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PERSPECTIVE

Tracking arctic marine mammal resilience in an era of rapid ecosystem alteration

Sue E. Moore[1]*, **Randall R. Reeves**[2]

1 National Oceanic and Atmospheric Administration Fisheries, Office of Science and Technology, Seattle, Washington, United States of America, **2** Okapi Wildlife Associates, Hudson, Quebec, Canada

* sue.moore@noaa.gov

Abstract

Global warming is significantly altering arctic marine ecosystems. Specifically, the precipitous loss of sea ice is creating a dichotomy between ice-dependent polar bears and pinnipeds that are losing habitat and some cetaceans that are gaining habitat. While final outcomes are hard to predict for the many and varied marine mammal populations that rely on arctic habitats, we suggest a simplified framework to assess status, based upon ranking a population's size, range, behavior, and health. This basic approach is proposed as a means to prioritize and expedite conservation and management efforts in an era of rapid ecosystem alteration.

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Introduction

Arctic marine ecosystems are changing fast, as manifested by loss of sea ice, ocean warming and freshening, storm prevalence and severity, and regional increases in primary productivity [1, 2]. The dramatic decline of sea ice thickness, extent, and duration is a key indicator of rapid ecosystem alteration. Images of starving polar bears (*Ursus maritimus*) or thousands of walruses (*Odobenus rosmarus*) massed together on beaches instead of hauled out on ice floes signal hard times for these species. Indeed, the polar bear has become a "poster species" for global warming, used by organizations either to (i) attract attention and funds by linking the bear's plight to that of nature as a whole or (ii) project images of healthy bears in an effort to discredit the irrefutable evidence of rapid planetary warming [3]. Arctic marine mammals rely on sea ice in a variety of ways, depending on their life history and behavioral ecology [4]. Polar bears use ice as a platform for resting, walking, and stalking seals; walruses and ice seals for pupping, nursing, molting, and resting. Sea ice loss means less suitable habitats for them. In contrast, increased primary and secondary productivity associated with the reduction in sea ice opens new feeding opportunities for cetaceans, including both endemic arctic species and species that migrate seasonally to arctic waters [5]. We recognize that this dichotomous portrayal is simplistic. For example, arctic cetaceans also benefit from sea ice, as it can protect them from predators [6] and likely reduces competition with seasonally migrant species [5]. Further, increased productivity would be expected to improve foraging for at least some pinnipeds and polar bears; however, on the whole, species requiring sea ice as a platform are the most challenged by its loss.

Marine mammals are ecosystem sentinels, capable of reflecting ocean variability through changes in their ecology and body condition [4]. Eleven species are endemic to the Arctic—3 cetaceans, 7 pinnipeds, and the polar bear [7]. At least 5 cetacean species migrate to arctic waters, principally to feed in summer and autumn months. Combined, these endemic and seasonally migrant species exhibit a wide range of life history traits that provide a varied phenotypic landscape for natural selection in the Arctic's regionally diverse and strongly seasonal habitats [8]. In such a setting, an overarching question is what capacity do arctic endemic species have to adapt to ecosystem alterations caused by rapid warming? Specifically, what aspects of their life histories contribute to resilience and can their status as ecosystem sentinels be harnessed to inform and guide conservation efforts?

Here, we propose a basic framework to both broaden and simplify metrics used to assess marine mammal population status as a means to prioritize and expedite urgently needed conservation and management actions in a rapidly changing Arctic. We briefly summarize evidence from decades-long studies of a few marine mammal species and identify features common to populations that appear to be doing well, and those that are not, in the face of rapid habitat alteration due to climate change. We use those features to broaden the discussion to matters related to species resilience, including the importance of (i) population size, (ii) seasonal range, (iii) behavioral plasticity, and (iv) health. We then propose a simplified approach to assess population status based on summed rankings of those 4 resilience metrics. The overarching goal is to use the resultant scores to prioritize management and conservation actions. While we do not delve here into specific anthropogenic threats to arctic marine mammals, such as those associated with offshore commercial activities [9, 10, 11], we recognize these activities as important contributors to ecosystem alteration. Similarly, while recognizing that complexity-focused approaches to marine mammal research and conservation are poised to advance [12], we suggest a simplified approach that incorporates multiple facets of animal ecology and health as an achievable step in the near future. We close with thoughts on the recent recognition of marine mammals as "essential ocean variables" in a program to monitor biodiversity and ecosystem changes through sustained ocean observation [13].

