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Distribution of endemic cetaceans in relation to hydrocarbon development and commercial shipping in a warming Arctic

Randall R. Reeves [a], Peter J. Ewins [b,*], Selina Agbayani [c], Mads Peter Heide-Jørgensen [d], Kit M. Kovacs [e], Christian Lydersen [e], Robert Suydam [f], Wendy Elliott [g], Gert Polet [h], Yvette van Dijk [i,1], Rosanne Blijleven [i,2]

[a] Okapi Wildlife Associates, 27 Chandler Lane, Hudson, Quebec, Canada J0P 1H0
[b] WWF-Canada, 245 Eglinton Avenue East, Suite 410, Toronto, Ontario, Canada M4P 3J1
[c] WWF-Canada, 409 Granville St., Suite 1588, Vancouver, B.C., Canada V6C 1T2
[d] Greenland Institute of Natural Resources, Box 570, 3900 Nuuk, Greenland
[e] Norwegian Polar Institute, 9296 Tromsø, Norway
[f] Department of Wildlife Management, North Slope Borough, Barrow, AK, USA
[g] WWF-International, 1196 Gland, Switzerland
[h] WWF-Netherlands, Driebergseweg 10, 3708 JB Zeist, The Netherlands
[i] Van Hall Larenstein, University of Applied Sciences, Agora 1, 8901 BV Leeuwarden, The Netherlands

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ABSTRACT

The Arctic is one of the fastest-changing parts of the planet. Global climate change is already having major impacts on Arctic ecosystems. Increasing temperatures and reductions in sea ice are particular conservation concerns for ice-associated species, including three endemic cetaceans that have evolved in or joined the Arctic sympagic community over the last 5 M years. Sea ice losses are also a major stimulant to increased industrial interest in the Arctic in previously ice-covered areas. The impacts of climate change are expected to continue and will likely intensify in coming decades. This paper summarizes information on the distribution and movement patterns of the three ice-associated cetacean species that reside year-round in the Arctic, the narwhal (*Monodon monoceros*), beluga (white whale, *Delphinapterus leucas*), and bowhead whale (*Balaena mysticetus*). It maps their current distribution and identifies areas of seasonal aggregation, particularly focussing on high-density occurrences during the summer. Sites of oil and gas exploration and development and routes used for commercial shipping in the Arctic are compared with the distribution patterns of the whales, with the aim of highlighting areas of special concern for conservation. Measures that should be considered to mitigate the impacts of human activities on these Arctic whales and the aboriginal people who depend on them for subsistence include: careful planning of ship traffic lanes (re-routing if necessary) and ship speed restrictions; temporal or spatial closures of specified areas (e.g. where critical processes for whales such as calving, calf rearing, resting, or intense feeding take place) to specific types of industrial activity; strict regulation of seismic surveys and other sources of loud underwater noise; and close and sustained monitoring of whale populations in order to track their responses to environmental disturbance.

1. Introduction

Polar amplification of climate change is having major implications for the wildlife and people of the Arctic region. Global warming, and in particular the reduction of multi-year ice and the seasonal sea ice extent and duration, has already begun to influence human activities in this region. Increased tourist traffic, shipping, exploration, and development will lead to more frequent and severe conflicts with Arctic marine wildlife. Arctic marine mammals, like other Arctic vertebrates, are specially adapted to take advantage of the climatic conditions that have prevailed in the Arctic for millions of years [1]. Arctic endemic whales, phocid seals, walruses (*Odobenus rosmarus*), and polar bears (*Ursus maritimus*) are of great interest and conservation concern for several reasons, including their role in the functioning of Arctic ecosystems, their importance in subsistence economies and cultures of some northern hunting communities, and their appeal as icons of tourism and subjects of scientific study. All of these

* Corresponding author. Tel.: +1 416 484 7711; fax: +1 416 489 3611.
E-mail address: pewins@wwfcanada.org (P.J. Ewins).
[1] Present address: Fongersplaats 133, 9725 LG Groningen, The Netherlands.
[2] Present address: Koningsspil 19, 1834 TG Sint Pancras, The Netherlands.

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animals have been important to northern nations as sources of oil, hides, and other valuable products and have provided important cultural elements and resources for coastal aboriginal communities.

Numerous recent studies have highlighted the threat to Arctic marine mammals posed by climate change (e.g. [2–9]). This review was stimulated by the need for a better understanding of the implications of ongoing environmental changes in the Arctic for cetaceans in order to develop effective conservation and management policies.

Three species of cetaceans occur year-round in the Arctic: the bowhead whale (*Balaena mysticetus*), the only baleen whale resident in the Arctic, and the narwhal (*Monodon monoceros*) and white whale or beluga (*Delphinapterus leucas*), two closely related toothed whales. All three species are restricted to high latitudes of the Northern Hemisphere and therefore can be regarded as Arctic endemics even though some populations (of belugas in particular) occur in sub-Arctic or northern cold temperate regions (e.g. southern Hudson Bay, Cook Inlet, southern Bering Sea, Sea of Okhotsk, south-western Greenland, River and Gulf of St. Lawrence). Many other cetacean species enter Arctic waters seasonally (e.g. gray whales, *Eschrichtius robustus*; blue whales, *Balaenoptera musculus*; humpback whales, *Megaptera novaeangliae*; common minke whales, *Balaenoptera acutorostrata*; killer whales, *Orcinus orca*; northern bottlenose whales, *Hyperoodon ampullatus*), but this paper focuses only on the three resident Arctic species.

This review summarizes what is known about, and maps, the current ranges of the three Arctic cetacean species. It then identifies areas where two specific types of human activity – oil and gas development and commercial shipping – overlap with those ranges. Both categories of industrial activity have the potential to affect marine mammals in multiple ways, and both will almost certainly contribute to the cumulative impacts of rapidly changing environmental conditions on the local or regional whale populations. Oil and gas development, from its initial prospecting phase involving marine seismic surveys through to the construction of artificial islands or offshore drilling platforms, and into the actual extraction and transport of hydrocarbon products phase, affects the acoustic environment and broader ecology of whales over considerable distances. These activities also put them at risk of ship strikes and increase the potential for exposure to spilled or leaked oil and other harmful substances. Commercial vessel traffic also adds underwater noise and increases the risk of ship strikes and pollution by oil and other contaminants. In short, the expansion of industrial and commercial activity in the Arctic, facilitated by the rapid, climate-induced retreat of sea ice cover, is bound to transform the marine environment in the North from its currently near-pristine state to one that has much higher levels of anthropogenic sound and is more crowded and hazardous for marine wildlife. This has implications not only for the conservation of these whales and their habitat, but also for the human communities that depend on marine mammals for nutritional sustenance and cultural cohesion in many Arctic regions.

For a working definition of the Arctic, this review uses boundary lines developed by the Arctic Council's Working Group on the Conservation of Arctic Flora and Fauna (CAFF), which combine climatic and bio-geographical criteria [10]. Although CAFF boundary lines occur on all of the distribution maps presented, the depictions of whale distributions represent the full ranges of the three species both within and outside the CAFF region. Our depictions of hydrocarbon development and shipping activity primarily cover areas inside the CAFF boundary but also include some contiguous temperate areas (linked to the Arctic by major currents) and the seasonally ice-covered Okhotsk Sea.

2. Materials and methods

2.1. Whale distribution maps

Production of the three maps of whale distribution was an iterative process. Initially, ArcGIS 9.3.1 was used to create a series of maps showing the year-round distribution of the three species based on the literature. The draft maps were sent to species experts and stakeholder groups for review, and revised drafts were prepared based on the feedback received and the co-authors' collective knowledge. The revised draft maps were sent to additional experts for further review (see Acknowledgments). Revised versions of the maps were then generated using ArcGIS 10. The resultant maps show annual ranges and main summer distributions, with migration routes largely subsumed within the annual ranges. It is important to note that the distribution maps were not derived directly from point (e.g. sightings, catches) or tracking (i.e. telemetry) data, and no attempt was made to produce density 'surfaces' or to rank the functional importance of different parts of the distribution (e.g. to identify 'critical habitat'; cf. [11]).

The problem of determining the relative importance of different areas within a species' or a population's entire range is a familiar one, but beyond the scope of this paper; in any event, for many regions the knowledge base is not sufficient to conduct such assessments. Although there are many records of extralimital occurrences of all three species over the past few centuries, these 'outliers' are not mapped herein because of the difficulty of interpreting their significance or relevance. Given the availability of considerable information on commercial catches of bowhead whales over the last few centuries, areas where these whales were encountered regularly by whalers historically are included in the range map, but are differentiated from currently occupied regions if they have not been re-occupied by significant numbers of whales since the end of commercial whaling. No similar attempt was made to map areas formerly inhabited by belugas from which they were effectively extirpated, such as south-western Greenland [12].

2.2. Hydrocarbon development map

Data were compiled on the distribution of oil and gas deposits and development activity in the Arctic (and adjacent cold temperate regions), including projects that are (a) already in production, (b) in an exploratory or verification phase, and (c) at the lease-sale or offering stage (see Appendix A). Locations of oil and gas wells and lease areas were downloaded from the websites of relevant data custodians for each region of the Arctic (see Appendix A). Where data were not readily available as GIS files, information from maps and reports available online were digitized to produce GIS files. The resultant dataset is by no means comprehensive, but it is a reasonable representation of the distribution of the main oil and gas industry activities and interests in the Arctic, based on available data as of late May 2013.

