levels in the Arctic several orders of magnitude.

(SOURCES: Miller, P.J.O., Isojunno, S., Siegal, E. and Curé, C. 2022. Behavioral responses to predatory sounds predict sensitivity of cetaceans to anthropogenic noise within a soundscape of fear. Proc. Nat. Acad. Sci. 119: e2114932119, https://doi.org/10.1073/pnas.2114932119; Morell, V. 2022. Why whales flee from sonar—sometimes to their death. Science, 21 March 2022, doi:10.1126/science.abq1516; Ladegaard, M., Macauley, J., Simon, M., Laidre, K.L., Mitseva, A., Videsen, S., Pedersen, M.B., Tougaard, J. and Madsen, P.T. 2021. Soundscape and ambient noise levels of the Arctic waters around Greenland. Sci. Rep. 11: 23360, https://doi.org/10.1038/s41598-021-02255-6)

Marine Traffic Produces the Loudest Noise in an Arctic Fjord

Summer noise measurements in Kongsfjorden (Spitsbergen, Svalbard, Norway) confirmed predicted noise maps that yielded marine traffic values from 85 to 145 dB at 125 Hz. Frequencies of 10–200 Hz could be heard thousands of kilometres away. Values were expected to increase as the Arctic warms. The authors suggested that their results could be used to develop strategies to mitigate the impact of marine traffic noise on marine species. This study could serve as a reference for underwater shipping noise.

(SOURCE: Sanjana, M.C., Latha, G. and Raguraman, G. 2021. Anthropogenic sound field and noise mapping in an Arctic fjord during summer. Mar. Pollut. Bull. 173: 113035, https://doi.org/10.1016/j.marpolbul.2021.113035)

Narwhals Display Major Reactions to Anthropogenic Sound at Levels Far Below Levels Considered 'Safe'

A group of six tagged narwhals in the Scoresby Sound fjord system, East Greenland, were exposed to anthropogenic sound—both from a ship's engine and a seismic airgun. Their echolocation rate was halved at 12 km from the ship, and they ceased echolocating (and thus foraging) at 7–8 km. Behavioural changes occurred at distances greater than 40 km from the sound source. The narwhals also stopped diving deeply and increased their fluking rate, which is similar to their behavioural response to killer whales. The cessation of foraging and increased fluking rate may have energetic implications for this species. The authors noted that the frequencies to which narwhals should be most sensitive were only just above ambient levels a few kilometres from the vessel. When narwhals completely stopped foraging, these frequencies were more than 10 dB re 1 μPa^2-s lower than the background noise level. This suggests that narwhals are able to detect signals, and react to them, even if they are embedded in background noise. This considerably changes our understanding of how cetaceans perceive sound. Current methods of estimating impacts of anthropogenic sound may largely be underestimating these impacts, which has major marine noise management implications, especially regarding Arctic cetaceans.

(SOURCE: Tervo, O.M., Blackwell, S.B., Ditlevsen, S., Conrad, A.S., Samson, A.L., Garde, E., Hansen, R.G. and Mads Peter, H.-J. 2021. Narwhals react to ship noise and airgun pulses embedded in background noise. Biol. Lett. 17: 20210220, https://doi.org/10.1098/rsbl.2021.0220)

GLOBAL

General

Room for Improvement in Assessing the Cumulative Impacts of Maritime Industries

The impacts of cumulative stressors upon marine mammals is a field of high interest, as any stressor typically occurs in conjunction with multiple other stressors. A Cumulative Effects Assessment (CEA) is a mandatory component of the Environmental Impact Assessment process of many countries. However, for marine mammals, critical thresholds for impacts of many stressors are unknown, and the synergistic effects of multiple stressors are often unknown, which makes assessing the consequences, to individuals and populations, of multiple stressors problematic. A review of 93 CEAs across 11 maritime industries in the UK rated the aquaculture industry's CEAs the poorest and the large offshore windfarm industry (≥ 20 turbines) most favourably. The authors noted that CEAs improved between 2009 and 2019, although this was largely due to five industries (cable, large and small offshore wind farms and tidal and wave energy). There was "inconsistency in the language used to define and describe cumulative effects" and "a lack of routinely applied methodology". There is clear room to improve CEA processes, such as standardising practices, with some industries likely underestimating their impacts due to poor CEAs.