Winners and losers

The bowhead whale (*Balaena mysticetus*) is the only baleen whale endemic to the Arctic. Bowheads are long lived (to approximately 200 years [14]) and fully adapted to arctic conditions, e.g., capable of breaking through sea ice (up to 18 cm thick) to breathe. Thus, it may seem counterintuitive that this pagophilic (ice-loving) species appears to be thriving during a period of rapid sea ice loss, at least in the Pacific Arctic region. There, population size has grown, calf counts have increased, and body condition of individual whales has improved over the last quarter-century [15, 16]. These positive outcomes have been attributed to overall expansion of primary production and an augmented food supply for bowheads due to increased zooplankton advection into the Pacific Arctic, accompanied by upwelling of prey during the extended open-water season [5]. While still recovering from over-harvest during the commercial whaling era, bowheads in the Davis Strait–Baffin Bay region appear to be increasing [7], and copious singing (up to 24 h/day) recorded throughout the winter in Fram Strait east of Greenland suggests a rebounding population there [17].

The situation for the beluga, or white whale (*Delphinapterus leucas*), is less clear. Trends in abundance are known for only 6 of 22 populations [18], and studies of diet and body condition are rare [19, 20, 21]. Beluga populations can be either local or migratory [18], with those that are local often considered to be at greater risk. Of note, habitat selection by 2 populations that undertake long migrations in the Pacific Arctic was associated primarily with bathymetric features rather than ice conditions during the recent period of sea ice loss [22]. A trend in one population toward longer, deeper dives was thought to be an indirect effect of sea ice loss, assuming that ecological changes shifted foraging opportunities to deeper water.

Cetaceans that migrate seasonally to arctic waters are also considered winners. In the Pacific Arctic, the gray whale's (*Eschrichtius robustus*) use of continental shelf habitats has been the focus of study since the 1980s [23], during which time population size has steadily increased [24]. With the open-water season extended by 2–4 weeks [6], humpback (*Megaptera novaeangliae*), fin (*Balaenoptera physalus*), and minke whales (*B. acutorostrata*) are now commonly seen north of Bering Strait, unlike 30 years ago [25]. The recent surge in sightings is probably due to a combination of increased survey effort, the growth of whale populations previously hunted commercially, and climate-driven environmental changes. These same 3 baleen whale species have long been common in parts of the Atlantic Arctic [26], especially the Barents Sea [27]. Competition for prey between them and the endemic bowhead may be mediated, at least in the near term, by differences in migration timing, prey preferences, and feeding behavior [5].

Polar bears are the iconic "losers" in reports of climate change impacts [3], with walruses and ringed seals (*Pusa hispida*) running close behind. While some polar bear populations show signs of stress, including extreme emaciation and reproductive failure, others still appear to be in good body condition [28]. Continued loss of sea ice will lead to range contraction and increasing isolation of some populations [29], and it is clear that polar bears rely on a fat-rich diet of marine mammals that cannot be easily obtained on land [30]. Walruses, ringed seals, and bearded seals (*Erignathus barbatus*) are also rapidly losing sea ice habitat, but while these pagophilic species may have to swim farther to feed, they have some capacity to adapt by hauling out on land, as walruses in the Atlantic Arctic and Russia often do [31] and as ringed and bearded seals sometimes do in Svalbard [32], parts of the Okhotsk Sea [33], and Alaska [34]. The endemic narwhal (*Monodon monoceros*) is another loser in the rapidly changing environments of the eastern Canadian Arctic, Greenland, and Svalbard [35]. With their restricted distribution and strong fidelity to pack-ice habitat where they feed in winter, narwhals are considered the most specialized of arctic cetaceans [35]. The extreme physiological adaptations of their skeletal muscles may make them especially sensitive to climate change [36].

