Ringed Seal

Arctic ringed seal (*Pusa hispida hispida*)
Okhotsk ringed seal (*Pusa hispida ochotensis*)
Baltic ringed seal (*Pusa hispida botnica*)
Ladoga ringed seal (*Pusa hispida ladogensis*)

Five-Year Status Review: Summary and Evaluation

February 2024

Photo Credit: Jessica Lindsay, University of Washington & NOAA Fisheries

National Marine Fisheries Service

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1. GENERAL INFORMATION

1.1. REVIEWERS

Lead Regional or Headquarters Office: National Marine Fisheries Service (NMFS) Alaska Region (AKR) – Jon Kurland, Tammy Olson, Kathleen Leonard, and Barbara Mahoney.

Lead Science Center: NMFS Alaska Fisheries Science Center (AFSC), Marine Mammal Laboratory – Peter Boveng, Shawn Dahle, John Jansen, Jessica Lindsay, and Heather Ziel, with literature review, bibliographic, and editing assistance by Skyla Walcott.

1.2. METHODOLOGY USED TO COMPLETE THE REVIEW

The ESA, under section 4(c)(2), directs NMFS to review the listing classification of each listed species at least once every five years. A 5-year review is a periodic analysis of a species' status conducted to ensure that the listing classification of a species as threatened or endangered is accurate. This five-year review was led by the NMFS Alaska Fisheries Science Center (AFSC). The review was prepared pursuant to the joint NMFS and U.S. Fish and Wildlife Service (USFWS) 5-Year Review Guidance and template (USFWS and NMFS 2006). The primary sources of information and data for this review came from reports, publications, and information that have become available from ongoing studies and reviews since the status review completed by Kelly et al. (2010) and the December 28, 2012, final rule published in the *Federal Register* (FR) to list the Arctic, Okhotsk, Baltic, and Ladoga subspecies of ringed seals under the Endangered Species Act (ESA) (77 FR 76706; December 28, 2012). Hereafter, we refer frequently to those documents as "the 2010 Status Review" and "the listing rule", respectively. When convenient, we also make frequent mention of the listing determinations simply as "the listings", "at the time of listing", or similar phrases. The vast majority of new information sources were obtained and archived throughout the intervening period in a research bibliography maintained by the Polar Ecosystems Program of the AFSC Marine Mammal Laboratory. We also gathered information[1] through: 1) literature searches on various search engines (e.g., Google Scholar, Research Gate, Web of Science); and 2) publication of a FR notice announcing initiation of the review and soliciting new information about the Arctic, Okhotsk, Baltic, and Ladoga subspecies of ringed seals, particularly information about their status, threats, and recovery. There is currently no recovery plan in place or completed recovery outline for any of the four ringed seal subspecies. Therefore, per the 5-Year Review Guidance, information available on the four ringed seal subspecies' biology and habitat, threats, and conservation measures was summarized and analyzed relative to the ESA definition of endangered and threatened, and in light of the ESA section 4(a)(1) factors, to determine whether reclassification or delisting may be warranted for any of these subspecies.

This review focused on four of the five ESA-listed subspecies of ringed seals, omitting the endangered Saimaa ringed seal (*Phoca* (=*Pusa*) *hispida saimensis*) because it was reviewed in 2018 (NMFS 2018).

1.3. BACKGROUND

1.3.1. FR Notice citation announcing initiation of this review

On November 27, 2020, NMFS published a notice announcing initiation of this review with a 60-day period to receive information requested from the public (85 FR 76017); the information request period was subsequently extended by 59 days (86 FR 4000; January 15, 2021). NMFS received five information submissions in response to that notice, which NMFS considered in preparing this 5-year review.

1.3.2. Listing history

<u>Original Listing</u>
FR notice: 77 FR 76706; December 28, 2012
Date listed: Effective February 26, 2013
Entity listed and classification:
Ringed seal, Arctic subspecies (*Phoca* (= *Pusa*) *hispida hispida*); Threatened
Ringed seal, Okhotsk subspecies (*Phoca* (= *Pusa*) *hispida ochotensis*); Threatened

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[1] Much of the published scientific information about the biology and ecology of ringed seals originated as local or traditional knowledge accumulated by Indigenous peoples in the Arctic. Many Indigenous people have shared some of their understanding of the species and its ecology since the first contacts with academically trained naturalists and scientists. Indigenous knowledge (IK) in Arctic coastal communities continues to advance and adapt as conditions change. We consider the Indigenous knowledge about ringed seals that is documented and available to us, to be part of the body of 'best available scientific and commercial information' on which this review is to be based. This practice is consistent with the Guidance for Federal Departments and Agencies on Indigenous Knowledge, issued November 30, 2022 by the President's Office of Science and Technology Policy and the Council on Environmental Quality.

Ringed seal, Baltic subspecies (*Phoca* (= *Pusa*) *hispida botnica*); Threatened
Ringed seal, Ladoga subspecies (*Phoca* (= *Pusa*) *hispida ladogensis*); Endangered

On March 17, 2016, the listing of the Arctic ringed seal as threatened under the ESA was vacated by the U.S. District Court for the District of Alaska (*Alaska Oil & Gas Ass'n* v. *Nat'l Marine Fisheries Serv.,* Case Nos. 4:14-cv-29-RRB, 4:15-cv-2-RRB, 4:15-cv-5-RRB, 2016 WL 1125744 (D. Alaska Mar. 17, 2016)). This decision was reversed by the Ninth Circuit on February 12, 2018 (*Alaska Oil & Gas Ass'n* v. *Ross,* 722 F. App'x 666 (9th Cir. 2018)), and the listing was reinstated on May 15, 2018.

On November 27, 2020, NMFS announced a 90-day finding on a petition submitted by the State of Alaska and the North Slope Borough to delist the Arctic ringed seal, concluding that the petition did not present substantial scientific or commercial information indicating that the petitioned action may be warranted (85 FR 76018).

The four subspecies that are the focus of this review were listed with the scientific name *Phoca (= Pusa) hispida.* In this 5-year review, we use the genus name *Pusa* to reflect currently accepted use (e.g., Committee on Taxonomy 2023; ITIS 2023).

1.3.3. Associated rulemakings

Critical Habitat Designation (Arctic Ringed Seal)
FR notice: 87 FR 19232; April 1, 2022
Date Designated: Effective May 2, 2022

1.3.4. Review History

This is the first, formal five-year review of the Arctic, Okhotsk, Baltic, and Ladoga subspecies of ringed seals. A status review ("2010 Status Review"; Kelly et al. 2010) and 12-month finding on a petition to list the ringed seal under the ESA were completed in 2010 and announced in the FR on December 10, 2010, when NMFS published a proposed rule to list these ringed seal subspecies under the ESA (75 FR 77476).

1.3.5. Species' Recovery Priority Number at start of five-year review

A species' recovery priority number is assigned based on the application of the Endangered and Threatened Species Listing and Recovery Priority Guidelines (84 FR 18243; April 30, 2019). The criteria for determining the recovery priority number include: 1) the species' demographic risk rank, which is based on the species' listing status and condition in terms of its productivity, spatial distribution, diversity, abundance, and trends (for threatened species, demographic risk rank may be assigned as either "low" or "moderate"); and 2) the three components of the species' recovery potential (whether major threats and the species' response to those threats are well understood; whether the United States has jurisdiction, authority, or influence to implement management or protective actions to address major threats; and the certainty that such actions will be effective), which may be categorized as either “low to moderate” or “high.” A species could potentially be assigned a recovery priority number ranging from 1—where the species’ demographic risk rank and all three components of the species’ recovery potential are categorized as “high”—to a recovery priority number of 11—where the species’ demographic risk rank is categorized as “low” and all three components of the species’ recovery potential are categorized as “low to moderate.” Once a recovery priority number is identified, species that are, or may be, in conflict with construction or other development projects or other forms of economic activity are assigned a *C*, which indicates a higher priority over those species that are not in conflict.

The Arctic ringed seal has a recovery priority number of 9C, as reported in the Recovering Threatened and Endangered Species, FY 2021-2022 Report to Congress (NMFS 2023a). This number reflects that the demographic risk rank is *moderate* (based on threatened status with lack of reliable data on trends in abundance), and the three components of the recovery potential criterion are categorized as *low to moderate* (as responses of the species to the principal threat of long-term habitat changes are not well understood; management or protective actions to abate this principal threat are mainly beyond U.S. jurisdiction, authority, or ability to influence; and other threats are of low significance). No recovery priority number has been issued for the Okhotsk, Baltic, or Ladoga ringed seal, which occur entirely outside U.S. jurisdiction.