(SOURCE: Hague, E.L., Sparling, C.E., Morris, C., Vaughan, D., Walker, R., Culloch, R.M., Lyndon, A.R., Fernandes, T.F. and McWhinnie, L.H. 2022. Same space, different standards: A review of Cumulative Effects Assessment practice for marine mammals. Front. Mar. Sci. 9: 822467, https://doi.org/10.3389/fmars.2022.822467)

Current Efforts to Tackle Marine Pollution Are Insufficient

Despite global efforts, marine pollution is increasing. A review of 2417 scientific papers addressing coastal and marine pollution, published from 2000–2018, revealed that chemical pollution was the most studied, followed by heavy metals and nutrients. The most frequently mentioned sources were oil spills, industry and wastewater. Most reports considered the issue to be a technical problem and focused on reactive interventions (e.g. clean-ups). The authors argued that bringing about a trend change would require examining the deeper drivers of pollution. This would mean treating the issue as a systemic social-ecological problem, involving proactive, pre-emptive interventions at "deep leverage points". They recommended pursuing inter- and transdisciplinary efforts encompassing a diversity of stakeholders. Such systemic changes would be the only strategy capable of meeting stated goals such as those given in the UN's Agenda 2030 for Sustainable Development, which aims to prevent and significantly reduce marine pollution of all kinds by 2025. This approach would also support the agenda for the UN Decade of Ocean Science for Sustainable Development (2021–2030).

(SOURCE: Riechers, M., Brunner, B.P., Dajka, J.-C., Duse, I.A., Lübker, H.M., Manlosa, A.O., Sala, J.E., Schaal, T. and Weidlich, S. 2021. Leverage points for addressing marine and coastal pollution: A review. Mar. Pollut. Bull. 167: 112263, https://doi.org/10.1016/j.marpolbul.2021.112263)

Habitat degradation

Marine debris

MICROPLASTICS IN MARINE BIOTA: AN INCREASING FOCUS OF MARINE POLLUTION STUDIES

Microplastics have become a major focus not only of marine debris studies but of marine pollution studies in general, with the journal *Marine Pollution Bulletin* a good example of this trend. A recent review of 132 articles from 2010–2020 indicated that the predominant type of microplastics in marine biota is fibres, the predominant polymer is polyethylene, and the size is under 2 mm. The most studied regions are the Atlantic, the Pacific and the Mediterranean. The Arctic and Antarctic Oceans are among the least studied. Sea turtles were the taxon with the highest percentage of individuals affected (88%), followed by marine mammals (60%). Most studies examined the gastrointestinal tract, while others focused on other organs or faeces. A 2019 IWC workshop on marine debris summarised the latest information regarding cetaceans, including plastic-associated chemical contaminants. The workshop suggested that humpback and fin whales would be the best candidates for monitoring microplastics pollution in cetaceans.

(SOURCES: Ugwu, K., Herrera, Al. and Gomez, M. 2021. Microplastics in marine biota: A review. Mar. Pollut. Bull. 166: 112540, https://doi.org/10.1016/j.marpolbul.2021.112540; Report of the IWC Workshop on Marine Debris: The Way Forward, 3–5 December 2019, La Garriga, Catalonia, Spain, SC/68B/REP/03)

BINDING INTERNATIONAL AGREEMENT ON PLASTICS POLLUTION IS IN THE MAKING

Plastics pollution is one of the most rapidly worsening environmental challenges in the early 21st century. Walker (2022) expressed concern that, despite decades of effort (MARPOL 73/78, Annex V; UN SDGs target 14.1; several UNEA resolutions; G7 Ocean Plastics Charter and G20 Action Plans), no binding global agreement to reduce marine plastics pollution has been reached. A new global treaty has been proposed, but the author estimated that negotiations and implementation could take up to 8–10 years. However, UNEP issued a press release on 2 March 2022, reporting that "representatives from 175 nations endorsed a historic resolution to end plastic pollution and forge an international legally binding treaty by 2024. The resolution addresses the full lifecycle of plastic, including its production, design and disposal". The newly established Intergovernmental Negotiating Committee will begin its work in 2022. UNEP considered this to be the most significant environmental multilateral deal since the Paris Accords.

(SOURCES: Walker, T.R. 2022. Calling for a decision to launch negotiations on a new global agreement on plastic pollution at UNEA5.2. Mar. Pollut. Bull. 176. https://doi.org/10.1016/marpolbul.2022.113447; https://www.unep.org/news-and-stories/press-release/historic-day-campaign-beat-plastic-pollution-nations-commit-develop)

BALEEN WHALES NEAR A COASTAL CITY CONSUMED MILLIONS OF MICROPLASTIC PARTICLES EVERY DAY

The faeces of Bryde's and sei whales from the Hauraki Gulf, New Zealand, were examined from a study site close to Auckland, New Zealand's largest city. The authors identified prey species from genetic analyses of the faeces. They also found 32 +/- 24 (SD) particles of microplastics per 6 g of faeces. The main route of microplastics uptake would be through consuming prey. Calculating microplastics uptake from levels in water would have underestimated uptake by four orders of magnitude. The authors estimated the whales consume about 25,000 particles of microplastics every time they capture prey, for a total of 3.4 million particles of microplastics per day.