Resilience

Resilience, in the present context, denotes the capacity to adapt to environmental change. Fundamentally, a population's resilience to habitat alteration depends on a combination of how it responds to perturbation (adapts, moves) and how sensitive it is to perturbation (life history traits, physiological limits) [37]. Generalist foragers with broad distributions are usually considered more resilient than feeding specialists with a restricted range [38]. A simple index of resilience can be devised based upon 4 metrics: (i) population size, (ii) range, (iii) behavior, and (iv) health (Fig 1). Greater resilience is associated with large populations that display behavioral flexibility (including diet) and show resistance to disease and stress, while the reverse generally signifies lesser resilience. We suggest applying a simple 5-point ranking scale, whereby a score of 1 denotes a large, wide-ranging population that displays considerable behavioral plasticity and resistance to disease, while a score of 5 indicates the opposite. By this method, the bowhead whale population in the Pacific Arctic would receive a score of 1, while the smaller Eastern Canada–West Greenland and Svalbard–Barents Sea populations might

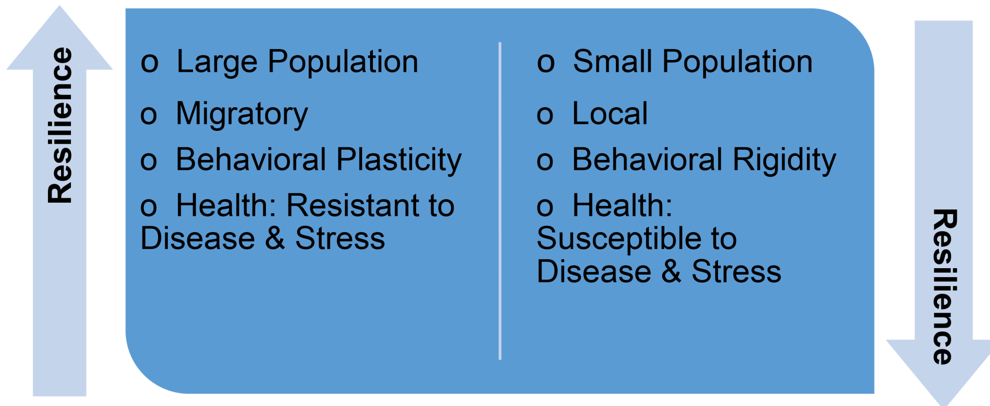

Fig 1. The resilience of marine mammal populations can be assessed based on population size, range, behavioral plasticity, and health. Each of these 4 metrics can be ranked from 1 to 5, with a rank of 1 representing large, migratory populations exhibiting behavioral plasticity (including diet) and resistance to disease and stress and a rank of 5 representing the opposite.

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score as 3 and 4, respectively. Similarly, large, wide-ranging polar bear and beluga populations would have a lower score (i.e., higher resilience) than small, local populations (i.e., lower resilience). This method of ranking resilience is similar to the sensitivity index developed a decade ago [34], but it is based on only 4 metrics (instead of 8), one of which is related to animal health [39]. While we recognize that such simplification brings the risk of overlooking or obscuring factors that could prove decisive in a given instance (e.g., loss of critical habitat or phenotypic uniqueness), the ranking method's strength lies in the capacity of marine mammals to integrate and reflect complex ecosystem changes through their ecological and physiological responses [4].