1.3.6. Recovery Plan or Outline

There is currently no recovery plan or recovery outline in place for any of the four ringed seal subspecies.

2. REVIEW ANALYSIS

2.1. APPLICATION OF THE 1996 DISTINCT POPULATION SEGMENT (DPS) POLICY

2.1.1. Is the species under review a vertebrate?

__X_ **Yes,** *go to section 2.1.2.*
_____ **No,** *go to section 2.2.*

2.1.2. Is the species under review listed as a DPS?

_____ **Yes**, *go to section 2.1.3.*
__X__ **No**, *go to section 2.1.4.*

2.1.3. Was the DPS listed prior to 1996?

____ **Yes**, *give date and go to section 2.1.3.1.*
__X_ **No**, *go to section 2.1.4.*

2.1.4. Is there relevant new information for this species regarding the application of the DPS policy?

____ **Yes**
__X_ **No**, *go to section 2.2., Recovery Criteria.*

2.2. RECOVERY CRITERIA

2.2.1. Does the species have a final, approved recovery plan[2] containing objective, measurable criteria?

____ **Yes**, *continue to section 2.2.2.*
__X_ **No**

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[2] Although the guidance generally directs the reviewer to consider criteria from final approved recovery plans, criteria in published draft recovery plans may be considered at the reviewer's discretion.

2.3. UPDATED INFORMATION ON BIOLOGY, HABITAT, DEMOGRAPHY, AND THREATS

2.3.1. New information on the species' taxonomic classification

The taxonomy of the subfamily Phocinae has varied over time and the names used have varied among authors. This inconsistency stems from the close relatedness and relatively recent divergence among the genera and species (e.g., Kelly et al. 2010; Fulton and Strobeck 2010). Some authors have placed ringed seals in the genus *Pusa* while others have used *Phoca*, as Kelly et al. did in the 2010 Status Review; they acknowledged, however, that the taxonomy remained incompletely resolved. Since the listings, Berta and Churchill (2012) and the Society for Marine Mammalogy (Committee on Taxonomy 2023) have recommended that ringed seals be placed in *Pusa* along with the Caspian seal (*Pusa caspica*) and the Baikal seal (*Pusa sibirica*). For this 5-year review we have followed these recommendations.

The validity of the Baltic subspecies of ringed seal, *Pusa hispida botnica*, is questionable due to a lack of morphological and genetic evidence that it is distinct from *P. h. hispida* (Berta and Churchill 2012). Baltic ringed seals have lower diversity and, at least with the relatively small numbers of genetic markers used thus far, have not been clearly differentiated from Arctic ringed seals, possibly dispersing into the Baltic only since the last glacial period (Palo et al. 2001). Newer genetic methods with larger numbers of markers might lend greater confidence about whether Baltic ringed seals warrant retention as a subspecies. The Committee on Taxonomy (2023), however, has retained *P. h. botnica* and, because the committee represents a broader consensus than the single review by Berta and Churchill (2012), we continue to recognize *P. h. botnica* as a valid subspecies.

2.3.2. New information on the species' biology and life history

Arctic Ringed Seal

Description—Kovacs et al. (2021) examined morphometric data for Arctic ringed seals from sampling sites located across much of their range and found that model-averaged estimates of asymptotic length for both female and male ringed seals each clustered into five groups, with the largest occurring in northeastern Canada and western Greenland and the smallest in the White Sea and Alaska. They only observed latitudinal trends in ringed seal body length and age-at-maturity within the eastern Canadian Arctic, where Ferguson et al. (2018, 2019) similarly reported that ringed seals at higher latitudes grew slower and to a larger size (both in length and mass) than did those to the south in the Hudson Bay region. The studies confirmed that additional research is needed to determine whether the variation in body size of Arctic ringed seals observed in their study represents adaptations to local conditions or genetically distinct ecotypes, and to improve understanding of the influence of environmental and other factors on body size and related aspects of Arctic ringed seal ecology.

Vocalization and hearing—Jones et al. (2014) described the underwater vocal repertoire of ringed, bearded (*Erignathus barbatus*), and ribbon seals (*Histriophoca fasciata*), as well as their seasonal vocal patterns and relationship to sea ice concentration, using autonomous acoustic recordings made during 2006–2009 along the continental shelf break in the Chukchi Sea north-northwest of Utqiaġvik (formerly Barrow), Alaska, between September and June. They found that ringed seal vocalizations recorded in the Chukchi Sea showed general similarity in both call types and their relative proportions in the recordings to those recorded in the Canadian High Arctic during April 1982 (Calvert and Stirling 1985), suggesting little geographic variation in ringed seal vocal behavior. Recent studies have also provided information on seasonal patterns in acoustic detections of ringed seals in the northern Chukchi Sea (Hannay et al. 2013), as well as in the Amundsen Gulf region of the Canadian Beaufort Sea near Ulukhaktok (Halliday et al. 2017, 2018), where the influence of environmental variables (e.g., sea ice concentration) on the acoustic presence of marine mammals was also assessed.

Sills et al. (2015) reported hearing data for two captive ringed seals that were obtained using psychophysical methods, including underwater and in-air audiograms, and critical ratio measurements in both media. The low critical ratio measurements documented in this study suggest that ringed seals have a good ability to detect signals within background noise.

Seasonal movement, diving, and haul-out behavior—The movements and habitat use of more than 55 ringed seals instrumented with satellite tags (hereafter "tagged") in Alaska from 2007–2019 have been documented in several recent publications and reports (Crawford et al. 2012, 2019; Quakenbush et al. 2019, 2020b; Von Duyke et al. 2020). Most of these ringed seals were tagged during summer and fall in Kotzebue Sound or near Utqiaġvik on the eastern coast of the Chukchi Sea. The ringed seals in these studies used continental shelf waters of the Chukchi and Beaufort seas for the most part during the open-water season; and they moved southward into the southern Chukchi and Bering seas for the winter, except for some animals tagged near Utqiaġvik that instead remained in the northeastern Chukchi Sea. Crawford et al. (2012, 2019) found that the tagged subadult ringed seals in their studies traveled south from the Chukchi Sea into the Bering Sea ice where they spent the winter near the ice edge before returning north with receding ice in the spring, whereas the tagged adults remained farther north in the southern Chukchi and northern Bering seas.

During mid-summer to early fall, some of the ringed seals tagged in Alaska since 2010 have made forays north of the continental shelf as the sea ice retreated into the deep Arctic Basin (Quakenbush et al. 2019, 2020b; Von Duyke et al. 2020). Von Duyke et al. (2020) reported that the tagged ringed seals in their study made such off-shelf trips over a period of 2 to 21 days (median = 7 days), during which time the seals tended to haul out for prolonged periods after encountering receding sea ice before usually returning to continental shelf waters. Using oceanographic data collected by the sensors on some ringed seals' tags, Quakenbush et al. (2020b) found that when north of the shelf break, the seals' dives deeper than 100 m often targeted Atlantic-origin water along the shelf break and in the Arctic Basin. When over the shelf during this same period, the seals made dives targeting several types of Pacific-origin waters, mainly Bering summer water (a combination of Anadyr water and central Bering shelf water). Dives suggestive of foraging documented for tagged ringed seals in continental shelf waters were often to depths at or near the seafloor (Crawford et al. 2019; Quakenbush et al. 2020b; Von Duyke et al. 2020).

Indigenous Knowledge (IK) documented in Alaska described foraging by ringed seals in nearshore areas near Utqiaġvik and in the Bering Strait region, especially during spring and fall in some areas (Oceana and Kawerak Inc 2014; Gryba et al. 2021). Additionally, IK holders in the Bering Strait region reported that ringed seals forage near river mouths in Norton Bay during spring, and some young ringed seals feed on fish at river mouths and upstream during summer and fall (Oceana and Kawerak Inc 2014). Observations of ringed seals at the mouths of rivers and in lagoon channels were also documented in the Bering Strait region along the eastern coast of the Kamchatka Peninsula (Melnikov 2022).