Potential future development is also highlighted via the presentation of data on hydrocarbon provinces (variably referred to as basins or regions, depending on the source), which were digitized from published maps [13]. In order to match the extent of the cetacean ranges in the western North Atlantic, the Atlantic Margin hydrocarbon basin off eastern Canada [14] was added to the dataset. Suitable maps or spatial data on hydrocarbon basins in the Sea of Okhotsk were not available, so this region was excluded from our examination of bowhead whale and beluga ranges in relation to oil and gas provinces.

The resultant overview map of hydrocarbon resources includes a layer showing the major known hydrocarbon provinces in the Arctic, as well as lease areas (including areas that have been leased, and areas that government authorities deem to be

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'available for lease', in other words possible future lease areas), and the sites of offshore wells (mainly fixed structures but in some cases the locations of temporary seasonal drilling sites). The precise criteria for these classifications vary by nation (see Fig. 4 and Appendix A).

On the map, no distinction is made between production and exploration wells, and in some cases the wells may have been capped (or plugged and abandoned). The extensions of hydrocarbon provinces and structures to the south across the 'Arctic' boundary are included on the map in order to show the intensity of offshore hydrocarbon exploration and development activity in areas just outside the margins of sea ice in relation to the limits of regular occurrence of the three whale species. This intensity may be indicative of what industrial expansion will look like as the limits of sea ice (and probably whale ranges) shift northward.

2.3. Shipping map

Overlap between commercial shipping and the ranges of the Arctic whales was examined after collating available data on ship traffic routes and the density or intensity of their use. While a variety of ship traffic datasets is available (e.g. [15]), none is comprehensive, i.e. covering the Arctic year-round and including all vessel types. Until recently, most monitoring in the Arctic has involved only voluntary reporting schemes such as that of the World Meteorological Organization (WMO, see below). Automatic satellite-based tracking is increasingly used to monitor ship traffic, but has not been fully implemented as yet in Arctic waters. The principal source used herein is a circum-Arctic shipping dataset compiled by the Norwegian Coastal Administration (NCA) and Det Norske Veritas (DNV) for all vessels carrying an Automatic Identification System (AIS) transponder in 2012 (Fig. 5; [16]). The Arctic traffic in 2012 is shown by vessel type and size class in Table 1.

3. Results

3.1. Bowhead whales

The distribution of bowhead whales is nearly circumpolar although the heavy ice conditions that have prevailed over the last millennium in the Arctic Basin have impeded (but not completely blocked [17,18]) their movement in the Northwest and Northeast Passages (Fig. 1). The global population of bowhead whales likely numbers well over 18,000 and some populations are increasing [22]. Two of the four currently recognized subpopulations are completely protected from whaling and are red-listed by IUCN as Endangered (Okhotsk Sea subpopulation) or Critically Endangered (Svalbard-Barents Sea subpopulation). A third, the Eastern Canada–West Greenland (ECWG) subpopulation, has not been assessed recently by IUCN but numbers in the thousands and is increasing [23–26]. The Bering–Chukchi–Beaufort Seas (BCB) subpopulation has recovered to the point that it is now classified as Least Concern by IUCN. It was estimated to number 12,631 animals (CV=0.2442) in 2004 [27] and to have increased at a rate of 3.4% (95% CI 1.7% to 5%) from 1978 to 2001 [22].

The distribution of bowhead whales is reasonably well known in most regions from whaling data (e.g. 19–21), visual surveys, passive acoustic monitoring, observations by hunters and other Arctic residents, and satellite-linked telemetry tracking records. However, their occurrence could go unnoticed in some parts of the Arctic (e.g. the Canadian High Arctic archipelago and areas off the Siberian coast) where there is little human activity or presence. In recent years, telemetry data have significantly improved the understanding of year-round movements and habitat use by bowhead whales [28–33]. All four subpopulations are migratory to some degree although the nature and scale of bowhead movements appear to vary locally or regionally. Movements into the Northwest Passage by satellite-tagged whales from both the BCB and ECWG subpopulations indicate the potential for regular mixing, a potential that is likely enhanced by the ongoing amelioration of sea ice conditions [34].

Based on old commercial whaling records, portions of the historical summer range of bowhead whales in the Bering Sea (19th century) and the range in various seasons in the Labrador/Gulf of St. Lawrence region (16th to 19th centuries) apparently have not been re-occupied even though commercial whaling for bowheads largely ceased about a hundred years ago. It is nonetheless notable that bowheads have been observed occasionally in recent years along the east coast of North America south to Newfoundland [35] and even Cape Cod, Massachusetts [36].

The sensitivity of bowhead whales to industrial activity has been the subject of study in northern Alaska and Canada since the 1980s [37–40]. They exhibit avoidance responses to ship, seismic, and other noise at low (received) levels at distances of 30–50 km in autumn but tend to tolerate higher noise levels when feeding, even though they may show subtle changes in diving, swimming, and acoustic behavior in these circumstances [41–44]. The risks to baleen whales of oil in the water have long been recognized [45,46]. In the case of bowheads, their long, finely fringed baleen creates special concern with respect to oil spills because their ability to feed efficiently would be impaired if the baleen were fouled by oil encountered at the surface or in the water column [47,48]. This concern is in addition to that arising from the

Table 1
Sailed distances in the Arctic during 2012 for vessels of different type and Gross Tonnage (GT) carrying AIS transponders. Distances are reported in nautical miles; data provided by the Norwegian Coastal Administration (NCA) and Det Norske Veritas (DNV).

Ship type	< 10,000 GT	1000–4999 GT	5000–9999 GT	10,000–24,999 GT	25,000–49,999 GT	50,000–99,999 GT	≥ 100,000 GT	Total
Oil tanker		145,268	17,919	53,659	85,868	124		**302,836**
Chemical /Production tanker	456	119,123	47,503	41,945	8029			**217,057**
Gas tanker							6769	**6769**
Bulk carrier		6014	1276	45,794	81,519			**134,602**
General cargo	21,219	322,840	138,514	44,042	1153			**527,769**
Container vessel			77,491	200,997				**278,487**
Roll-on/roll-off (RoRo)	14,352	2198		7463				**24,014**
Reefer	673	57,410	24,852	7787				**90,722**
Passenger	54,729	148,497	41,247	60,272	28,078	5384	3547	**341,753**
Offshore supply vessel	11,597	153,734	13,773	6753				**185,857**
Other offshore service vessel	45,704	1852		4545				**52,100**
Other activities	341,621	306,442	171,018	134,485	4219			**957,785**
Fishing vessel	955,999	1,572,398	46,300					**2,574,697**
Total	**1,446,350**	**2,835,776**	**579,894**	**607,741**	**208,866**	**5507**	**10,316**	**5,694,450**

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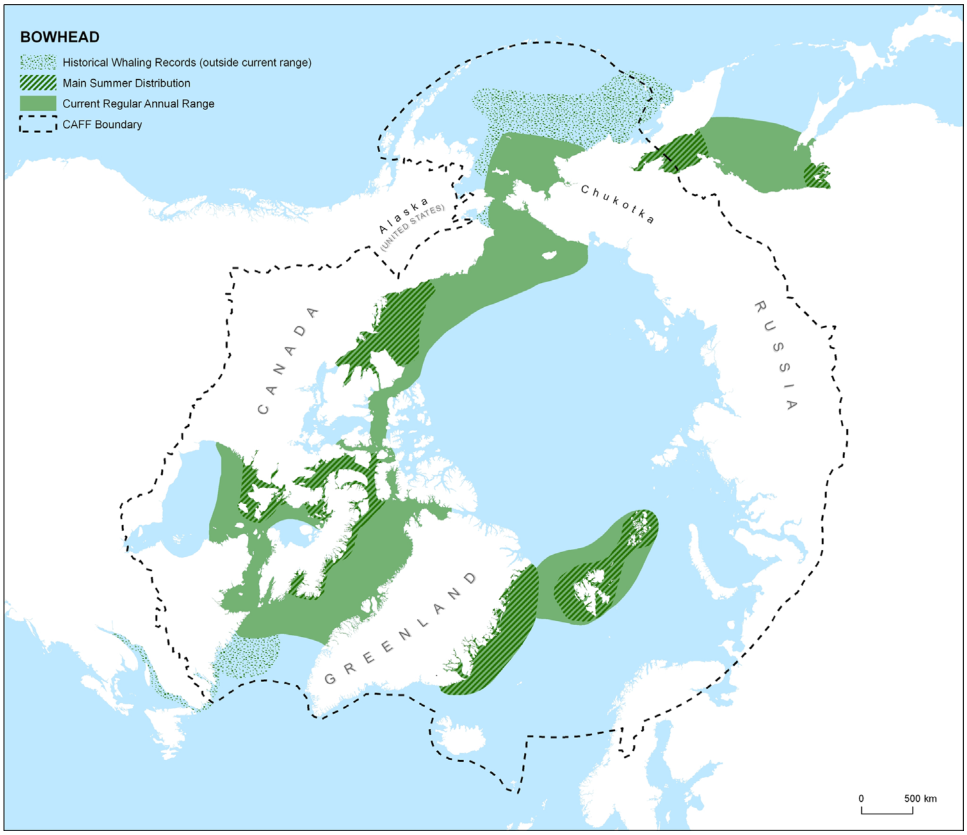

Fig. 1. Circumpolar distribution of bowhead whales, showing approximate current range where animals occur regularly during at least part of the year, as well as areas where they tend to occur in highest densities during the summer (July–September, inclusive). Additional stippled areas in the Bering Sea [19] and Labrador Sea/Gulf of St. Lawrence [20,21] represent historical whaling grounds where bowheads were observed during the summer and autumn in the 19th century (Bering Sea) and during various times of year in the 16th–19th centuries (St. Lawrence and Labrador), but where they no longer occur regularly, at least during those seasons.

potential for oil ingestion, directly or indirectly through affected prey.