Tracking arctic marine mammal resilience

Arctic marine mammal populations are often difficult to define and count, with comparatively few reliable estimates of numbers or trends [7]. Furthermore, detecting even precipitous declines in marine mammal population size is unlikely because surveys are too infrequent, and the estimates obtained are too imprecise [40]. Given these challenges and the rapid pace of environmental change in the Arctic, a more holistic approach to assess population status is urgently needed to guide conservation and management actions. We suggest a framework that links the best information available on population size (even if imprecise or only qualitative) to the other 3 metrics that contribute to resilience (Fig 2). A key strength of this framework is the inclusion of both ecological (geographical range and behavior) and physiological (health) metrics, which broaden the foundation of population assessment beyond demography alone. Further, the framework relies upon multidisciplinary science, which increases the likelihood of detecting changes in population status. For example, a shift in migratory timing, a switch in diet, or an outbreak of disease could alert resource managers to a problem that would go unnoticed when relying solely on trends in population size [40]. Importantly, the reliance of indigenous people upon arctic marine mammals makes urgent comprehensive marine mammal health monitoring due to food safety concerns [39]. This "marine mammal connection" also creates opportunities to improve understanding of the nature and trajectories of fast-changing ocean ecosystems through partnerships between conventional science practitioners and the holders of indigenous knowledge [41]. Marine mammals were recently recognized as "essential ocean variables" within a Global Ocean Observing System (GOOS) that is relevant for science