In the western Canadian Arctic, ringed seals (12 adult and 4 subadult) tagged during the summers of 1999, 2000, and 2010 near Ulukhaktok, in the eastern Amundsen Gulf, made extensive movements during the open-water season (total distance tracked: 1,182–7,582 km) (Harwood et al. 2015a). The seals spent more than half their open-water days in resident/foraging mode overall, mainly within Prince Albert Sound and the eastern Amundsen Gulf, but also in distant areas such as Viscount Melville Sound. Most of the ringed seals in this study returned to, and overwintered in, Prince Albert Sound and the eastern Amundsen Gulf, during which time they occupied winter home ranges that were markedly smaller than were their open-water home ranges. In contrast, seven ringed seals (1 adult female, 5 subadult, and 1 pup) tagged during early fall in the western Amundsen Gulf in 2001 and 2002 all made similar, sustained fall movements westward into the Chukchi Sea, traveling on average 2,138 km between the tagging site and Point Barrow, Alaska, within about a month (Harwood et al. 2012a, 2015b). The transmissions from four of the five tagged subadult seals, as well as the tagged pup, ended during fall or winter off the northern coast of the Chukotka Peninsula and eastern Siberia, while the tagged adult female moved through the Bering Strait and was located in the northern Bering Sea when her tag transmissions ceased in early spring (Harwood et al. 2012a).

In the eastern Canadian Arctic, six ringed seals (1 adult male and 5 subadult) tagged in Resolute Bay and Tremblay Sound during late summer to early fall of 2012–2013 and 2017–2018 initiated long-distance movements (range: ~1,711—~2,576 km) to southeastern Baffin

Island in fall to early winter before ice had formed, where some of the seals resided for at least a portion of the winter in Cumberland Sound (Ogloff et al. 2021). Three of the six seals traveled through central Baffin Bay before making directed movements southward, while the others more gradually traveled southward along the coast of Baffin Island. The seals that moved through central Baffin Bay made shallower and shorter dives than did the seals that traveled near the coast.

In Hudson Bay, Luque et al. (2014) reported that both non-adult (n = 22) and adult ringed seals (n = 13) tagged during mid-summer to early fall of 2006–2009 showed a distinct seasonal pattern in their movement behavior, more pronounced in the adults than the non-adults, wherein 'resident' movement was more likely toward the end of the open-water season and into the early-winter portion of the ice-covered season than at other times. They noted that the seasonal changes in movement behavior of these seals generally followed the seasonal cycle in blubber reserves documented in Arctic ringed seals (e.g., Young and Ferguson 2013), and thus it appeared to represent a seasonal pattern of foraging effort, although an alternative explanation is that dense sea ice restricts movement.

Yurkowski et al. (2016c) examined the influence of several environmental variables, including the duration of the open-water season, on ringed seal movements and diving using satellite telemetry data from 130 ringed seals (45 adult and 85 subadult) tagged at six sites located across the Canadian Arctic and in northwestern Greenland (Melville Bay) from 1999–2013. They found that the tagged ringed seals inhabiting higher latitudes generally spent less time in a resident state and more time traveling during the open-water season than did their counterparts at lower latitudes, where the open-water season was longer and less variable in length between years. The authors concluded that ringed seals are likely responding to differences in prey resource distribution between higher and lower latitudes, which is affected by sea ice phenology. Ferguson et al. (2019) similarly reported that distance traveled and rate of movement during the open-water season were greater for ringed seals tagged in the northern Canadian Arctic (3 adult and 10 subadult seals tagged from 2009–2017) than for individuals tagged in southern Hudson Bay (10 subadult and 27 adult seals tagged from 2006–2012).

In western Greenland, Schiøtt et al. (2023) found that nearly all of the 24 (6 adult and 18 non-adult) ringed seals tagged in Ilulissat Icefjord during July–September of 2012–2020, stayed within the fjord system throughout the period of data transmission, which extended into the spring of the following year for some individuals. The authors suggested that this was likely due to the high biological productivity in this glacial fjord system.

As noted in the 2010 Status Review, two distinct seasonal movement patterns have been documented for ringed seals in Svalbard following the molt—the seals either remain in coastal areas, mainly in association with tidal glacier fronts in fjords (Freitas et al. 2008; Hamilton et al.

2016, 2019b, 2019a), or they make offshore excursions in late summer and fall to the retreating ice edge, a pattern shown primarily by some subadults (Freitas et al. 2008; Hamilton et al. 2015, 2017b, 2018; Lone et al. 2019). A series of recent papers examined the movement, diving, and haul-out behavior of ringed seals tagged on the Svalbard coast before (n = 22 seals; 2002 and 2003) and after (n = 38 seals; 2010–2012) a marked shift in sea ice conditions occurred in the Svalbard-Barents Sea region (Hamilton et al. 2015, 2016, 2018). With this shift in the sea ice regime, the extent and seasonal duration of landfast sea ice cover in Svalbard declined sharply, particularly along the western coast, and summer sea ice extent in the Barents Sea declined such that the position of the ice edge in September shifted northward from over the continental shelf to over the deep Arctic Basin (e.g., Hamilton et al. 2015, 2016). The tagged ringed seals that made offshore trips used areas with similar sea ice characteristics before and after the decline in summer ice extent; however, during the later tracking period they traveled greater distances to reach the sea ice edge and spent more of their time over the Arctic Basin. In addition, changes in movement, diving, and haul-out behavior were documented for the offshore ringed seals in the later period that, taken together, suggest an increase in foraging effort occurred (Hamilton et al. 2015). The tagged ringed seals also exhibited changes in their diving behavior in coastal areas during the later tracking period, such as longer dive duration and shorter surface intervals between dives, suggesting that foraging effort also increased in coastal areas following the shift in the sea ice regime (Hamilton et al. 2016). Additionally, Hamilton et al. (2018) also documented changes in the haul-out behavior of tagged ringed seals in coastal Svalbard after the sharp decline landfast ice, such as shorter haul-out durations and longer intervals between haul-out bouts during winter and early spring, as well as less time spent hauled out on the western coast of Svalbard during these months. They found that weather conditions had a stronger influence on haul-out probability in winter and spring following the change in sea ice conditions, especially on the western coast of Svalbard where landfast ice loss was greatest. The authors concluded that the changes in haul-out patterns documented during winter and spring likely were the result of less time spent sheltered within subnivean lairs due to insufficient snow conditions.

Several of the satellite-tagging studies discussed above have also provided other information that supports and expands on what was known from previous studies about the influences of biological (e.g., maturity), temporal (e.g., time of day), and environmental variables (e.g., sea ice conditions) on Arctic ringed seal movement, haul-out, and diving behavior (Harwood et al. 2012a, 2015a; Hamilton et al. 2016, 2018; Quakenbush et al. 2019, 2020b; Crawford et al. 2019; Von Duyke et al. 2020; Ogloff et al. 2021; Schiøtt et al. 2023). In addition, a study by Benoit et al. (2010) reported ringed seal dive depths and dive frequency relative to the vertical distributions and diel vertical movements of Arctic cod (*Boreogadus saida*) during winter and spring within Franklin Bay in the western Amundsen Gulf, as determined via active acoustic technology.

Citta et al. (2018) compiled available satellite telemetry data for six ice-associated marine mammal species in the Pacific Arctic, including data from 118 ringed seals tagged in Alaska and western Canada from 1999–2015, and determined the seasonal distributions of daily locations for each species, overlap in species distributions, and multispecies core use areas. They showed that during May through November, the distribution of daily locations of ringed seals included the northern Bering, Chukchi, Beaufort, and East Siberian seas, and the distribution of locations was generally more concentrated near tagging sites, but also off the northern coast of the Chukotka Peninsula. In December through April, the distribution of tagged ringed seal locations largely shifted into the shelf waters of the southern Chukchi and northern Bering seas and into the Amundsen Gulf region of the Canadian Beaufort Sea. The authors noted, however, that because the location and season of tagging influenced the distribution of ringed seal telemetry locations, the data were unlikely to reflect the full population-level distribution of ringed seals within these regions.

Hamilton et al. (2022) used available satellite tracking data from 13 Arctic marine mammal species, including data from 263 ringed seals tagged from 2006–2019, to identify hotspots and areas with high species richness across the Arctic. Hotspots for ringed seals occurred in both coastal and offshore shelf habitats, and in the Canadian Arctic Archipelago and the Pacific Arctic, they were generally located farther south during winter than in summer and fall. Habitat features of the hotspots for ringed seals showed regional differences, such as less sea ice during winter in the East Greenland-Barents Sea region relative to the other two regions included in the analysis (Bering-Chukchi-Beaufort and Canadian Arctic Archipelago and West Greenland regions). The authors noted, however, that ringed seal tracking data were generally lacking for the molting period, as well as for the Russian Arctic, where the available data came from a single tagged animal. In addition, Hamilton et al. (2021) used available satellite telemetry data from marine mammals tagged around Svalbard and on the northeastern coast of Greenland, including data from 72 ringed seals tagged from 2010–2018, to identify hotspots and areas with high species richness in the Greenland and Barents seas.