3.2. Narwhals

Narwhals occur primarily in Arctic waters connected to the North Atlantic Ocean (Fig. 2). The total population is at least in the high tens of thousands, perhaps even in excess of 100,000. Recent estimates are: more than 60,000 in the Canadian High Arctic (Baffin Bay and adjacent waters) in the summer (2002–2004; [49]); another 14,000 off Northwest Greenland in the summer (2007: Inglefield Bredning 8368 (95% CI: 5209–13,442) and Melville Bay 6024 (95% CI: 1403–25,860); [50]); more than 6000 off East Greenland (2008: 6444 (95% CI: 2505–16,575); [50]); and about 12,500 in Hudson Bay and Hudson Strait (2011: 12,485 (95% CI 7515–20,743); [51]). The Svalbard-Barents Sea population has never been surveyed, but it is thought to be small (hundreds to low thousands). All populations are thought to be migratory and those that have been studied are quite predictable in their movements between summering and wintering areas.

The narwhal is red-listed by IUCN as Near Threatened [52]. Hunting levels in Greenland and Canada give cause for concern, particularly considering the lack of reliable data on hidden mortality and serious injury when shot or harpooned animals are not landed. Although loss rates are highly variable [53], one published study from Canada indicated that in ice-edge or ice-crack hunts more than half of the animals killed may be lost [54].

According to a comparative study of the sensitivity of different Arctic marine mammals to the ecological effects of climate change, the narwhal was judged to be one of the most sensitive species [3]. Its distribution is more limited than those of the other two endemic Arctic whales and it has a relatively narrow feeding niche. Concern has been expressed that noise from marine seismic surveys might disrupt the migratory behavior of narwhals and increase their risk of mass mortality from ice-entrapment [55]. Narwhals are shy by nature and have been observed to cease vocalizing and move away from large vessels at distances of 35–50 km [56,57]. Even the use of small outboard engines or the presence of sailboats can stimulate avoidance or the initiation of cryptic behavior in this species (K. Kovacs and C. Lydersen, and P. Ewins, pers. observ.).

In recent summers, narwhals, sometimes relatively large groups of them, have been observed in areas of the High Arctic where this species had rarely or never been reported previously. For example, in 2011 and 2012 groups were seen (and hunted) in Canada's Dolphin and Union Strait, well west of the previously known normal range [58]. Although there are few historical records of narwhals in Alaska, subsistence hunters reported eight observations along the North Slope between 1989 and 2008 (J.C. George and R. Suydam, North Slope Borough, Barrow, Alaska, unpublished data). Seven of these records were sightings of live animals in groups of up to 12 and one of them was a beach-cast tusk. The frequency of narwhal sightings appears to be increasing in northern Alaska and northwestern Canada. This shift in distribution is almost certainly related to ameliorating sea ice conditions. A marked increase in narwhal catches since 2002 at Siorapaluk, the northernmost community in Greenland, has been interpreted as reflective of major changes in sea ice conditions that give hunters easier access to the animals by boat in June and July [59]. It is unclear how to interpret recent observations of live narwhals or dead stranded ones along the ice-free west coast of Spitsbergen (Norwegian Polar Institute, Marine Mammal Sightings Database).

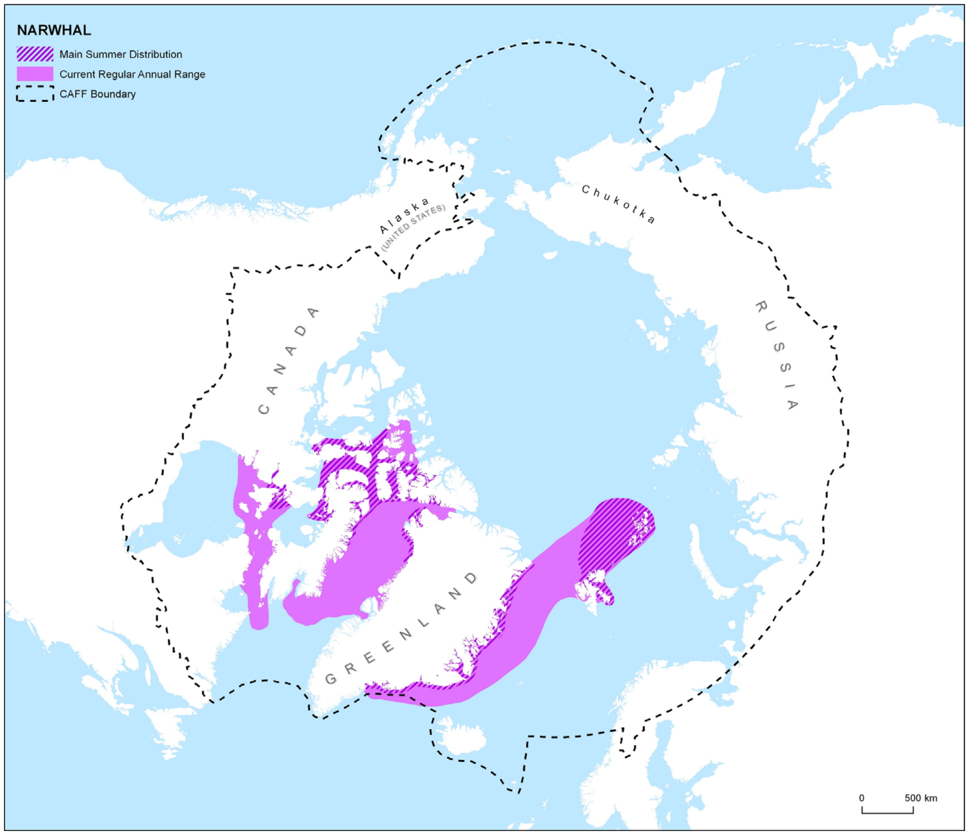

Fig. 2. Circumpolar distribution of narwhals, showing approximate current range where animals occur regularly during at least part of the year, as well as areas where they tend to occur in highest densities during the summer (July–September, inclusive).

3.3. Belugas

Belugas occur throughout much of the Arctic range of bowhead whales and narwhals, but they are more numerous and have a wider distribution that extends into the sub-Arctic (Fig. 3). Globally, there are probably at least 150,000 belugas, with more than 20 'stocks' or subpopulations, some of which are strongly migratory while others are fairly stationary [60–65]. The beluga, like the narwhal, is red-listed by IUCN as Near Threatened [66]. Some subpopulations are known to be in serious trouble, others have been considerably reduced but are still likely viable, and there is substantial uncertainty about beluga numbers and trends in some parts of the range. The largest subpopulations have reasonably good abundance estimates, including the animals that summer in the Beaufort Sea (39,258 in 1992; no confidence limits but considered negatively biased; [67]), eastern Bering Sea (28,406 in 2000; no confidence limits; [67]), western Hudson Bay (57,300, 95% CI: 37,700–87,100 in 2004; [68]), and the eastern Canadian Arctic (21,213 95% *CI*: 10,985–32,619 in 1996; [69]). Like narwhals, belugas are heavily hunted in some parts of their range, and some of the hunted populations remain depleted as a result of historical over-exploitation [12,64,67,70,71]. Seasonal movements of some populations are fairly local (e.g. Cook Inlet, St. Lawrence River, Svalbard; [61,64]), while others perform long-distance annual migrations (e.g. Beaufort Sea; [64,72]).

Belugas are sensitive to certain types of noise. For example, in studies in the Canadian Arctic, they were observed to flee rapidly from ice-breaking ships at distances of 35–50 km, and alarm vocalizations were triggered by a ship as far as 80 km away [41,56,57,73]. However, they clearly can habituate to non-threatening ship noise and are common in busy northern harbors such as Longyearbyen (Svalbard), Anadyr (Russia), Anchorage (Alaska), and Churchill (Manitoba) and in the St. Lawrence River (Quebec).