(SOURCE: Zantis, L.J., Bosker, T., Lawler, F., Nelms, S.E., O'Rorke, R., Constantine, R., Sewell, M. and Carroll, E.L. 2021. Assessing microplastic exposure of large marine filter-feeders. Sci. Total Environ. 818: 151815, https://doi.org/10.1016/j.scitotenv.2021.151815)

Ship Strikes

LOW LEVELS OF COMPLIANCE WITH VOLUNTARY SPEED RESTRICTIONS TO PROTECT WHALES

Ship strikes are a major threat to whales. A voluntary speed restriction zone (10 knots or less) for vessels over 300 tons was established in Californian waters (USA) to reduce the risk of ship strikes. Previous studies have shown low compliance levels (0–13%) in such zones. Ship position data were used to investigate compliance levels within the California zone between 2010 and 2019. While average ship speeds were reduced, the level of compliance was lower than the level needed to ensure ship strikes would be sustainable. A compliance level of 80% or higher was needed to reduce ship-strike mortality by 20–30%, but even a financial incentive-based speed reduction programme (with incentives ranging from $500–$50,000) did not lead to sufficient compliance. It was introduced in 2014—Protecting Blue Whales and Blue Skies—and scaled up in 2018, leading to a small (15%) increase in compliance, but it levelled out at approximately 50%. The authors suggested that purely voluntary speed restrictions are ineffective at reducing speeds to the level needed to protect whales. Legal speed limits, regulations and enforcement may be required.

(SOURCE: Morten, J., Freedman, R., Adams, J.D., Wilson, J., Rubinstein, A. and Hastings, S. 2022. Evaluating adherence with voluntary slow speed initiatives to protect endangered whales. Front. Mar. Sci. 9: 833206. https://doi.org/10.3389/fmars.2022.833206)

Chemical pollution

A Review of Polycyclic Aromatic Hydrocarbons in Marine Mammals, including Cetaceans

PAHs stem largely from anthropogenic activities, mostly from crude oil. Some are toxic and therefore incorporated in environmental monitoring programmes. A study found naphthalene was the predominant PAH in marine mammal tissue, but knowledge about the effects of PAHs on cetaceans is scarce. In general, the levels were not correlated with sex or age but were "associated with the influence of urban and industrialised areas in which the organisms lived, or eventually with an oil spill or oil products". The authors compiled a summary of PAH measurements in marine mammal tissue samples, but also noted that diverging methodological approaches affected these results.

(SOURCE: Lourenco, R.A., Taniguchi, S., da Silva, J., Costa Gallota, F.D. and Bicego, M.C. 2021. Polycyclic aromatic hydrocarbons in marine mammals: A review and synthesis. Mar. Pollut. Bull. 171: 112699, https://doi.org/10.1016/j.marpolbul.2021.112699)

Marine Ecotoxicology Facing a New Era

Marine ecotoxicology is facing new challenges related to the emergence of new and complex synthesised chemicals, combined with climate change. The authors called for updating the agenda and methodologies of this discipline, conducting long-term experiments, standardising sentinel species and benefiting from baseline studies and omics technologies. Because climate change may influence the fate of toxic substances, these proposed improvements must be seen in light of chronic chemical exposure, combined with changing physical parameters (e.g. seawater temperature and pH). While effects have been studied for conventional toxins, the effect of "climate change on the fate and potential interaction of emergent toxicants such as micro and nanoplastics, drugs and health/care products residues, nanoparticles and new synthesized pesticides" represents a research gap.

(SOURCE: Tlili, S. and Mouneyrac, C. 2021. New challenges of marine ecotoxicology in a global change context. Mar. Pollut. Bull. 166: 112242, https://doi.org/10.1016/j.marpolbul.2021.112242)

Climate change

Using Genetics to Investigate the Effect of Past Warming Events

Investigating the impact that the last rapid and extreme warming period had on cetaceans (during the Pleistocene-Holocene transition 7000–12,000 years ago) might give insight into how cetaceans will respond to modern global warming in the long term. The authors examined temporal changes in genetic diversity during the past 30,000 years, which suggest that, as temperatures warmed, cetacean populations initially expanded in the Atlantic and Pacific Ocean basins. Presumably this increase in cetacean abundance during the Holocene was associated with changes in prey abundance and climate; for example, there were increases in both baleen whales and their prey in the Southern Ocean, suggestive of a dramatic increase in ocean productivity. However, Atlantic minke whale numbers began to decline with the onset of the Holocene, until ~4000 years ago when populations started to increase exponentially. Blue and North Atlantic right whales initially increased in number with the onset of the Holocene, but then started to decline about 6000–8000 years ago. These trends might have been the result of the so-called '8.2 kya event', when there was a sudden, major release of meltwater into the North Atlantic, lowering water temperatures and causing a decrease in ocean productivity. Assessments such as this can help assess how whale populations might respond to modern changing climate and oceanic conditions and suggest that some impacts may be long-lasting.