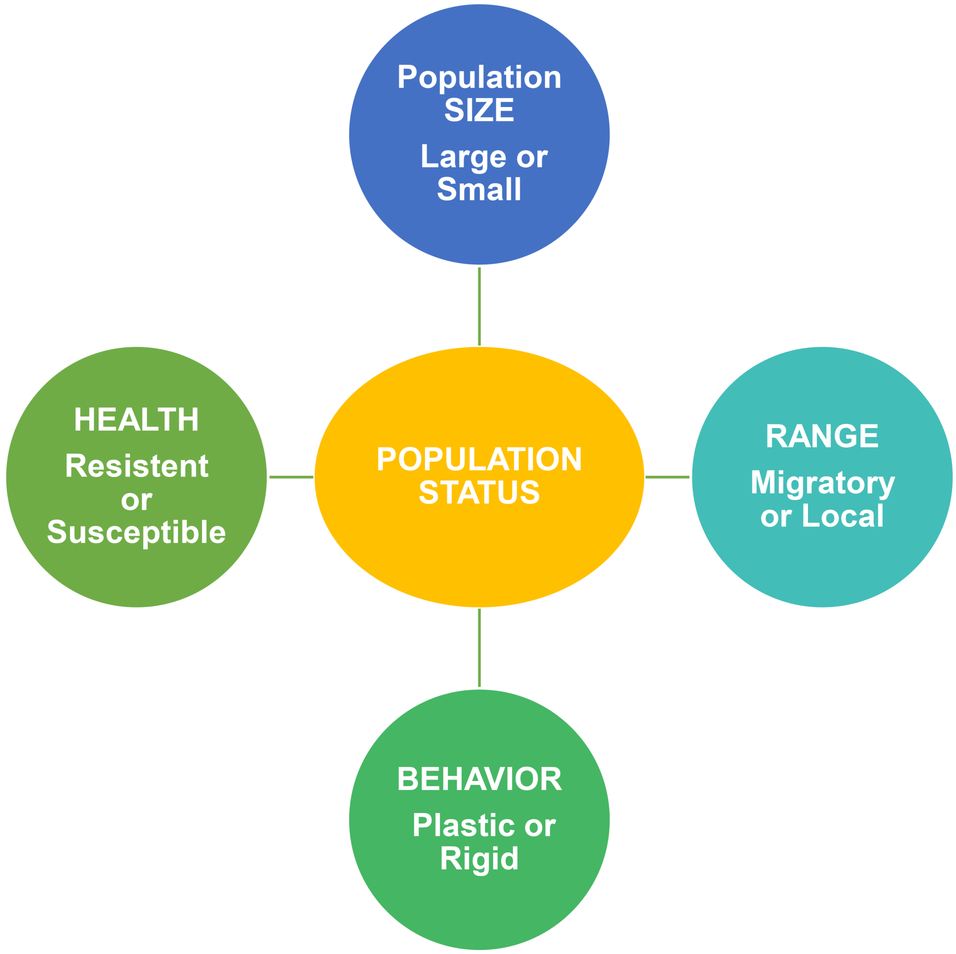

Fig 2. Contribution of 4 metrics to an assessment of a marine mammal population's status; a simplified approach relevant everywhere but needed with special urgency to prioritize and expedite management and conservation actions in the context of ongoing rapid ecosystem alteration in the Arctic.

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and public awareness [13]. An arctic marine mammal tracking framework such as we describe could provide the GOOS with essential evidence on the status of these ecosystem sentinels, and the observatory could in turn provide an online portal for quick delivery of information to resource managers. While the goals set forth by GOOS are challenging [13], they offer a path toward sustainability through improved prediction, more precaution, and wiser policy in this era of global environmental change [42].

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The views presented here reflect the authors' personal perspectives based on compiled evidence and over 40 years of research on marine mammals in the Arctic. They do not reflect policy positions of their employing organizations.

References

1. Wood KR, Bond NA, Danielson SL, Overland JE, Salo SA, Stabeno P, Whitefield J (2015) A decade of environmental change in the Pacific Arctic region. Prog Oceanogr 136: 12–31.