3.4. Major oil and gas developments under way or planned in Arctic cetacean ranges

Known petroleum hydrocarbon provinces cover large portions of the marine continental shelf in the Arctic, with a notable exception being much of the eastern Russian Arctic shelf (Fig. 4). Although globally significant methane hydrate deposits are frozen into the seabed across large portions of the Arctic, the focus here is conventional oil and natural gas deposits, based on industry sources of spatial information. Exploration and production leases and past and present wells occur in many of the identified hydrocarbon provinces. Since fluctuations in world prices of oil and natural gas have led to the capping of some viable production wells in recent decades, all wells have been depicted on the grounds that they are indicative, as are leases, of serious interest and future potential for commercial extraction of the underlying reserves. As mentioned earlier, Fig. 4 includes spatial oil and gas information for some regions adjacent to the CAFF Arctic boundary, focusing especially on areas where one or more of the three Arctic cetaceans occur or occurred prior to commercial whaling.

Hydrocarbon provinces and areas currently open for leasing, or already leased, to commercial interests overlap portions of the annual and main summer ranges of all three Arctic cetacean species (Table 2; Figs. 1–4). The proportion of the annual circum-Arctic range that overlies known petroleum hydrocarbon provinces varies from roughly 58% (narwhal) to 63% (bowhead), and the overlap with current or possible future oil and gas lease areas is 8–13 % for these species. Overlap of the circum-Arctic summer range with petroleum hydrocarbon provinces varies from around

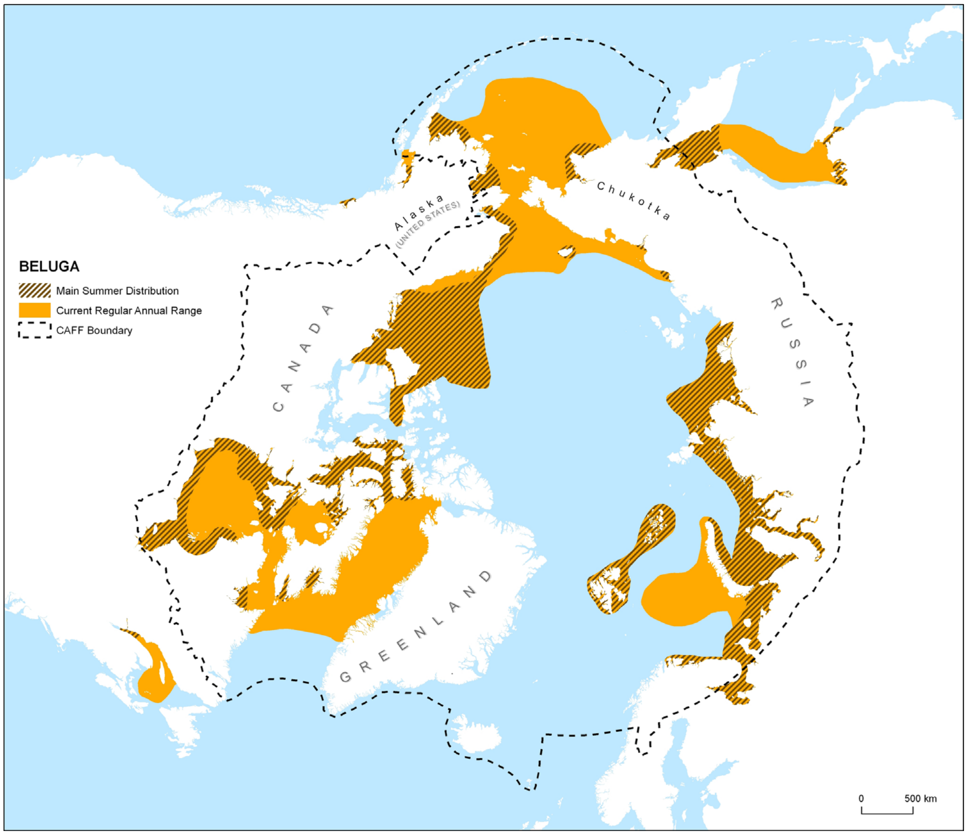

Fig. 3. Circumpolar distribution of belugas, showing approximate current range where animals occur regularly during at least part of the year, as well as areas where they tend to occur in highest densities during the summer (July–September, inclusive).

49% (narwhal) to 73% (bowhead) and the overlap with current or possible future oil and gas lease areas ranges from 1% (narwhal) to 12% (beluga). Considering individual populations of bowheads, belugas, and narwhals, the overlap ranges from near 0% to close to 100%.

It is important to emphasize in the context of a rapidly changing Arctic that the acoustic footprint of noise-generating activities such as transiting by large vessels, drilling, and especially seismic surveying, can be considerably larger than implied by a map showing only the production/leasing zones (e.g. [74–78]). Further, seismic surveys are being conducted in many areas that are not yet leased or where development/production is not yet under way (e.g. west coast of Svalbard; [79]). Therefore, our estimates of overlap are likely strongly negatively biased when considering the size of noise footprints.

The coarse nature of these illustrative calculations must be acknowledged. Percentage overlap calculated on a circum-Arctic scale, as done here, is of limited utility from an operational standpoint. A more practical and meaningful approach might be to estimate the fraction of the total world population of a given species likely to be put at risk by a particular activity or development. For instance, a major oil development in the Beaufort Sea would likely have no effect on the world's narwhals but it could affect a large proportion of the world's bowheads and a relatively small but significant number of belugas.

3.5. *Commercial shipping: ongoing and anticipated traffic*

Shipping in the Arctic is very poorly documented. Available data from 2012 covering the main regions inhabited by Arctic cetaceans reveals a considerable range of intensity of ship traffic (Fig. 5, [16]). In southern portions of the whale ranges, such as the Sea of Okhotsk, southern Bering Sea, southern Alaska, southwestern Greenland and the St. Lawrence River, there is significant ship traffic, with some routes experiencing over 1000 vessel transits annually. Farther north, many areas have few vessel transits annually; those that occur are mainly in the August–September period when there is generally the least sea ice cover and thus the most open water. Most of the traffic in the far north presently involves re-supply of communities or industrial sites, tourism, military operations, or scientific research.

The fact that whales migrate and ships move complicates the task of defining and interpreting the overlap of Arctic whales and ship traffic. At least in Alaska, some cetacean populations migrate far to the north in the summer, which effectively reduces the risk of ship strikes and acoustic impacts associated with current commercial shipping routes. The animals in more southerly populations may have accommodated to ship activity to some degree, but the whales in more northerly populations likely remain quite naive with respect to ships and ship noise.

Much greater intensity of ship traffic is anticipated in coming decades as sea ice becomes less of an obstacle to navigation (Fig. 6) and industries and governments enhance infrastructure (e.g. port development, refueling services, emergency support) and markets respond to new opportunities. The Arctic Council's Arctic Marine Shipping Assessment (AMSA) [15] summarized these trends and outlined the rapidly emerging economic and transportation opportunities. It also recommended that great caution be exercised in managing the pursuit of those opportunities, especially in ecologically and culturally important areas that contain sensitive natural habitat. The AMSA recommendation IIC urges Arctic states to identify “areas of heightened ecological and cultural significance in light of changing climate conditions and increasing multiple marine use and, where appropriate, encourage implementation of measures to protect these areas from impacts of Arctic marine shipping, in coordination with all stakeholders and

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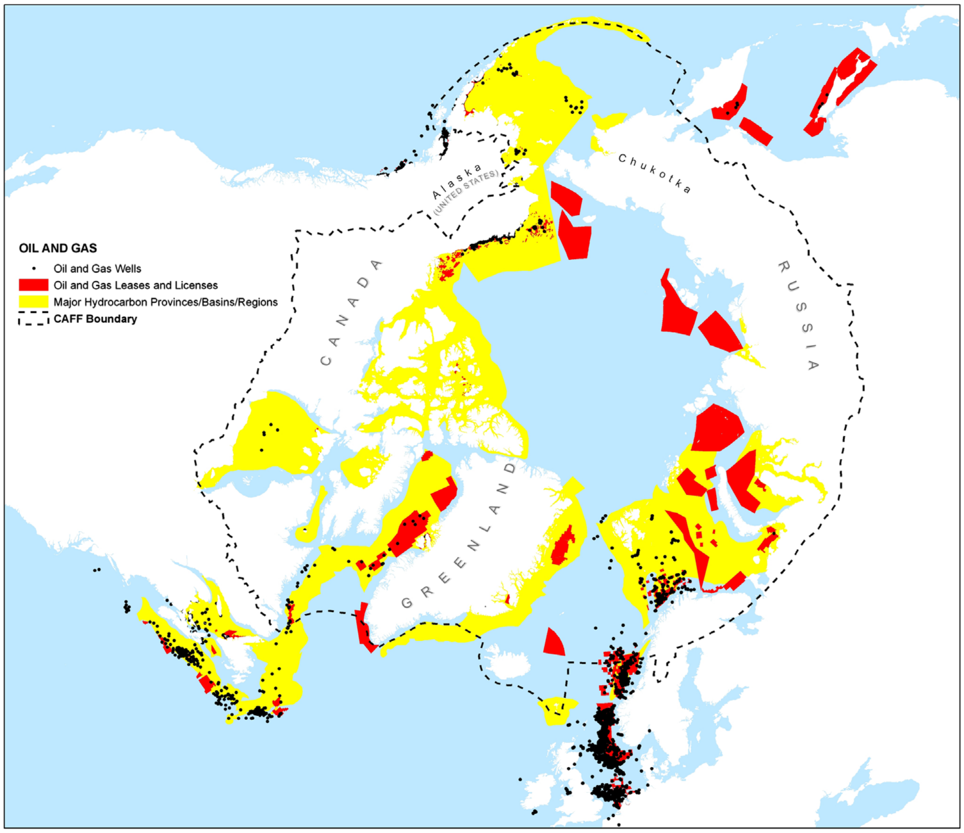