(SOURCE: Cabrera, A.A., Schall, E., Bérubé, M. et al. 2022. Strong and lasting impacts of past global warming on baleen whales and their prey. Global Change Biol. 28: 2657–2677, https://doi.org/10.1111/gcb.16085)

Gulf Stream Migration Makes Northwest Atlantic One of the Fastest Warming Ocean Regions

The Northwest Atlantic Shelf is experiencing marine heat waves, changes in fisheries composition and a surge in sea level rise. This is an area inhabited by many cetacean species, most notably the endangered North Atlantic right whale. Satellite data show that, when the Gulf Stream migrates closer to the underwater plateau of the Grand Banks (Newfoundland), it blocks the southwest flow of the Labrador Current, which would bring less saline, colder and more oxygen-rich water to the North American shelf. The most recent decade has been the hottest on record at the edge of the northeast United States and Canada, because the presence of the Gulf Stream prevented the inflow of this cooler water. By monitoring the flow of these currents (via satellite), it may be possible to predict impacts on this area and its marine ecology.

(SOURCE: Gonçalves Neto, A., Langan, J.A. and Palter, J.B. 2021. Changes in the Gulf Stream preceded rapid warming of the Northwest Atlantic Shelf. Comm. Earth Environ. 2: 74, https://doi.org/10.1038/s43247-021-00143-5)

Latest IPCC Report: "Oh God, Oh God, We're All Gonna Die" (Wash, *Serenity*, 2005)

The Latest IPCC report has some stark predictions for the planet. More than a trillion tons of anthropogenic carbon dioxide have entered the atmosphere since the start of the Industrial Revolution, leading to an average global temperature rise of more than 1^{o} C compared to the late 19th century. These emissions, even if they ceased tomorrow, have set in motion a certain amount of irreversible change, leading to impacts that are larger than estimated in previous assessments. Shifts in seasonal timing of natural processes, such as annual animal migrations, have already occurred, with many species populations shifted poleward. Stronger hurricanes have damaged coastal ecosystems. Aquatic diseases, including zoonoses, are emerging in new areas. The oceans have become warmer, more acidic and depleted of oxygen, resulting in kelp forests, sea grass beds, coral reefs and other marine habitats being severely degraded. "Globally, and even within protected areas, unsustainable use of natural resources, habitat fragmentation, and ecosystem damage by pollutants increase ecosystem vulnerability to climate change". The best case scenarios, which look increasingly unlikely given the lack of emissions reductions, have a minimum temperature rise of 1.5^{o} C, which risks a biodiversity loss for marine species ranging from "moderate" to "very high", including the loss of most coral reefs. The window of opportunity within which to act is ever smaller, and any action now must be significant to make a difference. In less than a century, the annual extinction rate could equal the rate caused by human activities over the past 12,000 years. To date, climate adaptation responses around the world have largely been reactive, small and "designed to respond to current impacts or near-term climate change risks", rather than to the major changes that are coming.

(SOURCE: IPCC. 2022. Climate Change 2022. Impacts, Adaptation and Vulnerability, https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/)

Researchers Discover a Surprising Cause for the 'Little Ice Age' and Implications for the Currently Changing Climate

The 'Little Ice Age', a period of cooling in the North Atlantic that started approximately 600 years ago, was one of the coldest periods of the last 10,000 years. It had a major impact on human history, agriculture and ecosystems. The authors reconstructed 3000 years of North Atlantic sea surface temperatures. Normally warm water from the tropics flows northwards and across the Atlantic, and, when it reaches cold Arctic waters, cools, becomes denser and sinks. This process is known as the Atlantic Meridional Overturning Circulation (AMOC). In the late 1300s, there was an unusually strong northward transfer of warm water and the waters south of Greenland and off Norway became much warmer than usual. This resulted in rapid Arctic ice loss. In only two decades, this melting led to large amounts of ice and meltwater entering the North Atlantic. This cooled North Atlantic waters and also reduced the salinity of surface waters and surface water density, ultimately leading to a severe weakening of the AMOC. Without this conveyor belt of warm tropical water transferring to the North Atlantic weather systems, Europe experienced the Little Ice Age. The fact that an increasing flow of warm water and melting Arctic ice triggered this substantial climatic shift, and over a period of just 20 years, has implications for the possible trajectory of our current climate.