2. Arrigo KR, van Djiken GL (2015) Continued increases in Arctic Ocean primary production. Prog Oceanogr 136: 60–70.
3. Harvey JA, van den Berg D, Ellers J, Kampen R, Crowther TW, Roessingh P, et al. (2018) Internet blogs, polar bears, and climate change denial by proxy. BioScience 68: 281–287. https://doi.org/10.1093/biosci/bix133 PMID: 29662248
4. Moore SE (2018) Climate Change, pp 194–197 in Encyclopedia of Marine Mammals 3rd Edition, B Wursig, JGM Thewissen, KM Kovacs eds, Elsevier-Academic Press, San Diego USA
5. Moore SE (2016) Is it 'boom times' for baleen whales in the Pacific Arctic region? Bio Lett 12: 20160251.
6. Higdon JW, Hauser DDW, Ferguson SH (2012) Killer whales (orcinus orca) in the Canadian Arctic: distribution, prey items, group sizes and seasonality. Mar Mamm Sci 28: E93–E109, https://doi.org/10.1111/j.1748-7692.2011.00489.x
7. Laidre KL, Stern H, Kovacs KM, Lowry L, Moore SE, Regehr EV, et al. (2015) Arctic marine mammal population status, sea ice habitat loss, and conservation recommendations for the 21st century. Con Bio https://doi.org/10.1111/cobi.12474 PMID: 25783745
8. Carmack E, Wassman P (2006) Food webs and physical-biological coupling on pan-Arctic shelves: unifying concepts and comprehensive perspectives Prog Oceanogr 71: 446–477.
9. Reeves RR, Ewins PJ, Agbayani S, Heide-Jørgensen MP, Kovacs KM, Lydersen C, et al. (2014) Distribution of endemic cetaceans in relation to hydrocarbon development and commercial shipping in a warming Arctic. Mar Pol 44: 375–389.
10. Hauser DDW, Laidre LK, Stern HL (2018) Vulnerability of Arctic marine mammals to vessel traffic in the increasingly ice-free Northwest Passage and Northern Sea Route. PNAS, www.pnas.org/cgi/doi/10.1073/pnas.1803543115.
11. McWhinnie LH, Halliday WD, Insley SJ, Hilliard C, Canessa RR (2018) Vessel traffic in the Canadian Arctic: management solutions for minimizing impacts o whales in a changing northern region. Ocean & Coastal Manage. 160, https://doi.org/10.1016/j.ocecoaman.2018.03.042.
12. Lewison R, Johnson AF, Verutes GM (2018) Embracing complexity and complexity-awareness in marine megafauna conservation and research. Front. Mar. Sci. https://doi.org/10.3389/fmars.2018.00043
13. Miloslavich P, Bax NJ, Simmons SE, Klein E, Appeltans W, Aburto-Oropeza O, et al. (2018) Esential ocean variables for global sustained observations of biodiversity and ecosystem changes. Global Change Bio https://doi.org/10.1111/gcb14108
14. George JC, Bada J, Zeh J, Scott L, Brown SE, O'Hara T, Suydam R (1999) Age and growth estimates of bowhead whales (*Balaena mysticetus*) via aspartic acid racemization. Can J Zool 77(4): 571–580. https://doi.org/10.1139/z99-015.
15. George JC, Druckenmiller ML, Laidre KL, Suydam R, Person B (2015) Bowhead whale body condition and links to summer sea ice and upwelling in the Beaufort Sea. Prog Ocean 136: 250–262.
16. Drukenmiller ML, Citta JJ, Ferguson MC, Clarke JT, George, JC, Quakenbush L (2017) Trends in sea-ice cover within bowhead whale habitats in the Pacific Arctic. Deep-Sea Res II https://doi.org/10.1016/j.dsr2.2017.10.017.
17. Stafford KM, Lydersen C, Wiig Ø, Kovacs KM (2018) Extreme diversity in the songs of Spitsbergen's bowhead whales. Biol Lett http://dx.doi.org/10.1098/rsbl.2018.0056.
18. NAMMCO (2018) Report of the Global Review of Monodontids, 13–16 March 2017, Hillerød, Denmark, https://nammco.no/
19. Harwood LA, Kingsley MCS, Smith T (2014) An emerging pattern of declining growth rates in belugas of the Beaufort sea: 1989–2008. Arctic 67: 483–492.
20. Quakenbush LT, Suydam RS, Bryan AL, Lowry LF, Frost KJ, Mahoney BA (2015) Diet of beluga whales, Delphinapterus leucas in Alaska from stomach contents, March-November. Mar Fish Rev https://doi.org/dx.doi.org/10.7755/MFR.77.1.7
21. Nelson MA, Quakenbush LT, Mahoney BA, Taras BD, Wooller MJ (2018) Fifty years of Cook Inlet beluga whale feeding ecology from isotopes in bone and teeth. Endangr Species Res 36:77–87.
22. Hauser DDW, Laidre KL, Stern HL, Suydam RS, Richard PR (2018) Indirect effects of sea ice loss on summer-fall habitat and behavior for sympatric populations of an Arctic marine predator. Biodiv Res https://doi.org/10.1111/ddi.12722
23. Moore SE, DeMaster DP, Dayton PK (2000) Cetacean habitat selection in the Alaskan Arctic in summer and autumn. Arctic 53 (4): 432–447.
24. Laake JL, Punt AE, Hobbs R, Ferguson M, Rugh D, Breiwick J (2012). Gray whale southbound migration surveys 1967–2006: An integrated re-analysis. J Cet Res Manage 12(3):287–306.