Fig. 4. Approximate distribution of major marine hydrocarbon (oil and gas) provinces/basins, lease areas*, and well sites in the Arctic as well as in adjacent marine areas (see Section 2 for details of terms). Data from various sources (see text and Appendix A). *Notes*: No hydrocarbon province maps were available for the Sea of Okhotsk. *The following terminology/criteria are used by different Arctic nations to delineate areas identified by governments as available for leasing in the future: Alaska – 'Areawide Sale Tracts'; Canada – 'Call for Bids' areas; Norway – 'Awards in predefined areas' and 'Areas awarded lease licenses'; Russia – 'Tender blocks' and 'Tender prospects open for licensing'.

consistent with international law" [15]. From the point of view of safeguarding healthy populations of the three endemic Arctic cetaceans, these are logical and very reasonable recommendations that we believe should be implemented swiftly and firmly across all range states. A recent analysis of projected trends to 2040-59 [80] reinforces the view that shipping in the Arctic could increase dramatically in coming decades even though, apart from sea ice conditions, "numerous additional factors, including dearth of services and infrastructure, high insurance and escort fees, unknown competitive response of the Suez and Panama Canals, poor charts, and other socioeconomic considerations, remain significant impediments to maritime activity in the region" (also see [16]).

3.6. Country profiles

The five principal range states of the Arctic endemic whales – Norway, Russia, United States, Canada and Greenland – are all pursuing new economic opportunities offered by changing environmental conditions in the Arctic. Here, illustrative aspects of this pursuit are summarized briefly.

3.6.1. Accelerating industrial pressures in Arctic Norway

The Svalbard Archipelago is already among the most heavily trafficked areas in the High Arctic because the warm West Spitsbergen Current keeps the west coast free of ice most of the year despite the high latitude. Cruise tourism in the region has expanded its season of operation markedly and has more than doubled in terms of the number of passengers during the last 15 years [81]. Commercial fishing now occurs right up to the northern ice edge, and Barents Sea fisheries have expanded both in terms of catch levels and the area covered by the fisheries as sea ice has declined (e.g. [82–84]).

Oil and gas interests are rapidly expanding northward and further increases in shipping and development are virtually certain in the coming decades in the Norwegian Arctic. For example, Statoil and partners are currently in the public hearing phase regarding programmes designed to conduct consequence analyses of exploration in a large region around Jan Mayen Island, the Skrugard–Havis fields, which are well north of existing developments. New oil discoveries in the northeastern Barents Sea, in the Hoop region close to Bjørnøya, are also receiving considerable attention. These new finds are being described as a new oil province and are thought to contain between 65 and 165 million barrels of oil. This is the northernmost oil discovery to date and it has stimulated plans for Statoil to drill even further north in 2014 [85].

3.6.2. Accelerating industrial pressures in Arctic Russia

Industrial pressures from the oil and gas sector, commercial shipping related to supply of coastal ports and mining, and commercial fisheries have been escalating in recent decades along portions of the Russian continental shelf. This has been facilitated by the progressive lengthening of the navigable season, particularly through the Northeast Passage (Northern Sea Route), as a result of climate warming and the thinning and retreat of sea ice cover. As one example, the head of the Polar Research Institute of China recently projected that there would be a massive increase in commercial shipping from China to Europe via the Northeast

Table 2
Approximate sizes of annual ranges and main summer ranges (in km^2) of the three Arctic whale species, with percentages of those ranges that are within known hydrocarbon provinces, or within existing or possible future oil and gas lease areas.

Species - range type	Approx. area (km^2)	% of range in known hydrocarbon provinces[a]	% of range in existing or possible oil & gas lease areas
Bowhead			
Current regular annual range	5,747,308 (4,970,149[a])	63	13
Main summer distribution	1,796,488 (1,596,405[a])	73	8
Narwhal			
Current regular annual range	2,835,391[b]	58	8
Main summer distribution	893,803[b]	49	1
Beluga			
Current regular annual range	7,720,828 (7,178,872[a])	60	9
Main summer distribution	3,474,121 (3,292,474[a])	55	12

[a] Area excluding Sea of Okhotsk.
[b] Narwhal range does not extend into the Bering Sea or the Sea of Okhotsk.

Passage by 2020 as long as adequate infrastructure was established to support it [86].

Oil fields in the Pechora Basin of the eastern Barents Sea have been producing for over a decade now, and this was preceded by only superficial environmental impact assessment, at best. Although market trends and fluctuations (as well as national politics) will always help determine the rate of hydrocarbon development, most observers expect an overall increase in exploration, drilling, production and shipping associated with the Barents–Pechora region's hydrocarbon reserves. Huge new offshore exploration leases have been granted in recent years in the Barents, Kara, Laptev and western Chukchi Seas (see Fig. 4), and it is reasonable to expect major increases in shipping, seismic exploration, test drilling, and infrastructure in this region. A major LNG terminal (15 M tonnes capacity) is being constructed on the Yamal Peninsula. By 2020–2030 over 700 laden oil/gas tanker transits are expected to shuttle annually between the Pechora Basin and Murmansk [87]. It is undeniable that risks of major accidents involving oil spills are increasing in the Russian Arctic. (For example, very recently, in September 2013, a diesel oil fuel tanker using the Northern Sea Route struck ice and took on water north of the Taimyr peninsula [86]).

Substantial commercial fisheries exist in the Russian portions of the Barents Sea, mainly for Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), Greenland halibut (*Reinhardtius hippoglossoides*) and capelin (*Mallotus villosus*), and exploratory fisheries are opening in the Kara Sea. There is also an extremely lucrative fishery for king crab (*Paralithodes camtschaticus*) in the southern Barents Sea in both Norwegian and Russian waters. Very large catches of pollock (*Theragra chalcogramma*) already occur in the Sea of Okhotsk and Russian waters off Kamchatka and Chukotka, and shipping routes are experiencing increasing intensity of use in these regions.

3.6.3. *Accelerating industrial pressures in Arctic USA (Alaska)*

Industrial and other human activities have been increasing in the Alaskan Arctic, especially since about 2006. These activities include oil and gas development, mining, commercial shipping, tourism and science. One large zinc/lead mine exists in northwestern Alaska and contributes considerable ship traffic during the open-water period when ore is transported to the south, but traffic from the large Red Dog mine has not necessarily increased recently.

There has been considerable interest in finding and developing offshore oil and gas in the Alaskan Arctic since the 1970s. Many thousands of kilometers of seismic lines have been surveyed, but only 35 exploratory wells had been drilled by the end of 2011. In 2006, the industry's interest increased as the price of oil climbed dramatically. For example, the U.S. Minerals Management Service (now the Bureau of Energy and Ocean Management) received ~$2.7 billion (USD) for tracts leased in the Chukchi Sea in 2008. Considerable interest remains in acquiring additional seismic data, drilling exploratory wells, and possible development in both the Chukchi and Beaufort Seas. Additional drilling is planned for 2014 and beyond.

Commercial shipping, other than that involved in re-supply of communities and onshore oil and gas infrastructure, has remained minimal in the northern Chukchi Sea and Alaskan Beaufort Sea. In contrast, transiting of commercial ships through the southern Chukchi Sea and Bering Strait has increased markedly in recent years, with forecasts for even more rapid increases in the future as the summer sea ice cover continues to shrink. Most of the ships currently use the Northern Sea Route across Russia. Tourism has also increased, involving both cruise ships and small vessels, primarily sailboats. At least one cruise ship and multiple private vessels now pass through the Northwest Passage every year. Just ten years ago this was a rare event.

Intensive pot fisheries (for crabs *Paralithodes* and *Chionoecetes* spp. and Pacific cod *Gadus macrocephalus*) occur in the Bering Sea in the autumn and winter, and bowheads sometimes become entangled in the pot lines, leading to debilitation or death [9,88]. At present, entanglement does not appear to represent a serious population-level threat to BCB bowheads, but this is due in part to the fact that there is a moratorium against the opening of new commercial fisheries in the U.S. Arctic north of the Bering Strait. Should this situation change, the entanglement risks to bowheads (and other marine mammals) could increase substantially.

Finally, the number of vessels in Alaska's Arctic that are associated with scientific research, mostly focused on issues related to climate change, and the U.S. Coast Guard (USCG) has also increased. Scientific endeavors in northern Alaska have involved researchers from a variety of countries including the U.S., Canada, China, South Korea and Japan. Some of these projects are academic in nature but some are also concerned with mapping the extended continental shelf, as defined by the Law of the Sea, and surveying fish stocks for potential commercial exploitation. The increased USCG presence is associated with increases in other human activities and the need for safety and monitoring.