(SOURCE: Lapointe, F. and Bradley, R.S. 2021. Little Ice Age abruptly triggered by intrusion of Atlantic waters into the Nordic Seas. Sci. Adv. 7: eabi8230, https://www.science.org/doi/pdf/10.1126/sciadv.abi8230)

Climate Change Impacts on Marine Mammals: Many Climate Change Predictions Realised but also Some Surprise Effects

Orgeret *et al.* (2022) reviewed the literature on impacts of climate change on marine mammals (n = 154 studies), encompassing 23 species of toothed whale and 11 species of baleen whale (as well as polar bears and 22 species of pinniped). Eighty-three percent of the data came from the northern hemisphere and 53% from polar regions. Thirty-four percent reported on demographic changes such as decreases in reproductive success and increases in adult mortality. Five percent reported on phenology and 8% on climate influences on diet. Very few investigated physiological impacts of climate change. Studies had to continue for 10 years at a minimum before an impact on marine mammals could be detected. Studies on Arctic marine mammals needed at least 19 years before an impact was detected. Species with a narrow window of thermal tolerances and longer generation times were more likely to be affected by changing climate. Gulland *et al.* (2022) also reviewed documented climate change effects on marine mammals, but focused on US waters and on which observations matched past predictions. Observed effects included species distribution shifts, but as yet there have been few studies showing evidence of changes in population abundance or vital rates in this region. While many of the observed effects of climate change were predicted (including shifting distributions), there have also been surprises, often because of a combination of climate change effects and human activities (e.g. increasing entanglement rates because of shifts in migration timing or distributions, leading to new overlaps with fisheries) or alterations in predator-prey relationships (e.g. increased attacks by killer whales on bowhead whales, or by bottlenose dolphins on harbour porpoises, as distributions shift). Such unpredicted effects complicate implementing conservation actions. Moreover, some climate change predictions have yet to be confirmed with evidence. The latter may reflect a lack of research attention. Gulland *et al.* emphasised the need for more focused research on the effects of climate change on marine mammals, and the need for managers to monitor closely, and be able to react quickly, should more unexpected climate change impacts occur.

(SOURCES: Orgeret, F., Thiebault, A., Kovacs, K.M., Lydersen, C., Hindell, M.A., Thompson, S.A., Sydeman, W.J. and Pistorius, P. 2022. Climate change impacts on seabirds and marine mammals: The importance of study duration, thermal tolerance and generation time. Ecol. Lett. 25, 218-239, https://doi.org/10.1111/ele.13920; Gulland, F.M.D., Baker, J.D., Howe, M., LaBrecque, E., Leach, L., Moore, S.E., Reeves, R.R. and Thomas, P.O. 2022. A review of climate change effects on marine mammals in United States waters: past predictions, observed impacts, current research and conservation imperatives. Climate Change Ecol. 3: 100054, https://doi.org/10.1016/j.ecochg.2022.100054)

WHALE DISTRIBUTION HAS SHIFTED IN RESPONSE TO CLIMATE CHANGE FASTER THAN THEIR PREY SPECIES

It has been assumed that warm-blooded marine mammals would be less affected by changing water temperatures than their cold-blooded prey. The authors investigated the effect of climate change on the movement of long-finned pilot whales and their prey, over a 25-year period. The distribution of whales in the waters off the northeast United States shifted northwards as ocean temperatures rapidly warmed, but this distribution surprisingly shifted at three times the rate of their fish and squid prey species. The shifts in whale distribution were correlated with sea surface temperatures rather than with shifts in their prey distribution, which may have major implications for food web ecology and ecosystem structure.

(SOURCE: Thorne, L.H. and Nye, J.A. 2021. Trait-mediated shifts and climate velocity decouple an endothermic marine predator and its ectothermic prey. Sci. Rep. 11: 18507, https://doi.org/10.1038/s41598-021-97318-z)

Noise impacts

PORTS CAN PLAY AN IMPORTANT ROLE IN REDUCING VESSEL NOISE

In an effort to reduce the noise stress on killer whales in the Canadian Pacific Ocean, the port of Vancouver offers incentives for quieter ships, but methodological issues hinder determining relative quietness. Ainslie *et al.* (2022) described two Canadian-led projects seeking to improve the harmonisation of underwater radiated noise measurements. One project supported efforts by the International Organization for Standardization; the other project involved efforts by ship classification societies. Virto *et al*. (2022) also examined the role ports can play in reducing vessel noise. Ports can support changes in hull, propeller and engine design, along with measures such as reduced speeds, route changes and even travel in convoy. Discounted port fees and reduced ship waiting times for quieter vessels are additional ways ports can facilitate the development of quieter vessels. The authors also noted that noise measurement methodologies should be standardised and that few vessel owners know their noise emissions. Noise reduction programmes should align with ongoing vessel-owner issues, such as fuel and ballast water requirements. Finally, Vakili *et al*. (2021) argued for a transdisciplinary policy framework—aligned with the IMO's initial Greenhouse Gas strategy—within which shipping companies would mitigate underwater noise pollution.