As noted in the 2010 Status Review, although Arctic ringed seals use sea ice as a resting platform throughout the year, they have been observed hauled out on offshore islands and sandbars in the White Sea during summer and autumn (Lukin et al. 2006). Similarly, Svetochev et al. (2022) reported that ringed seals in the White Sea have been observed resting on coastal rocks and shallows during summer and autumn. Since the ESA-listing, terrestrial haul-out by Arctic ringed seals has been reported in other areas. On the western coast of Svalbard, ringed seals have been observed during the sea-ice free season in recent years (ca. 2016) hauled out on rocks exposed at low tide (Lydersen et al. 2017). In addition, ringed seals were seen during the summer of 2016 hauled out on intertidal mudflats within a lagoon on the western coast of Svalbard together with harbor seals (*Phoca vitulina*), a species that had not been observed in this area before (Lydersen et al. 2017). During the sea ice-free season, five ringed seals tagged inside this lagoon in 2016 all hauled out on shore there, and also used glacier ice in the adjacent fjord as a haul-out platform to some degree (Lydersen et al. 2017). Similarly, some of the ten ringed seals tagged inside this lagoon in 2017 used shorelines within the lagoon for haul-out during summer (Vacquié-Garcia et al. 2021). In contrast, four ringed seals tagged inside this same lagoon in 2012 exclusively used glacier ice outside the lagoon as a haul-out platform during the sea-ice free season, but used sea ice that formed within the lagoon later in the year as a haul-out platform, as did some of the seals tagged there in 2016 and 2017 (Lydersen et al. 2017; Vacquié-Garcia et al. 2021). Quakenbush et al. (2019) also identified four occasions when ringed seals (pup and three adults) tagged on the coast of Alaska from 2014–2016 hauled out on land during summer and fall (see also Quakenbush et al. 2020b). Similarly, IK documented for Alaskan coastal communities indicates that ringed seals, particularly juveniles, sometimes haul out on shore during summer and fall in the Bering Strait region and near Utqiaġvik (Oceana and Kawerak Inc 2014; Gadamus et al. 2015; Huntington et al. 2017; Gryba et al. 2021). Additionally, along the eastern coast of the Chukotka Peninsula in the Bering Strait region, observations of ringed seals mainly recorded between 1994 and 2005 included records of ringed seals hauled out together with spotted seals (*Phoca largha*) during summer and fall on rocks, as well as the coastline in several places (Melnikov 2022).

Breeding habitat**—**As discussed in detail in the 2010 Status Review, Arctic ringed seals excavate lairs in areas of drifted snow on stable ice during winter and spring within which they rest, and females shelter their pups during nursing and whelping. Cameras placed inside some haul-out lairs (i.e., lairs without evidence of a pup) in 2022 also documented ringed seals resting and sleeping in lair access holes without hauling out, during which time small temperature increases occurred in some lairs (Quakenbush et al. 2022).

Hauser et al. (2021) reported findings from spring surveys for ringed seal structures (i.e., breathing holes and lairs) conducted on landfast ice in southern Kotzebue Sound and Ledyard Bay in the eastern Chukchi Sea in 1983 and 1984 but not previously published. In both survey areas, ringed seal structures classified as pup lairs were in general characterized by deeper snow and greater ice deformation than those identified as simple haul-out lairs, in agreement with similar studies conducted in other parts of the Arctic (Hauser et al. 2021). In the Beaufort Sea, Quakenbush et al. (2022) reported that snow depths measured at lairs identified during a survey conducted in May 2022 on landfast ice near the Northstar Island oil production facility were similar to those documented in this area in 1983 (Kelly et al. 1986; Kelly and Quakenbush 1990), although fewer lairs and more breathing holes (14 lairs and 47 breathing holes) were found per unit area in 2022 than in 1983 (27 lairs and 16 breathing holes). Nearly all of the lairs found in both survey years were classified as haul-out lairs.

Lindsay et al. (2021) used spring aerial survey data collected in the Bering Sea (2012 and 2013) and Chukchi Sea (2016), along with remotely-sensed snow and sea ice data, to investigate spatiotemporal patterns in ringed seal counts and breeding habitat selection. They found that ringed seal total counts and pup counts in both seas were more strongly affected by date than by the habitat variables included in their analysis. However, the effect of snow depth on total counts in both the Bering Sea and Chukchi Sea was positive (as was melt progression), especially in the Chukchi Sea, highlighting the importance of deeper snow for ringed seal habitat and lair construction. The same aerial survey data from the Chukchi Sea were used by Boveng et al. (in review)[3] to estimate ringed seal abundance and its relationship with snow depth. They found that ringed seal densities increased strongly with remotely-sensed average snow depth up to 20 cm and reached a plateau between 20 and 30 cm. The result is in close concurrence with the studies reviewed in the 2010 Status Review that were based on *in situ* snow measurements, collectively showing that less than 20 cm average snow depth is suboptimal for ringed seal breeding habitat. The result also demonstrated the capability for remotely monitoring this key habitat feature across extensive regions of the Pacific Arctic ringed seal range. There were broad confidence intervals for ringed seal densities at snow depths greater than 25 cm, which may reflect that the seals use areas of greater snow depths but are not necessarily found at high densities in all cells with deep snow; other habitat dimensions are likely to be important, too. But the narrow intervals and strong increase in seal densities as snow depths increased up to 25 cm seem supportive of ringed seals' selection of breeding habitat with sufficient snow for lair construction and integrity.

Similarly, Lindsay et al. (2023) reported that counts of both ringed seal groups and pups detected on landfast ice during drone-based surveys conducted during spring of 2019 near Kotzebue, Alaska, were associated with both bright Landsat 8 pixel values and intermediate pixel variability, which were in turn correlated with on-ice measurements of deep snow and ice surface roughness, respectively, although the survey was conducted during a year of unusually limited sea ice and snow in Kotzebue Sound. They noted that ringed seal densities observed in the surveys were higher than observed in previous studies conducted in Kotzebue Sound, which may have been related to the abnormally limited sea ice availability that year. Mahoney et al. (2021) reported that the limited sea ice near Kotzebue during the winters of 2017–2018 and 2018–2019 likely was the thinnest since at least 1945, which contributed to surface flooding and snow-ice formation (resulting from subsequent freezing of flooded snow), especially in 2019 when snowfall was above-average. Lindsay et al. (2023) observed ringed seal pups on the ice near Kotzebue still in their natal lanugo in early May 2019, just a few days prior to early onset of ice breakup.

In a study of the effects of climate change on Indigenous marine mammal hunting in 14 coastal villages of Alaska, the dominant physical changes reported by hunters were related to sea ice forming later, remaining thinner, breaking up earlier in spring, and being scarce or absent in

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[3] Boveng, P. et al. Manuscript in review. Abundance and distribution of bearded and ringed seals in the Chukchi Sea: a reference for future trends. Available from NOAA Alaska Fisheries Science Center, Marine Mammal Laboratory, 7600 Sand Point Way NE, Seattle, WA 98115.

the summer (Huntington et al. 2016, 2017). Hunters in Kotzebue Sound described thinner ice, with fewer pressure ridges where snowdrifts can form, and thus less habitat for ringed seal lairs. There was less snow on sea ice near Elim and Scammon Bay in the Bering Strait, and thus less habitat for seal lairs in that region, as well. Consistent with information presented in the 2010 Status Review, it was noted by IK holders in Kotzebue that when the snow melts early, there is no protection for ringed seal pups from predators such as foxes, as well as jaegers and ravens (Huntington et al. 2017). IK compiled for Alaskan coastal communities in the Bering Strait region similarly identified ravens, wolverine, foxes, and grizzly bears as predators of ringed seal pups when they are not concealed within lairs (Gadamus et al. 2015).