The bowheads and belugas in northern Alaska appear sensitive to human activities and specifically to the noise associated with those activities, and there is great concern that increased activity will cause physical damage (e.g. ship strikes, hearing loss or impairment), physiological harm (e.g. elevated levels of stress

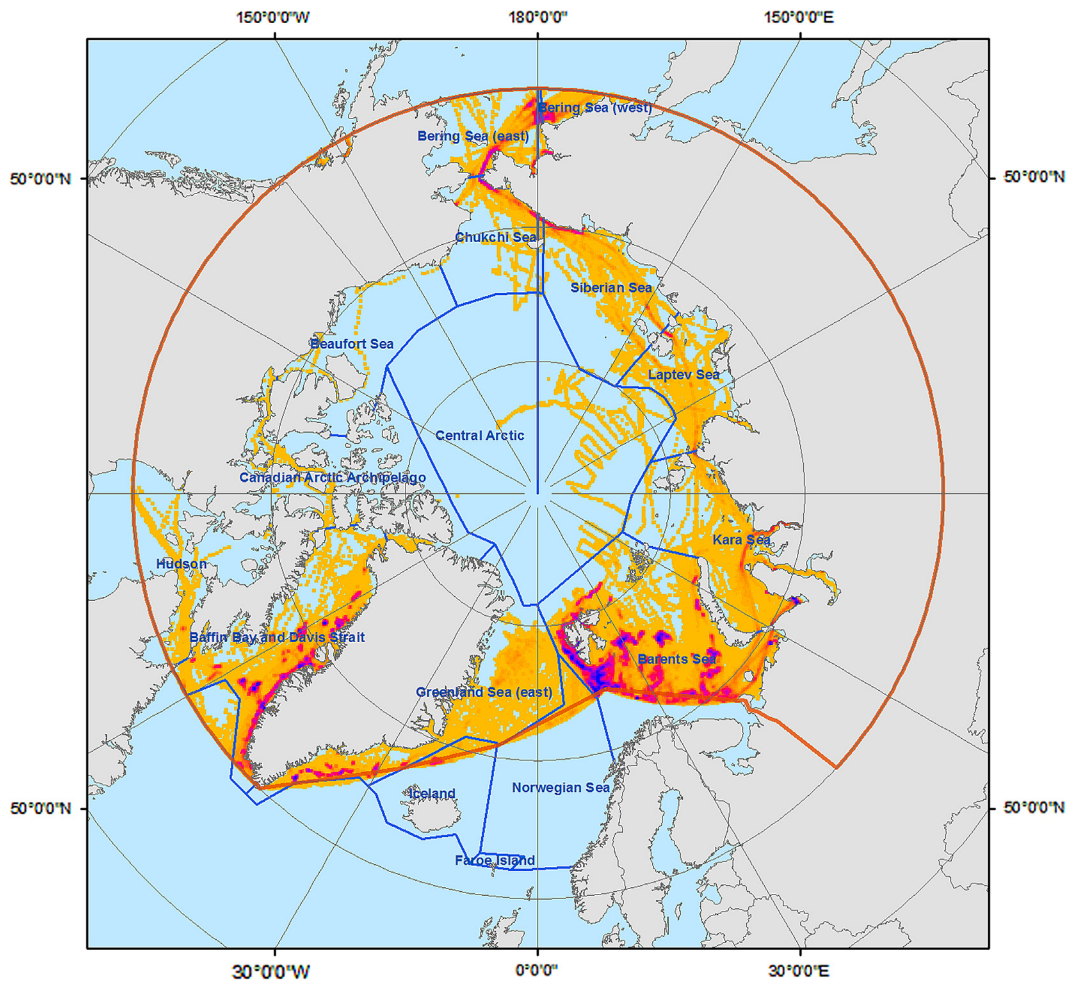

Fig. 5. Shipping within the Arctic (as defined in the IMO 'Polar Code') in 2012. Includes activity with all vessels with AIS transponders on board. Ship traffic density colored as follows: Yellow (light gray)= Low; Red (medium gray)= Medium; Blue (dark gray)=High. *Source*: Norwegian Coastal Administration and Det Norske Veritas. Reproduced from [16] (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

hormones), and changes in behavior (i.e. deflection away from molting, feeding, calving, and resting areas or migration routes). These negative effects on the whales could, in turn, affect the availability of the animals to subsistence communities. There are many data gaps (e.g. documentation of habitat use) and careful planning will be needed to manage current and foreseeable human activities in northern Alaska, especially in the context of a vibrant Inuit culture tightly linked to cetacean exploitation in some communities and a rapidly changing climate.

3.6.4. Accelerating industrial pressures in Arctic Canada

Industrial and strategic interest in exploiting the resources of northern Canada has increased in recent years as the open-water season has lengthened. Virtually all of the same issues raised above for Norway, Russia and the USA apply to Canada. Petroleum reserves in the Beaufort Sea and Baffin Bay are attracting more attention than ever before (e.g. old leases, new plans for 2D seismic surveys of the entire north-eastern Canadian shelf). The port of Churchill in south-western Hudson Bay has come to be viewed as a promising major shipping route to and from the Canadian Prairies, especially if linked to the Northwest Passage. Commercial fisheries (for shrimp and Greenland halibut especially) are expanding in Baffin Bay. A recently approved giant (> $4 billion CDN) iron mine in northern Baffin Island (known as the Mary River Project of Baffinland Iron Mines Corporation) will bring more ship traffic to the region. Current plans are that construction equipment and ore will be hauled to and from the mine site via Milne Inlet at the head of Eclipse Sound, one of the most important summering areas for narwhals. The custom-built, icebreaker-strength ore freighters will operate year-round, bringing significant additional risks of oil pollution, ship strikes and acoustic disturbance.

Other major industrial development projects include construction of at least one deep-water port on the Northwest Passage, increased military activity there and expanding cruise-ship operations in the Canadian Archipelago. In 2013 two cargo vessels transited the Northwest Passage, adding to the steady increase in shipping there. There are plans for road connections to ports on the western Canadian Arctic coast that would greatly enhance the economic viability of base-metal and diamond mines in the mineral-rich Slave Geological Province (which straddles the border of Nunavut and the Northwest Territories). Significant, but as yet unexploited, hydrocarbon deposits are also known to exist in the Canadian Arctic, notably coal in the High Arctic islands, oil and gas in the Mackenzie Delta and Beaufort Sea and natural gas in the Sverdrup Basin (apparently 25% of Canada's remaining untapped natural gas reserves).

3.6.5. Accelerating industrial pressures in Arctic Greenland

Greenland is moving towards greater economic independence from Denmark and this is stimulating interest in developing new ways to generate income from mineral resources. There is a perceived need to reduce the country's present reliance on the export of fish and shrimp products, which are subject to price

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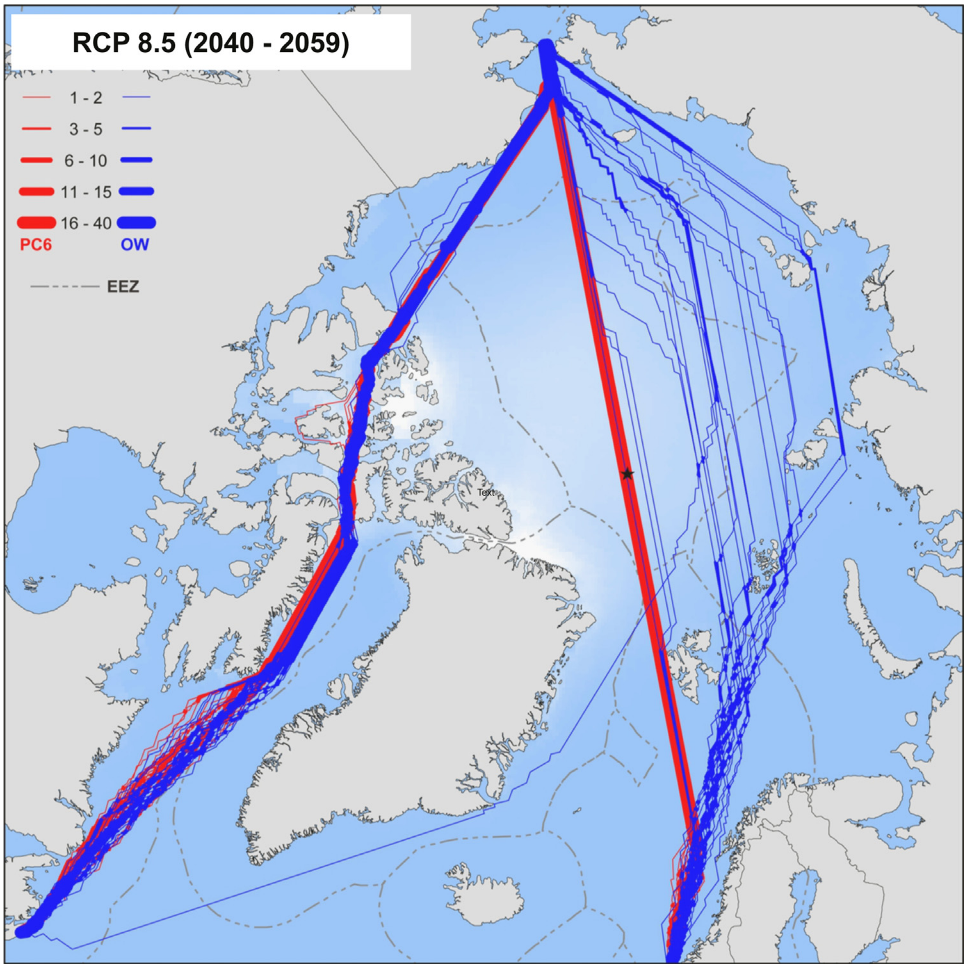