(SOURCES: Ainslie, M.A., Martin, S.B., Trounce, K.B., Hannay, D.E., Eickmeier, J.M., Deveau, T.J., Lucke, K., MacGillivray, A.O., Nolet, V. and Borys, P. 2022. International harmonization of procedures for measuring and analyzing of vessel underwater radiated noise. Mar. Pollut. Bull. 174: 113124, https://doi.org/10.1016/j.marpolbul.2021.113124; ¿ Virto, L.R., Dumez, H., Romero, C. and Bailly, D. 2022. How can ports act to reduce underwater noise from shipping? Identifying effective management frameworks. Mar. Pollut. Bull. 174: 113136, https://doi.org/10.1016/marpolbul.2021.113136; Vakili, S., Ölcer, A.I. and Ballini, F. 2021. The development of a transdisciplinary policy framework for shipping companies to mitigate underwater noise pollution from commercial vessels. Mar. Pollut. Bull. 171: 112687, https://doi.org/10.1016/j.marpolbul.2021.112687)

WHALES REACT TO PETROL ENGINE WHALE WATCHING VESSELS BUT NOT TO ELECTRIC ENGINE VESSELS

Drones were used to monitor the behaviour of short-finned pilot whale mother and calf pairs in relation to whale watching vessels off the coast of Tenerife, Spain. Groups were passed by electric and petrol-engine vessels at a distance of 60 m (in compliance with Canary Islands whale watching guidelines). Mothers approached by the vessel with the petrol engine spent on average 29% less time resting and 81% less time nursing their calves. However, there was no significant difference in resting or nursing behaviour in whales approached by the vessel with the electric engine, when compared to those not approached by a vessel.

(SOURCE: Arranz, P., Glarou, M. and Sprogis, K.R. 2021. Decreased resting and nursing in short-finned pilot whales when exposed to louder petrol engine noise of a hybrid whale-watch vessel. Sci. Reports 11: 21195, https://doi.org/10.1038/s41598-021-00487-0)

NEW METHODOLOGIES IMPROVES UNDERSTANDING OF FREE-RANGING SMALL CETACEAN RESPONSES TO NAVY SONAR

Navy mid-frequency active sonar is used for submarine detection and has caused atypical mass strandings in certain (deep-diving) cetaceans. This has triggered much research on cetacean responses to this noise source. A controlled exposure experiment approach involving shore-based group tracking, aerial photogrammetry and passive acoustics improved response detection in faster-swimming small cetaceans, for which high-resolution, multi-sensor tags are not an option. Importantly, these methodologies allow researchers to study group behaviour, which is a more relevant metric than individual responses for social species such as these.

(SOURCE: Durban, J.W., Southall, B.L., Calambokidis, J., Casey, C., Fearnbach, H., Joyce, T.W., Fahlbusch, J.A., Oudejans, M.G., Fregosi, S., Friedlaender, A.S., Kellar, N.M. and Visser, F. 2022. Integrating remote sensing methods during controlled exposure

experiments to quantify group responses of dolphins to navy sonar. Mar. Pollut. Bull. 174: 113194, https://doi.org/10.1016/j.marpolbul.2021.113194)

Efforts to Harmonise Underwater Noise Measurements and Reduce Noise in ORCA Class Navy Ships

In the framework of better understanding noise with respect to Canadian whale populations, an effort was made to redesign the propeller of a Royal Canadian Navy ORCA-class training vessel. Numerical approaches showed promise for reducing propeller noise, but model scale testing failed to show the expected improvements. These efforts will be continued both for the navy vessel and for civilian ships, focusing on retrofit scenarios and examining trade-offs (e.g. speed). This includes the manufacture, installation and testing of a noise-optimised propeller on an ORCA training vessel.