Diet and foraging ecology**—**As detailed in the 2010 Status Review and further supported by the findings of studies completed since 2010, Arctic ringed seals feed on a wide variety of fish and invertebrate prey throughout their circumpolar range. While ringed seals do not show specific morphological traits associated with suction feeding (Kienle and Berta 2015; Kienle et al. 2021), both biting (pierce feeding) and suction feeding strategies were employed by captive ringed seals when feeding on individual prey (capelin, *Mallotus villosus*) in controlled feeding trials (Kienle et al. 2018). Fish are generally more important than invertebrates, and members of the cod family are most prevalent in their diets in many areas, particularly Arctic cod (*Boreogadus saida*), which is often reported to be among the most important Arctic ringed seal prey species, especially at higher latitudes (e.g., Labansen et al. 2011; Crawford et al. 2015; Quakenbush et al. 2020a; Bengtsson et al. 2020; Ghazal 2021; Insley et al. 2021; Ross et al. 2022; Schiøtt et al. 2023). However, Arctic ringed seal diet composition varies geographically, seasonally, and generally differs between juveniles and adults. For example, using stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) values of ringed seal tissues and potential prey species in Bayesian mixing models, Yurkowski et al. (2016b) identified a shift in dietary composition between subadult and adult ringed seals from five locations ranging from low to high latitudes in the Canadian Arctic. Specifically, their analysis indicated that adult ringed seals consumed more fish than did subadults, and subadults consumed more zooplankton than did adults. But these age class differences were most pronounced in ringed seals from the highest latitude (Resolute Bay), where isotopic niche size for adults was smaller than for subadults, and fish consumed by ringed seals were largely Arctic cod; and they decreased at lower latitudes, where isotopic niche size was similar between the two age classes, and other subarctic fish species (e.g., capelin) contributed to the seals' diets, in addition to Arctic cod.

Interannual variation and/or shifts in the foraging habits of Arctic ringed seals over time have been reported in a number of recent studies, with regional variation in the nature of these changes. Quakenbush et al. (2020a) observed differences in the species composition of prey organisms identified in stomachs collected from ringed seals harvested by Alaska Natives in the Bering and Chukchi seas between the periods 2000–2015 and 2016–2020. They found that among other changes during the recent five-year period, saffron cod (*Eleginus gracilis*) and rainbow smelt (*Osmerus dentex*; called *O. mordax* in this study) were more frequently consumed by non-pup ringed seals, while Arctic cod was less frequently consumed by both non-pup ringed seals and pups. Analysis of stable isotopes in claw growth bands of female ringed seals from multiple locations in the Alaskan Bering and Chukchi seas also showed a temporal shift between 1953–1968 and 1998–2014 to more negative $\delta^{13}C$ in ringed seal claws during the later period, but no difference between periods in $\delta^{15}N$ (Crain et al. 2021). A more negative $\delta^{13}C$ could indicate that the seals consumed a more diverse diet during the later period, as the prevalence and diversity of fish species identified in the stomachs of ringed seals from the Bering and Chukchi seas increased from the 1960s and 1970s to the 2000s (Quakenbush et al. 2011; Crawford et al. 2015; Crain et al. 2021). In addition, results from stable isotope analysis of ringed seal claws collected in 2008–2010, from sites mainly located in the eastern Chukchi Sea, provide evidence of high variability in diet among individual ringed seals (Carroll et al. 2013).

Toward the southern periphery of the Arctic ringed seal's range in western Hudson Bay, stomach content analyses showed that the diet of ringed seals from 1991–2006 was dominated by sand lances (*Ammodytes* spp.), although seal consumption of capelin, which first occurred in ringed seal stomachs in 2000, appeared to be increasing during spring (Chambellant et al. 2013). Capelin were among the most important fall fish prey for ringed seals from eastern Hudson Bay in some years between 2003 and 2006, along with sand lance and Arctic cod depending on the year (Young and Ferguson 2014). The feeding habits of Hudson Bay ringed seals also showed interannual variation in relation to the annual timing of sea ice breakup and spring temperature, the latter of which appeared to influence the abundance and/or distribution of their prey (Chambellant et al. 2013; Young and Ferguson 2014).

In the western Canadian Arctic, (Insley et al. 2021) reported that both the fish and invertebrate prey taxa identified in the stomachs of ringed seals from the Amundsen Gulf region in 2015–2018 were more diverse than documented in the 1980s (Smith 1987), with the addition or increased consumption of subarctic fish species (e.g., capelin and sand lance), although prey items such as Arctic cod and hyperiid amphipods (*Themisto* spp.) remained important. In addition, using stable isotope values from ringed seal claw growth bands, (Boucher et al. 2020) showed that the isotopic niche width of ringed seals from the Canadian Beaufort Sea and Amundsen Gulf increased from the 1960s to 2000s, suggesting that the diet of ringed seals or their prey had become more diverse since the 1960s. They also found that ringed seal stable isotopes were significantly influenced by cyclonic circulation regimes of the Arctic Ocean Oscillation, as well as summer sea surface temperature. Similarly, Yurkowski et al. (2016b) found that the isotopic niche size of adult ringed seals from Amundsen Gulf and Cumberland Sound on the southeastern coast of Baffin Island (determined using isotopic values in ringed seal liver and muscle), increased between 1990–1996 and 1999–2011, which they suggested likely was attributable to recent increases in the prevalence of subarctic fish species such as capelin in these areas. Further, using stable isotope analysis with Bayesian mixing models, Yurkowski et al.

(2018) found that forage fish contributions to the diets of ringed seals, beluga whales (*Delphinapterus leucas*), Greenland halibut (*Reinhardtius hippoglossoides*), and Arctic char (*Salvelinus alpinus*) from Cumberland Sound (Arctic cod in 1990–2002; Arctic cod/capelin in 2005–2012) increased between 1990–2002 and 2005–2012 after availability of capelin increased within this region beginning in the mid-2000s, resulting in a more trophically redundant apex predator assemblage.

Along the western coast of Svalbard, Lowther et al. (2017) reported that a shift in the diet of adult ringed seals or their prey occurred between 1990 and 2013 based on changes observed in the stable isotope composition of ringed seal whiskers. Using analysis of gastrointestinal tracts from ringed seals collected in western Svalbard from 2014–2017, a subsequent study found that Arctic prey species, especially Arctic cod, continued to dominate the diet. However, the contribution of prey species associated with Atlantic water to their diet increased in comparison to earlier studies (e.g., Labansen et al. 2007), and included a very small amount of blue whiting (*Micromesistius poutassou*), a member of the cod family which had not been previously documented in the diet of ringed seals (Bengtsson et al. 2020).

Several recent studies have investigated the degree to which Arctic ringed seals are supported by primary production originating from sea ice algae to improve understanding of how ongoing environmental and ecosystem changes might affect them through their prey (Brown et al. 2014a; Wang et al. 2016b, 2016a; Kunisch et al. 2021, 2021; Carlyle et al. 2022; Desforges et al. 2022). For example, using measurements of certain source-specific highly branched isoprenoid diatom lipids (HBIs) in ringed seal tissue samples collected from Cumberland Sound, Brown et al. (2014a) showed that the sampled seals were supported by sympagic (ice-associated production year-round, and that HBI contributions from pelagic phytoplankton and sea ice algae to Cumberland Sound ringed seals during summer varied interannually, with increased contributions from pelagic phytoplankton observed in association with decreased September Arctic sea ice extent in the previous year. Longer-term trends in ringed seal carbon use have also been documented; $\delta^{13}C$ decreased in western Hudson Bay ringed seal samples from 2003–2015, suggesting that ringed seals are obtaining more of their carbon energy from pelagic phytoplankton-derived sources (Yurkowski et al. 2020). Similarly, Carlyle et al. (2022) analyzed ringed seal tissue samples collected from sites located in the low to high Arctic for stable isotopes and HBIs to investigate variation in ringed seal diet relative to latitudinal variation in sea ice conditions. They identified a latitudinal shift in ringed seal carbon source use from more depleted $\delta^{13}C$ and a higher contribution of pelagic phytoplankton-derived carbon in the seals from western Hudson Bay to more enriched $\delta^{13}C$ and a higher contribution of sea ice-derived carbon in the seals from the high Arctic, which paralleled latitudinal differences in sea ice conditions and phenology from low to high Arctic.

As noted in the 2010 Status Review, the diet of Arctic ringed seals overlaps with those of other Arctic marine predators, suggesting that interspecific competition for food may occur in some areas. Using analyses of stomach content and stable isotopes with Bayesian mixing models, Matley et al. (2015) found that Arctic cod was the main prey item of ringed seals, beluga whales, and narwhals (*Monodon monoceros*) from Allen Bay and Resolute Bay in the Canadian High Arctic during the open-water season. However, ringed seals consumed smaller Arctic cod and appeared to rely more on nearshore foraging than did beluga whales and narwhals. Additionally, analysis of isotopic niche metrics for beluga whales and ringed seals from multiple locations across a latitudinal range of environmental conditions in the low to high Canadian Arctic provided evidence of individual dietary specialization in ringed seals from some locations, but not in beluga whales (Yurkowski et al. 2016a). After major changes occurred in the sea ice regime in Svalbard, Hamilton et al. (2019a) observed contrasting changes in the coastal habitat use patterns of tagged beluga whales and ringed seals which they attributed to differences between these species in levels of dietary specialization and behavioral plasticity. Specifically, following this shift in environmental conditions, ringed seals spent significantly more of their time near glacier fronts, resulting in smaller home ranges, whereas beluga whales spent significantly less of their time near glacier fronts and showed other changes in their spatial use patterns that the authors attributed to a shift in foraging to include Atlantic-water-associated prey.