Fig. 6. Projections for 2040-59 September Arctic shipping routes and intensity of Polar Class 6 (PC6; medium ice hull strengthening) and Open Water (OW; no ice hull strengthening) vessel traffic based on the RCP 8.5 emissions scenario (i.e. high radiative forcing). Dashed line boundaries indicate the Exclusive Economic Zones which extend up to 200 nm from each nation's coast. Star indicates the North Pole. Figure reproduced from [80].

changes on the world market and also susceptible to the effects of climate change and over-fishing. The increasing interest in non-renewable resources has spurred major new developments in land-based mining as well as offshore oil and gas exploration in both East and West Greenland. Some of the mining activities involve extensive year-round shipping to and from the sites (e.g. an iron mine in Nuuk Fjord developed by London Mining, a lead mine in Citronen Fjord, Northeast Greenland, an aluminum Smelting facility developed by Alcoa Greenland close to Maniitsoq in West Greenland).

So far, hydrocarbon exploration has consisted mainly of extensive seismic surveys and a few exploratory deep-water drilling exercises. In 2012, seismic surveys took place in northern Baffin Bay close to one of the two main summering grounds of narwhals in West Greenland. No overt effects were detected during the narwhal population's stay on the summering ground but no studies were conducted during the critical fall migration period when the population would have passed through areas with seismic activity.

4. Discussion

The whale range maps and the maps of recent or anticipated oil and gas activity and ship traffic in the Arctic leave no doubt that there is already substantial overlap between the endemic Arctic whales and potentially harmful human activities. This overlap is bound to increase as more of the region becomes accessible, for longer periods, with ongoing sea ice retreat.

It is important to re-emphasize that, given the great distances over which low-frequency noise can be transmitted, areas far from ship traffic lanes and industrial activities (particularly seismic surveys) are often ensonified, implying the potential for much more extensive acoustic impacts than a simple overlay of human activities on whales' ranges would imply. For example, noise from seismic survey airguns, presumably operating thousands of kilometers away, is almost constant throughout the winter months in the middle of Fram Strait off north-eastern Greenland [8]. Airgun sounds were recorded almost 4000 km from seismic survey vessels in the North Atlantic [78]. It is clear that the sounds produced by seismic exploration propagate over considerable portions of the Arctic already. The impact on cetaceans of underwater noise from both ship traffic and industrial activities has become a major global concern over the past decade (e.g. [89–91]) and this concern has often been raised explicitly in relation to the Arctic. Moore et al. [77], for example, proposed a new assessment framework, involving the analytical development of “acoustic habitats” that take account of the aggregate sound field from multiple sources, as a way of addressing the cumulative impacts of increasing anthropogenic sound in the Arctic marine environment.

Based on recent observations and current conditions, it is difficult to determine whether there are meaningful differences in exposure risk among the three Arctic whale species. All three currently have at least a few areas of seasonal occupancy that are

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relatively remote from regular industrial activities and ship traffic (e.g. the bowhead 'nursery' in northern Foxe Basin, Canada, and the presumed breeding area for bowheads deep in the ice of Fram Strait in winter; some of the narwhal summering sites in fiords of northern Baffin Island; and some of the estuaries in the Canadian Arctic where belugas congregate and molt in summer). As noted earlier, however, whales are exposed to distant seismic pulses even when they are in extremely isolated locations such as the ice-covered waters of Fram Strait in winter, and the animals from all such remote seasonal aggregation sites are likely exposed to industrial activities when they leave those areas. Some populations of each of the three species are already at risk from high levels of exposure to oil and gas activities and ship traffic, as well as other anthropogenic stressors, within their normal range of distribution. The limited or non-existent monitoring efforts and the incomplete understanding of cause-effect linkages mean that impacts on most Arctic whale populations are not currently being tracked and assessed.

The resilience of the whales themselves may ameliorate the risks of increased traffic and development in the Arctic to some extent. For example, belugas in the St. Lawrence River persist in an area of heavy ship traffic with only limited evidence that they are significantly affected by ship strikes or ship noise [92,93], and this is in spite of the fact that they are among the most heavily contaminated marine mammals on the planet due to the bioaccumulation of persistent organochlorine pollutants [94]. Similarly, thousands of belugas summer at the mouth of the Churchill River in south-eastern Hudson Bay, where in the July–September period over 20 large freight vessels load at the port, within 1–2 km of the main whale use areas. It is also notable that the populations of belugas in Cook Inlet and Anadyr Gulf appear to be reasonably well adapted to an environment with only light to moderate seasonal sea ice conditions. In other words, belugas may be able to cope with the summer loss of sea ice, per se, while a number of other factors that accompany that loss (e.g. greater competition for prey, increased predation, and exposure to increasingly diverse human activities) could prove less tolerable. Another example that is enlightening regarding the plasticity of Arctic cetaceans is the BCB bowhead whale population, which has been increasing steadily for decades [22] despite the annual removal of dozens of whales by subsistence hunting [95], substantial shipping and commercial fishing activity in its winter range [9], and the presence of major offshore oil and gas exploration and development in much of its summer and autumn range.

4.1. *Recent and projected changes in Arctic sea ice*

Although the endemic Arctic whales and other ice-adapted marine mammals have experienced major changes in climate and ecosystems during their evolutionary history (e.g. [1,96]), the current rates and projections of change are unprecedented [97,98] and therefore the implications for these species are not only uncertain but also worrisome [3,5,6,96]. Not all parts of the Arctic are equally affected by climate-driven changes in sea ice. Although some areas show very little change, the overall picture is one of rapid decline in the extent and thickness of sea ice (e.g. [97,99,100]). At current rates of greenhouse gas emissions, Arctic marine waters are projected to be ice-free in summer within the next 20–30 years (e.g. [101–104]).

Each year the minimum extent of Arctic sea ice occurs in September, and the ice coverage at this time has declined markedly since 1979, at a mean rate of 14% per decade ([105]; Fig. 7A). Annual, as opposed to multi-year, sea ice is presumed to be of greatest relevance for the three ice-adapted Arctic whale species [7]. Annual sea ice has declined since 1979 at an average of about 3% per decade with regions at the southern edge of the Arctic experiencing the greatest reductions in duration of the sea ice season. The most dramatic effects on ice-dependent wildlife have been documented in these regions (e.g. [105–108]). A comparison of the winter maximum (March) sea ice coverage over the period in which satellite-based records are available (since 1979) indicates a substantial retreat in the Sea of Okhotsk, northern Barents Sea and Greenland Sea (Fig. 7B). Since 1979, the summer minimum (September) sea ice coverage has declined most dramatically in the Laptev, East Siberian and Chukchi seas and in the Arctic Basin (Fig. 7C). Such rapid shifts in the extent and duration of sea ice cover are unprecedented and represent significant challenges for ice-adapted biota, including the endemic Arctic whales and their prey.

4.2. *Effects of climate change on Arctic whales*

Climate change will have both direct and indirect impacts on Arctic cetaceans. Besides the individual and cumulative impacts from changes in human activities associated with climate change (e.g. increased ship traffic, oil and gas exploration and development, and expansion of commercial fisheries), Arctic whales are being, and will continue to be, significantly affected by the changes in their biophysical environment that accompany rapid climate change (e.g. see [3,7,100,108,110–112]), including the acidification of Arctic waters [113,114].

The northward expansions of temperate-region species will almost certainly increase competition for prey. And in the case of killer whales, their expanded distribution could well have significant predation consequences for the Arctic whales (e.g. [3,115–117]). The reduction in sea ice will mean that killer whales are less likely to be deterred from entering the areas inhabited by bowheads, narwhals and belugas.

Timing of the annual formation and decay of sea ice is an important factor that influences the timing and other dynamics of phytoplankton production in areas where bowhead whales feed heavily on copepods, which ascend toward the surface to feed on phytoplankton (e.g. [108,118–120]). Disruption of the timing of this production, due to reduced sea ice that will allow an earlier phytoplankton bloom, could affect seasonal feeding opportunities for bowhead whales in some areas, although it is possible that the whales will simply move to less affected areas (as long as these exist). Bowheads appear to have better body condition in years with less-than-average summer sea ice in the Beaufort Sea [121]. However, peaks in food abundance and timing of migration could become detached seasonally, creating a problematic mismatch. How bowheads will adapt to a regime with much-reduced sea ice is difficult to predict (e.g. [96]) but may depend on the ecological development at a number of small and diverse habitat patches used for feeding.