(SOURCE: Gilroy, L. 2022. Ship noise management and the ORCA class of ships. Mar. Pollut. Bull. 174: 113196, https://doi.org/10.1016/j.marpolbul.2021.113196)

Seal Bomb Explosives to Protect Fishing Gear a Cause for Concern

Acoustic devices are often used to deter marine predators from aquaculture sites and fishing gear. In Southern California, explosives, referred to as 'seal bombs', are often used to deter pinnipeds from fishing gear. Between 2005 and 2016, passive acoustic monitoring within the Southern California Bight and near Monterey Bay recorded high numbers of these explosions. Up to 2800 explosions were recorded per day at received sound exposure levels of up to 189 dB re 1 μPa^2 -s, i.e. at sound levels high enough to cause impacts to cetaceans. The spatio-temporal patterns of the explosions suggested seal bombs were being used extensively in the Californian squid purse-seine fishery. The impacts of this wide-scale use of explosives need to be evaluated, and environmental regulations should be required to reduce the impacts of these explosives on marine life.

(SOURCE: Krumpel, A., Rice, A., Frasier, K.E., Reese, F., Trickey, J.S., Simonis, A.E., Ryan, J.P., Wiggins, S.M., Denzinger, A., Schnitzler, H.-U. and Baumann-Pickering, S. 2021. Long-term patterns of noise from underwater explosions and their relation to fisheries in Southern California. Front. Mar. Sci. 8: 796849, https://doi.org/10.3389/fmars.2021.796849)

Small Boats—Beyond Shipping Vessels—Need to be Considered in Reducing Noise Levels

Small boats are abundant in most shallow waters worldwide. Wilson *et al.* (2022) examined four high-pressure recreational boating sites in New Zealand, some of which include MPAs and enjoy the highest protection the country affords to marine habitats. Such boats, however, significantly increased the low-frequency (100–88 kHz) component of the soundscape—the frequency band used by many species for communication, orientation and predator avoidance. Only half of the world's marine reserves currently place restrictions on recreational boating, and the authors argued for a zoned marine reserve design and/or implementing speed restrictions, "as has been successful in reducing sound emissions and ship strikes of whales by commercial ships". Lo *et al.* (2022) made progress in estimating vessel speeds in the critical habitat of the endangered southern resident killer whales in Canada. Vessel speed is another important criterion determining noise levels, and this study also included small boats that lack Automatic Identification Systems.

*(SOURCES: Wilson, L., Pine, M.K. and Radford, C.A. 2022. Small recreational boats: a ubiquitous source of sound pollution in shallow coastal habitats. Mar. Pollut. Bull. 174: 113295, https://doi.org/10.1016/j.marpolbul.2021.113295; Lo, C.F., Nielson, K.A., Ashe, E., Bain, D.E., Mendez-Bye, A., Reiss, S.A., Bogaard, L.T., Collins, M.S. and Williams, R. 2022. Measuring speed of vessels operating around endangered southern resident killer whales (*Orcinus orca*) in Salish Sea critical habitat. Mar. Pollut. Bull. 174: 113301, https://doi.org/10.1016/j.marpolbul.2021.113301)*

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Appendix 1

GLOSSARY

Glossary of terms

Bathymetry: The measurement of water depth in oceans, seas or lakes.

Benthic: Of, relating to or occurring at the bottom of a body of water, such as the ocean.

Bioaccumulation: Increase in concentration of a pollutant within an organism compared to background levels in its diet. Pollutant levels are highest in older individuals.

Biological carbon pump: The ocean's biological sequestration of carbon from the atmosphere and land runoff to the seabed sediments, where it often remains for thousands of years.

Biomagnification: To increase the concentration of a contaminant from one link in a food chain to another. Pollutant levels are highest in top predators.

CCAMLR: Commission for the Conservation of Antarctic Marine Living Resources.

Chlordane: An organochlorine pesticide.

Copepod: A small or microscopic aquatic crustacean.

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

Diatom: A single-celled alga that has a cell wall of silica.

DL-PCB: Dioxin-like polychlorinated biphenyl.

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

Diene: A hydrocarbon.

El Niño: The warm phase of the El Niño-Southern Oscillation and is associated with a band of warm ocean water that develops in the central and east-central equatorial Pacific, including the area off the Pacific coast of South America.

Endemic: Native and restricted to a certain place

HAB: Harmful algal bloom.

HCB: Hexachlorobenzene, a chlorinated pesticide.

HCH: Hexachlorocyclohexane, a chlorinated pesticide.

Heptachlor: An organochlorine compound that was used as an insecticide.

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

IMO: International Maritime Organisation.

IPCC: Intergovernmental Panel on Climate Change.

IUCN: International Union for Conservation of Nature.

Keystone species: A species on which other species in an ecosystem largely depend, such that if it were removed the ecosystem would change drastically.

µg: Microgram, one thousandths of a gram.