Ringed seals and harp seals (*Pagophilus groenlandicus*) were found to consume many of the same prey species in Cumberland Sound, Ilulissat Icefjord, and the White Sea when they co-occur during parts of the year (Svetocheva and Svetochev 2015; Ogloff et al. 2019; Schiøtt et al. 2023). However, Ogloff et al. (2019) reported that harp seals consumed considerably more and larger fish than did ringed seals in Cumberland Sound, similar to findings of a previous study in the Barents Sea by (Wathne et al. 2000). Further, in northwestern Baffin Bay and Svalbard, comparisons of dietary biomarkers found clear niche separation between ringed seals and harp seals (Kunisch et al. 2021; Desforges et al. 2022).

In the northern Bering and Chukchi seas, comparison of blubber fatty acid profiles also showed clear niche separation among ringed seals, bearded seals, and spotted seals, and little separation between ribbon seals and spotted seals (Wang et al. 2016b); which was also observed for ringed, bearded, and spotted seals from Kotzebue Sound (Wang et al. 2016a). Comparisons of the space use, activity patterns, and diving behaviors of tagged ringed seals and bearded seals in Kongsfjorden on the western coast of Svalbard also indicated that interspecific competition between these species likely was low and spatially limited to shallow areas near tidal glacier fronts (Hamilton et al. 2019a).

Molting and seasonal cycle in body condition—Adult and juvenile Arctic ringed seals have been observed to experience seasonal variation in blubber reserves, where blubber reserves decline during spring and reach their minimums following the molting period, after which they gradually increase and reach their maximums during winter, as documented using data collected for each month of the year from ringed seals harvested for subsistence in Alaska (Quakenbush et al. 2020a) and southern Hudson Bay (Young and Ferguson 2013). In the eastern Canadian Arctic, Ferguson et al. (2020) found that seasonal changes in sternal blubber depth were far more pronounced in ringed seals from the Hudson Bay region compared to those from more northerly latitudes, where blubber accumulation also began and ended later than in ringed seals from Hudson Bay.

The observed timing of seasonal fluctuations in blubber stores and body mass of three captive Arctic ringed seals, which became evident by age 4, was similar to that reported for wild Arctic ringed seals, but these seasonal changes were less pronounced in the captive ringed seals (Hartwick 2020; Rosen et al. 2021). Seasonal changes in food intake were also observed in the captive seals, with minimum food intake generally occurring about a month before the start of visible molt, and maximum food intake occurring during summer just before molt completion, although the timing of hypophagia and hyperphagia gradually shifted several months earlier from age 6 to 9 in the female with the longest record (Rosen et al. 2021). Resting metabolic rates of these seals markedly increased in association with the period of visible molt, which lasted 28 days on average (standard deviation = 6 days) (Thometz et al. 2021). While the progression and duration of the annual molt was similar for all three ringed seals, the onset of molt occurred earlier in the ringed seal housed in California than in the two ringed seals housed in Alaska (Thometz et al. 2021). Thometz et al. (2023) reported that resting metabolic rates measured in both air and water for one of these ringed seals and three captive spotted seals were elevated during molt, but were similar between media regardless of molt status. Further, the difference in resting metabolic rates between the molting and non-molting periods was greater for in-air measurements than for in-water measurements. The findings of their study suggest that molting ringed seals maintain sufficient control of peripheral circulation to limit heat loss in water; thus, they likely spend more time hauled out during the molting period to increase skin temperatures and peripheral blood flow to support tissue regeneration rather than to reduce heat loss, with elevated metabolism mainly reflecting the energetic cost of tissue regeneration.

Using photogrammetry and visual observations, McHuron et al. (2020) documented a clear seasonal pattern of whisker loss for an adult female ringed seal which coincided with the annual molt. The seal's regrowth of whiskers following loss was rapid, with whiskers reaching their asymptotic length within a few months.

Okhotsk Ringed Seal

Ringed seals are aquatic-mating pinnipeds that display relatively large vocal repertoires (Rogers 2003). At least eight types of underwater calls have been identified in ringed seals, but the functions of the call types are unknown because it is difficult to observe behaviors associated with vocalizations in wild seals (Mizuguchi et al. 2015). Underwater vocalizations and associated behaviors of three captive Okhotsk ringed seals at Otaru Aquarium in Hokkaido, Japan, were examined to look at seasonality, sexual differences, and behavioral contexts (Mizuguchi et al. 2015). Six types of calls were recorded, and three categories of social behaviors (male courtship, aggression, submission) associated with the calls were observed. Five of the six call types recorded in this study had been recorded previously in wild seals, but one call type (long snort) had not been described before this study. This call was only heard from the adult male during courtship behavior towards the adult female, during the breeding season. The new call type and the relationships between call types and behaviors identified in this study will improve the ability to use passive acoustic recording of wild ringed seals in the Sea of Okhotsk to assess both distribution and behavior (Mizuguchi et al. 2015).

The 2010 Status Review noted that ringed seals have been observed to haul out on various shores in the Sea of Okhotsk during summer and autumn since at least 1987 (Lagarev 1988) and 1999 (at Piltun Bay, Sakhalin Island; Trukhin et al. 2000). Since the listing, Trukhin and Permyakov (2021) provided details about ringed seals' use of the shores at the mouth of Piltun Bay, Sakhalin Island, where up to 801 individuals have been counted during the ice-free period from June through October. The seasonal maximum number of ringed seals occurred from the last 10 days of August to the first 10 days of October, for all the years studied. Lebedev et al. (2021) documented a new, smaller haul-out site at Nabil Bay on Sakhalin Island, where up to 50 ringed seals have been observed since 2014. They also cited references from the first half of the 20th century documenting rare ringed seal haul-out sites in the Shelikhov Gulf and the Shantar Archipelago.

Ringed seals as well as bearded and spotted seals exploit abundant aggregations of fishes and other prey at the mouth of Piltun Bay, Sakhalin Island (Trukhin and Permyakov 2021). The arrival of large numbers of ringed seals in the nearshore waters in June coincided with spawning migrations of small to medium-sized fish, including Pacific herring (*Clupea pallasii*), pond smelt (*Hypomesus olidus*), big-scaled redfin (*Tribolodon hakonensis*), capelin, three-spined stickleback (*Gasterosteus aculeatus*), and other marine fishes. Many of the aquatic invertebrates and fish species that are common in diets of ringed seals in the Sea of Okhotsk are also abundant in Piltun Bay (Fedoseev 1965; Trukhin and Permyakov 2021).

Baltic Ringed Seal

Oksanen et al. (2015b) investigated the foraging habitats of 26 ringed seals in the northern Baltic Sea using satellite telemetry tags during August to May, 2011–2014. Tracked seals ranged over large areas of the Bothnian Sea and Bothnian Bay: mean maximum distance from capture sites was 392 ± 195 km and mean home range size was 8,030 ± 4,796 km^2. Most of the seals (n =

17) were long-range foragers that used several spatially remote foraging areas. Two of these seals moved randomly and foraging areas could not be identified for them. The other seals (n = 9) were local foragers having only one foraging area or a shorter mean distance between several areas. Two clusters of foraging "hot spots" were identified: one in northern Bothnian Bay and the other in the Quark (northern Bothnian Sea). Foraging areas of all seals were generally in shallow waters (13 ± 49 m deep), close to the mainland (10 ± 14 km away), and partially overlapped with marine protected areas and coastal fisheries.

Based on otolith counts from 327 digestive tracts collected during 1968–1971 and 2008–2009, Scharff-Olsen et al. (2019) reported that fish prey in the Baltic ringed seal's diet consisted primarily of three-spine stickleback (*Gasterosteus aculeatus*; 74%) and Atlantic herring (*Clupea harengus*; 14%). Sixteen other fish species occurred in low numbers (< 3%). Atlantic herring were the second most common fish in the Baltic Sea (after sprat; *Sprattus sprattus*) based on commercial catch data, and the most common fish prey of grey seals (*Halichoerus grypus*) in the Baltic Sea.