Narwhals are heavily dependent on the availability of prey during the winter, when they feed intensively at great depths on a limited number of prey species, Greenland halibut being the most important [122]. Changes in halibut spawning and migratory habits, competition with temperate-water species, and steep increases in commercial fishing (e.g. [123]), are expected to affect narwhals negatively. Due to the rigidity of their annual migratory patterns and their susceptibility to ice entrapment [124], narwhals will likely have difficulty adapting to any additional stressors such as rapid changes in prey availability, and their sensitivity to human activity seems to be the most extreme among the Arctic whales, with no evidence to this point of any habituation to human industrial activities in occupied habitat.

Belugas feed on a greater variety of prey and generally have more plasticity than narwhals in their distribution, movement patterns, prey preferences and habitat use. Therefore belugas are thought to be better suited than narwhals for adaptation to major

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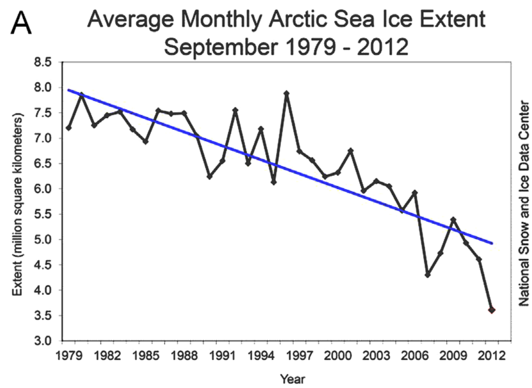

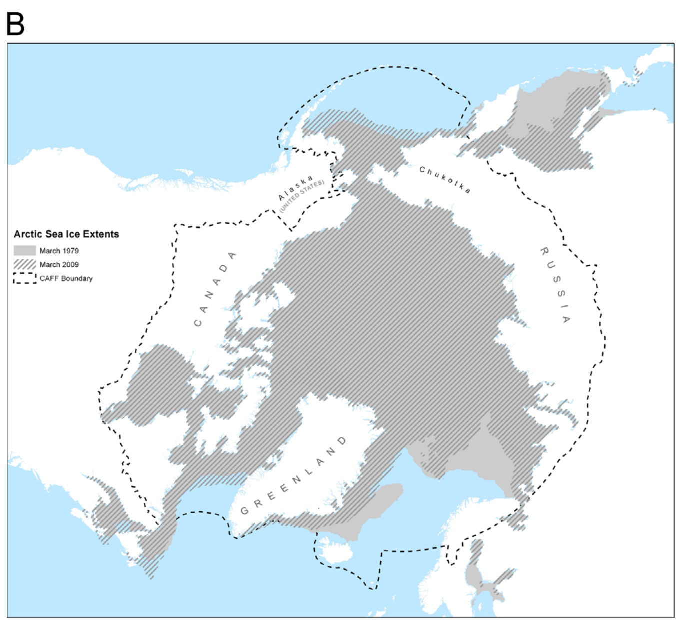

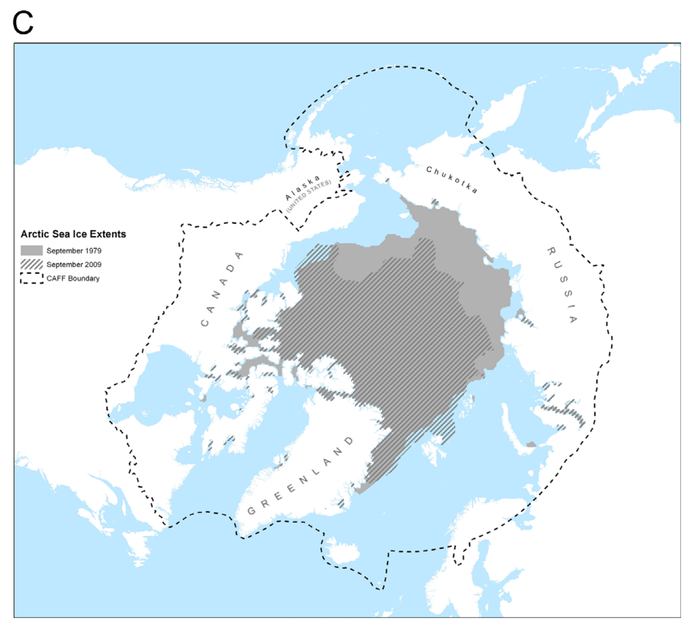

Fig. 7. Trends in sea ice cover in the Arctic. (A) Average sea ice extent in September from 1979 to 2012 [105]. (B) Comparison of mean March sea ice extent in 1979 and 2009 [109]. (C) Comparison of mean September total sea ice extent in 1979 and 2009 [109].

climate-induced environmental change [3]. For example, belugas in the Beaufort Sea seem to rely heavily on Arctic cod (*Arctogadus glacialis*) as prey, but rapid marine ecosystem changes and expansions of capelin and salmon species (Salmonidae) into the region may create new foraging opportunities and lead to shifts in prey targeted and hence in habitat use [64,100,125].

Another concern is that as other organisms, including other marine mammals, move farther north and spend longer periods there, they will bring with them pathogens and parasites that are novel to the endemic Arctic cetaceans [4]. This could have serious implications for their long-term health status. Additionally, the loss of sea ice will expose the Arctic cetaceans to greater storm activity, which is predicted to intensify, over a greater part of their range. This could be particularly important to neonatal survival [108].

In summary, Arctic whales currently face many significant challenges arising directly or indirectly from rapid climatic change that is altering their physical habitat and the biological communities of which they are a part.

5. Conclusions

The futures of the three whale species endemic to Arctic marine waters are uncertain. Processes associated with rapid climate warming have already caused major changes in the biophysical environments inhabited by these whales, bringing new risks and exacerbating old ones. The nature and pace of environmental change in the Arctic has prompted concern on many fronts. Two particular areas of concern, both related to the decline of sea ice as an obstacle to safe human navigation, are rapidly expanding hydrocarbon exploration and development and commercial shipping. More than half of the annual circum-Arctic range of all three whale species overlaps known or suspected offshore oil and gas deposits; poorly or inadequately managed development in this sector represents high risk for the Arctic cetaceans. The underwater environment in the Arctic is becoming much noisier than ever before. More and faster vessels are transiting Arctic waters, escalating the risks of ship strikes and contamination by oil and other toxins as well as adding noise. Data on Arctic ship traffic is currently woefully inadequate for environmental assessment purposes, as is understanding of the general and dose-specific responses of Arctic whales to the new types and levels of disturbance associated with escalating human use of the marine environment.

Since the endemic whale species are highly valued by people, both locally and globally, management decisions regarding future human activities within the Arctic marine system should be well-informed and based on solid scientific data on current and future projected key habitat, thresholds of tolerable effects and impacts, and trends in population abundance and health parameters. Many Arctic cetacean populations receive little or no monitoring attention, despite escalating threats from industrial activities. Investment in research and monitoring must keep pace with economic development in the Arctic. Better information on the scale and trends of human activities and greater understanding of the effects and impacts of such activities on whales (and other wildlife) are not optional accessories – they are fundamental to responsible development.

Beyond the global imperative to reduce greenhouse gas emissions, which are the ultimate driver of rapid sea ice loss, it is important to build resilience in Arctic ecosystems, starting with full implementation by Arctic nations of the recommendations of the Arctic Council's AMSA, especially IIC, to adequately protect a network of areas of heightened ecological and cultural significance. Many of these already-identified areas provide key habitat, at certain times of the year, for whales. Special protection of such a network should help mitigate impacts not only of shipping but also of oil and gas activities and other anthropogenic stressors.

International management instruments may also be good mechanisms for implementing or at least preserving conservation options. For example, the United Nations International Maritime Organization (IMO) has designated 13 large areas globally (though none yet in the Arctic) as Particularly Sensitive Sea Areas. Similarly, the designation of Special Areas under the 1973 International Convention for the Prevention of Pollution from Ships should be considered for some of the most critical areas inhabited by Arctic cetaceans. Such areas would need to be linked to jurisdictional policies and regulations and to measures taken by industry to prevent pollution from ships [126]. Another potential mechanism to consider is the IMO's planned development (by 2014) of a mandatory 'Polar Code' which aims to upgrade and harmonize vessel operating standards in international Arctic waters [127]. Finally, it should be borne in mind that the United Nations Convention on the Law of the Sea obligates signatories to protect and preserve the marine environment [128] and the purpose of the International Convention for the Regulation of Whaling is inter alia to provide for the proper conservation of whale stocks [129].

Regardless of what combination of policy frameworks and area-based protective regulations is used by the range states and the international community, the following measures should be implemented, or at least seriously considered, to mitigate the impacts of human activities on the endemic Arctic whales and the aboriginal people who depend on them for subsistence: careful planning of ship traffic lanes (re-routing if necessary) and ship speed restrictions; temporal or spatial closures of specified areas (e.g. where critical processes for whales such as calving, calf rearing, resting, or intense feeding takes place) to specific types of industrial activity; strict regulation of seismic surveys and other sources of loud underwater noise; and close and sustained monitoring of whale populations in order to track their responses to environmental disturbance.

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Appendix A. Supplementary materials

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.marpol.2013.10.005.

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