25. Brower AA, Clarke JT, Ferguson MC (2018) Increased sightings of subarctic cetaceans in the eastern Chukchi Sea, 2008–2016: Population recovery, response to climate change, or increased survey effort? Polar Bio https://doi.org/10.1007/s00300-018-2257-x.
26. Vikingsson GA, Pike DG, Valdimarsson H, Schleimer A, Gunnlausgsson T, Silva T, et al. (2015) Distribution, abundance, and feeding ecology of baleen whales in Icelandic waters: have recent environmental changes had an effect? Fornt Ecol & Evol, https://doi.org/10.3389/fevo.2015.0006
27. Skern-Mauritzen M, Johannesen E, Bjørge A, Øien N (2011) Baleen whale distributions and prey associations in the Barents Sea. Mar Ecol Prog Ser 426: 289–301.
28. Regehr EV, Laidre KL, Akçakaya H R, Amstrup SC, Atwood TC, Lunn NJ, et al. (2016) Conservation status of polar bears (Ursus maritimus) in relation to projected sea-ice declines. Biol Lett http://dx.doi.org/10.1098/rsbl.2016.0556.
29. Laidre KL, Born EW, Atkinson SN, Wiig Ø, Andersen LW, Lunn NJ, et al. (2018) Range contraction and increasing isolation of a polar bear subpopulation in an era of sea-ice loss. Ecol & Evol, https://doi.org/10.1002/ece3.3809 PMID: 29468025
30. Pagano AM, Durner GM, Rode KD, Atwood TC, Atkinson SN, Peacock E, Costa DP, Owen MA, Williams TM (2018) High-energy, high-fat lifestyle challenges an Arctic apex predator, the polar bear. Science 359: 568–572. https://doi.org/10.1126/science.aan8677 PMID: 29420288
31. Kovacs KM, Aars J, Lydersen C (2014) Walruses recovering after 60+ years of protection in Svalbard, Norway. Polar Res 33, http://doi.org/10.3402/polar.v33.26034
32. Lydersen CL, Vaquie-Garcia J, Lydersen E, Christensen GN, Kovacs KM (2017) Novel terrestrial haul-out behavior by ringed seasl (*Pusa hispida*) in Svalbard, in association with harbor seals (*Phoca vitulina*). Polar Res 36, https://doi.org/10/1080/17518369.2017:1374124
33. Heptner, V.G., Chapskii, K.K., Arsen'ev, V.A. and Sokolov, V.E. 1976. Mammals of the Soviet Union. Vol. II, Part 3, Pinnipeds and Toothed Whales Pinnipedia and Odontoceti. Vysshaya Shkola Publishers, Moscow. [English edition published in 1996 by Smithsonian Institution Libraries and National Science Foundation, Washington, D.C.]
34. Huntington HP, Quakenbush LT, Nelson M (2016) Effects of changing sea ice on marine mammals and subsistence hunters in northern Alaska from traditional knowledge interviews. Bio Lett, http://dx.doi.org/10.1098/rsbl.2016.0198
35. Laidre KL, Stirling I, Lowry LF, Wiig Ø, Heide-Jørgensen MP, Ferguson SH (2008) Quantifying the sensitivity of arctic marine mammals to climate-induced habitat change. Ecol App 18: S97–S125.
36. Williams TM, Noren SR, Glenn M (2010) Extreme physiological adaptations as predictors of climate-change sensitivity in the narwhal. Mar Mamm Sci, https://doi.org/10.1111/j.1748-7692.2010.00408
37. Moritz C, Agudo R (2013) The future of species under climate change: resilience or decline? Science 341: 504–508. https://doi.org/10.1126/science.1237190 PMID: 23908228
38. Sydeman WJ, Poloczanska E, Reed TE, Thompson SA (2017) Climate change and marine vertebrates. Science 350: 772–777.
39. Moore SE, Gulland FMD (2014) Linking marine mammal and ocean health in the 'New Normal'. Ocean & Coast Mgt 102: 55–57.
40. Taylor BL, Martinez M, Gerrodette T, Barlow J (2007) Lessons from monitoring trends in abundance of marine mammals. Mar Mamm Sci 23: 157–175.
41. Moore SE, Stabeno PJ, Grebmeier JM, Okkonen SR (2016) The Arctic Marine Pulses Model: linking annual oceanographic processes to contiguous ecological domains in the Pacific Arctic. Deep-Sea Res II, http://dx.doi.org/10.1016/j.dsr2.2016.10.011.
42. Schindler DE, Hilborn R (2015) Prediction, precaution, and policy under global change. Science 347: 953–954. https://doi.org/10.1126/science.1261824 PMID: 25722401