Ladoga Ringed Seal

Loseva et al. (2022) observed a female ringed seal nursing and rearing its pup on the rocky shoreline of northern Lake Ladoga for 34–37 days during March–April 2020 when less than 1% of the lake was covered in ice. This was the first recorded case of nursing on shore in the lake. The authors suggested that this rare behavior was possible due to the pup's traits such as its high level of vigilance, early ability to swim, and brown-colored lanugo which camouflaged the pup well on the granite substrate, all of which helped protect the pup against predators.

2.3.3. Abundance and population trends

Arctic Ringed Seal

As was the case at the time of listing, the world-wide population size of Arctic ringed seals is not accurately known (Boveng 2016b). A recent review of Arctic marine mammal status cited various regional estimates that compose a large portion of the subspecies' range, totaling about 2.9 million individuals (Laidre et al. 2015). NMFS and partners from the Russian Federation conducted comprehensive surveys for ringed seals in the Bering Sea in 2012 and 2013 (Chernook et al. 2018; Boveng et al. In prep), and the Chukchi Sea in 2016 (Chernook et al. 2019; Boveng et al. In prep.). A survey of the Beaufort Sea in 2021 by NMFS (analysis pending) will provide the results needed to determine a complete estimate for ringed seal abundance in the seas surrounding Alaska. The total estimate of ringed seals in those regions of the Pacific Arctic is anticipated to substantially exceed one million individuals.

In western Hudson Bay, densities of ringed seals recorded during aerial surveys in 1995–2013 were highly variable from year to year (Young et al. 2015). There were no significant trends in density with respect to year, survey date, proportion of open water, or other environmental variables. Densities appeared to follow an approximately decadal cycle, with the exception of 2013 when ringed seal densities were unusually low; the authors speculated that this could reflect a decline in abundance or interannual variation in peak haul-out timing, as this would affect what fraction of the population is available for detection (Young et al. 2015). As was the case at the time of listing, there is no reliable basis for judging trends in abundance for any substantial portion of the Arctic ringed seal's range (Boveng 2016b).

Okhotsk Ringed Seal

The most recent population estimate for Okhotsk ringed seals is about 120,000 animals. This estimate was obtained from an aerial survey of the Sea of Okhotsk in 2013, which used thermal scanners and digital photography to count seals (Chernook et al. 2014; Boveng 2016a). This recent population estimate is much lower than the estimate published in the 2010 Status Review (676,000 animals), which was estimated using data from ten aerial surveys conducted during 1968–1990 (Fedoseev 2000; Kelly et al. 2010). Both estimates are highly uncertain, making the current population trend in the Sea of Okhotsk unknown (Boveng 2016a), but these estimates indicate the possibility of a large decrease in numbers over the past 20 years. However, a recent study that examined seasonal use of ringed seals at a large haul-out site on Sakhalin Island found that the total number of ringed seals at that haulout did not change significantly from 1999 to 2014–2017 (Trukhin and Blokhin 2003; Trukhin and Permyakov 2021).

Catch per unit effort (CPUE) can be used as an index of population abundance and trends when certain assumptions are met. Trukhanova et al. (2017) analyzed information from previously unpublished Russian sealing log books to review and describe the state-regulated harvest of ice-associated seals in the Sea of Okhotsk in the 1970s–1990s. The trends in annual mean CPUE (number of seals caught by one boat in one day) and total take numbers recorded in the sealing log books were non-linear for ringed seals, starting with high CPUE and total take in 1972–1974 (total take of 18,020–24,372 seals per year), then a sharp decline in 1975–1977 (total take of 1,440-5,000 seals per year), and then a gradual increase to a plateau in daily catches (total take of ~15,000 seals per year) during the rest of the study period. This complex pattern was likely due to changes in, and problems with harvest management, rather than population dynamics, so the CPUE data do not provide reliable new information about the Okhotsk ringed seal population trend in the 1970s–1990s. The harvest data from the log books corresponded well with seal distributions obtained from more recent aerial surveys in the Sea of Okhotsk (Trukhanova et al. 2017).

Baltic Ringed Seal

The Baltic Marine Environment Protection Commission—also known as the Helsinki Commission (HELCOM)—is an intergovernmental organization of the Baltic Sea region that was established to protect the marine environment, preserve biological diversity, and promote the sustainable use of marine resources. HELCOM (2023a) evaluates Baltic ringed seals in two separate management units: 1) Bothnian Bay, and 2) the southern management unit, which consists of subpopulations in the Archipelago Sea, Gulf of Finland, and western Estonia/Gulf of Riga (Figure 1). The Bothnian Bay population is surveyed annually using aerial strip-transect methods. In 2012, the estimated number of seals hauled out on ice was 6,092 animals and the annual growth rate (i.e., percent increase in population size) during 2003–2012 was 6.8% per year (Figure 2). A Bayesian analysis for 2003–2012 showed 80% support for an annual growth rate ≥ 5.0%. Since 2012, survey estimates have been anomalously high with extreme interannual variation, likely due to earlier ice breakup and lower ice coverage that have resulted in ringed seals hauling out in large groups and a larger portion of the total population being observed. Survey results from 2015—a year with very limited ice cover and early ice breakup—revealed that the population size probably exceeded 20,000 seals. Trend analyses for the period after 2012 show increases that are not biologically possible so no trend is available for this period:

> Even if trend calculation for recent years is not possible, no improvement of the population growth rate is expected given deteriorating breeding conditions and increased hunting pressure. There have, however, been no indication[s] of a major decrease in the population. (HELCOM 2023a)

In the southern management unit, new survey methods have been under development due to a lack of ice in most years (Halkka et al. 2017; HELCOM 2023a). The western Estonia/Gulf of Riga population has been surveyed five times in recent years (2016, 2018–2021) with results indicating a stable count of about 1,000 seals hauled out on land during the molt, and an estimated population of about 1,500 seals. Ice-free survey methods are still under development in the Archipelago Sea. Based on sporadic surveys over ice and incomplete counts during ice-free winters, the total population size is estimated to be about 200 seals with no indication of an increasing trend. In the Gulf of Finland, traditional aerial surveys were conducted in three recent years with sufficient ice conditions (2017, 2018, and 2021). The results varied around 100 ringed seals with no indication of a trend (HELCOM 2023a).

Figure 1. Approximate ringed seal breeding areas (dark blue) and abundance (white numbers) in the Baltic Sea (from Halkka et al. 2017, Map 1).

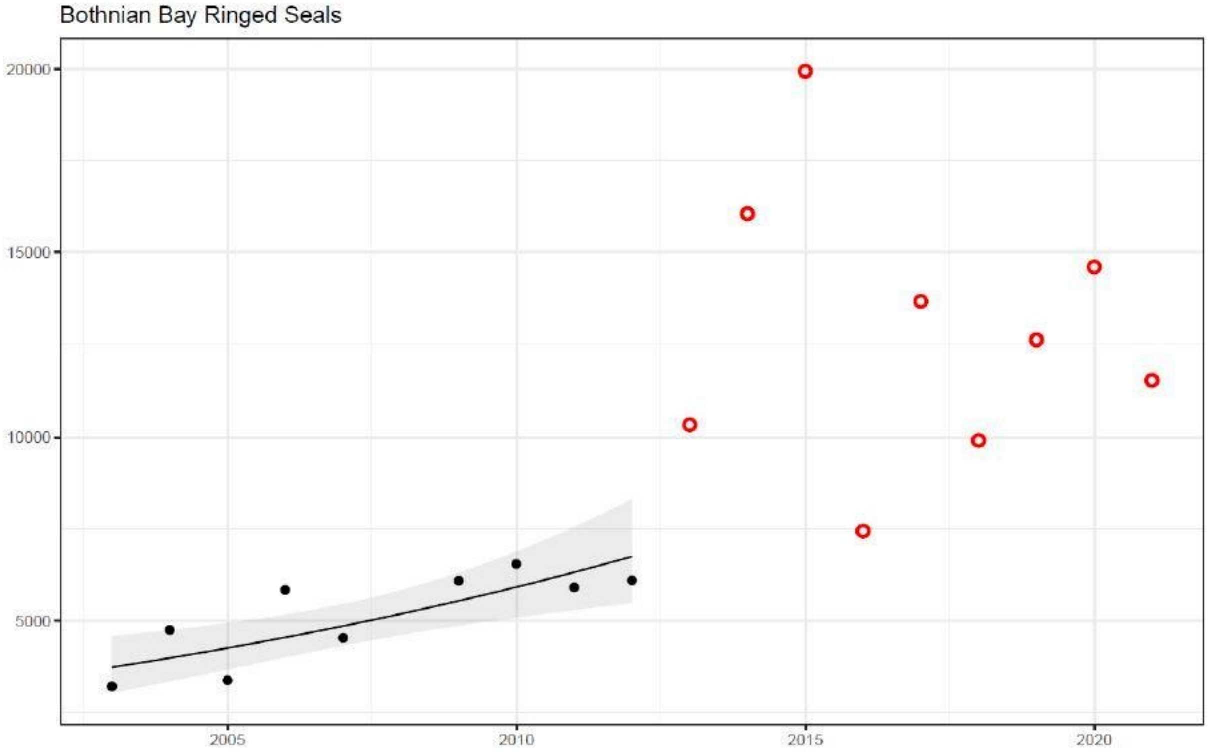

Figure 2. Estimated number of ringed seals hauled out on ice in Bothnian Bay during molt, 2003–2021. The annual growth rate during 2003–2012 was 6.8%. The modeled count index (black line) with 95% confidence interval (gray area) are shown. After 2012 (red circles), the data are not comparable as a different fraction of the seal population was hauling out, making them statistical outliers (from HELCOM 2023a, Figure 3).