μPa^2-s: Micropascal squared per second, a reference pressure for underwater sound exposure level.

MARPOL: The International Convention for the Prevention of Pollution from Ships.

Microplastics: Plastic particles 0.3-5 mm 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.

Nanoplastics: Plastic particles less than 1 µm in diameter.

Niche partitioning: The process by which natural selection drives competing species into different patterns of resource use or different ecological niches.

Ocean acidification: A reduction in the pH of the ocean over an extended period of time, caused primarily by uptake of carbon dioxide from the atmosphere.

OHI: Ocean Health Index.

Omics: The branches of biology ending in the suffix *-omics*, such as genomics, proteomics, and metabolomics. Omics sciences aim to characterise and quantify biological molecules that translate into the structure, function and dynamics of an organism or organisms.

OPEs: Organophosphate esters, widely used in industry and households as plasticisers, flame retardants and antifoaming agents.

PAH: Polycyclic aromatic hydrocarbon.

PAME: Protection of the Arctic Marine Environment.

PBDE: Polybrominated diphenyl ether.

PCB: Polychlorinated biphenyl.

PCDDs: Dibenzo-p-dioxins.

PCDFs: Polychlorinated dibenzofurans.
Phenology: The study of cyclic and seasonal natural phenomena, especially in relation to climate and plant/animal life.
Photogrammetry: The use of photography to measure distances between, or size of, objects, including animals.
Polyamide: A polymer with repeating units linked by amide bonds. Polyamides occur both naturally and artificially.
Polyethylene: A tough, light, flexible synthetic resin made by polymerising ethylene, chiefly used for plastic bags, food containers and other packaging. The most common plastic in use today.
Polymer: A substance that has a molecular structure consisting chiefly or entirely of a large number of similar units bonded together, e.g. many synthetic organic materials used as plastics and resins.
Polypropylene: A synthetic resin, a polymer of propylene, used especially for ropes, fabrics and moulded objects.
Polystyrene: Styrofoam.
POPs: Persistent organic pollutants, organic compounds that are resistant to degradation and thus persist in the environment.
PPCP: Pharmaceutical and personal care products.
Pteropod: A small mollusc with wing-like extensions to its body that it uses for swimming.
Salp: A free-swimming marine invertebrate related to the sea squirts, with a transparent barrel-shaped body.
SD: Standard deviation.
Sentinel species: Organisms, often animals, used to detect risks to humans by providing advance warning of a danger.
UN: United Nations.
UNEA: United Nations Environment Assembly.
UNEP: United Nations Environment Programme.
Water column: A conceptual column of water extending from the sea surface down to the seafloor.
Zoonosis: A disease transmissible from other animals to humans and vice versa (plural: zoonoses).

Species glossary

Antarctic minke whale	*Balaenoptera bonaerensis*
White (beluga) whale	*Delphinapterus leucas*
Blue whale	*Balaenoptera musculus*
Bowhead whale	*Balaena mysticetus*
Bryde's whale	*Balaenoptera edeni*
Common bottlenose dolphin	*Tursiops truncatus*
Common minke whale	*Balaenoptera acutorostrata*
Fin whale	*Balaenoptera physalus*
Gray whale	*Eschrichtius robustus*
Harbour porpoise	*Phocoena phocoena*
Humpback whale	*Megaptera novaeangliae*
Killer whale	*Orcinus orca*
Long-finned pilot whale	*Globicephala melas*
Narwhal	*Monodon monoceros*
North Atlantic right whale	*Eubalaena glacialis*
Northern bottlenose whale	*Hyperoodon ampullatus*
Sei whale	*Balaenoptera borealis*
Short-finned pilot whale	*Globicephala macrorhynchus*
Sperm whale	*Physeter macrocephalus*
White-beaked dolphin	*Lagenorhynchus albirostris*
Crabeater seal	*Lobodon carcinophagus*
Harbour seal	*Phoca vitulina*
Northern fur seal	*Callorhinus ursinus*
North Pacific sea otter	*Enhydra lutris*
Polar bear	*Ursus maritimus*
Ross seal	*Ommatophoca rossii*
Steller sea lion	*Eumetopias jubatus*
Weddell seal	*Leptonychotes weddellii*
Northern fulmar	*Fulmarus glacialis*
Black-footed kittiwake	*Rissa tridactyla*
Antarctic silverfish	*Pleuragramma antarcticum*
Antarctic krill	*Euphausia superba*
Krill	Family Euphausiidae (euphausiids)

Heavy metals

Cd	Cadmium
Cu	Copper
Fe	Iron
Hg	Mercury
Pb	Lead
Zn	Zinc