HELCOM (2023a) assesses the status of seals in the Baltic Sea by comparing population data against threshold values that have a long-term objective of allowing the populations to recover towards carrying capacity. The threshold value for abundance is ≥ 10,000 seals and the threshold value for annual population growth rate is ≥ 7%. The Bothnian Bay management unit exceeds the abundance threshold but is considered below the growth rate threshold based on available data. The southern management unit is reported as “alarmingly” below the thresholds for both abundance and growth rate. Confidence in these “indicator” evaluations is considered to be high for the southern management unit and low for the Bothnian Bay management unit (HELCOM 2023a).

Sundqvist et al. (2012) analyzed the effect of decreasing ice cover on the population dynamics of Baltic ringed seals using Baltic Sea ice projections for 2010–2100, a ringed seal demographic model, and a simplistic relationship between ice area and pup survival. For future environmental conditions, they obtained January air temperature projections from a Baltic Sea regional model climate model using the IPCC's Special Report on Emissions Scenarios (SRES) scenario A1B, which assumes CO_2 emissions will continue to increase until 2050 and decline thereafter (Nakicenovic and Swart 2000). There was a linear relationship between mean January air temperatures and the amount of suitable breeding ice available in early February during 1969–2010, so Sundqvist et al. (2012) applied this relationship to the air temperatures from the climate model to predict ice availability in February 2010–2100. Pup survival was assumed to decline linearly when the amount of suitable ice was insufficient for the number of breeding females. Their model results projected that the Bothnian Bay subpopulation would increase to a maximum of 33,800 seals by 2065 and then decrease to 22,550 seals by 2100. The Gulf of Finland subpopulation showed continuous positive growth with numbers projected to reach 8,100 seals by 2100. The Gulf of Riga subpopulation was predicted to reach a maximum of 2,820 seals by 2019 and then decline to only 75 seals by 2100. The total Baltic Sea population was projected to peak at 38,740 seals in 2068 and then decline to 30,730 seals by 2100.

By comparison, Sundqvist et al. (2012) found that if ice area was not limiting and the growth rate remained 4.6% per year (i.e., the growth rate found in Bothnian Bay during 1988–2011), the Baltic Sea population would only take 60 years to reach its early 20th century size of 190,000 seals (Harding and Härkönen 1999). Thus, Sundqvist et al. (2012) concluded that the predicted reduction in Baltic Sea ice during the 21st century will hamper or reduce growth rates of all ringed seal subpopulations, limiting their ability to recover from previous steep declines, especially in the Gulf of Riga which could become seriously threatened. The Sundqvist et al. (2012) model only considered the effects of declining February ice area on the ringed seal population, and did not consider other human-caused (e.g., shipping) or climate-related effects such as declining snow depth and earlier breakup timing that could contribute to pup mortality. For example, ringed seals in the Gulfs of Finland and Riga have been forced to give birth to their pups on land in years with particularly early ice breakup, and this may affect survival (Halkka et al. 2017). If these factors had been included in the Sundqvist et al. (2012) model, it is possible that more severe population declines would have been predicted for all three ringed seal subpopulations in the Baltic Sea.

This new information does not indicate a substantial change in the Baltic ringed seal's status since the 2010 Status Review. At that time, the Bothnian Bay subpopulation was relatively large and appeared to be increasing while the southern subpopulations were small and either stable or trending downward, and that appears to remain the case now based on the available data.

Ladoga Ringed Seal

The most recent lake-wide aerial survey of the Ladoga seal population—conducted in April 2012 using strip-transect methods—estimated 5,068 (95% CI: 4,026-7,086) seals basking on the ice, which was thought to be biased low (BFN 2013; Trukhanova et al. 2013). The total number of seals in the lake (i.e., including those in the water during surveys, thus not available to be counted, or on ice during the surveys but not detected by observers) was roughly estimated to be 6,000-9,000 seals (BFN 2013). This indicated an annual growth rate of 7.5% when compared with previous surveys (conducted in 2001) that estimated 2,000 (± 70) basking seals and a total population of 3,000-5,000 seals (Agafonova et al. 2007). BFN (2013) considered this somewhat unrealistic, especially considering the high annual bycatch rate, and suggested that the previous survey results may have been underestimated to some extent. Even so, the authors concluded that the population exceeded 5,000 seals and may be recovering from steep declines due to uncontrolled harvest in the past (BFN 2013).

Although the larger population estimate obtained in the most recent survey of Ladoga ringed seals is encouraging, the inability to confidently reconcile the recent estimate with purported trends in the late 20th century (BFN 2013) suggests that the new information should not alter the judgment expressed by the Biological Review Team (BRT) in the 2010 Status Review that risks associated with abundance in Ladoga ringed seals are moderate at present but high in the foreseeable future.

2.3.4. Demographic features or trends (e.g., age structure, sex ratio, family size, birth rate, age at mortality, mortality rate, etc.)

Arctic Ringed Seal

Since the 2010 Status Review, two studies have synthesized information across multiple seal species to produce estimates of vital rates, including for ringed seals. As part of a hierarchical analysis of 11 phocid species, Trukhanova et al. (2018) generated curves of age-specific ringed seal survival rates. Their findings suggested that, compared to the other species in the study, ringed seals have higher survival rates and less pronounced senescence (i.e., increases in mortality in older individuals). Conn and Trukhanova (2022) expanded on this study to generate Leslie population matrices and stable stage proportions for ringed seals and other ice-associated seal species in the Bering, Chukchi, and Beaufort seas. The stable stage distribution for ringed seals was estimated to consist of 18% pups, 38% juveniles, and 44% adults (sum of males and females in Figure 4 of Conn and Trukhanova 2023). However, the authors noted that there may be spatial heterogeneity in stage structure for ringed seals if different age classes have different habitat preferences (e.g., Crawford et al. 2012).

Relationships between snow depth and ringed seal vital rates—The 2010 Status Review included studies prior to the listing that found associations between regional snow depth and ringed seal survival, reproduction, or indices of condition (Kelly et al. 2010). Hammill and Smith (1991) found that a decrease from 23 cm to 10 cm in average snow depth in Barrow Strait, Canada, in the mid-1980s coincided with an increase in the predation rate by polar bears from 0.1 to 0.4 seals/km^2. Ferguson et al. (2005), based on data from seals harvested in western

Hudson Bay during 1991–2001, found that an index of recruitment was sharply lower for cohorts born in years of spring average snow depths less than about 32 cm.

Since the listing, several more studies have found relationships between snow cover on sea ice and ringed seal vital rates. Chambellant et al. (2012) found that their index of pup survival was optimized between about 25 and 52 cm of snow depth (peak at 38 cm) measured on the ground near their study area in western Hudson Bay during 1991–2006. Iacozza and Ferguson (2014) found that spatial variability in remotely-sensed spring snow depth in western Hudson Bay from 2003–2010 was negatively related to the proportion of young-of-the-year in the autumn harvest at Arviat. The number of 'dry snow cover days', which is an index of the duration of winter snow cover, was positively related to pup survival, and together, the two indexes accounted for 82% of the variation in the young-of-the-year harvest numbers. Hamilton et al. (2018) found that ringed seals hauled out less frequently and—during winter—in shorter bouts and for less time overall, after the cessation of annual formation of landfast ice that occurred in 2006 around Svalbard. Although the changes were not directly linked to vital rates, the implication was that without landfast ice and its associated snow cover, ringed seals were hauling out less in lairs, with likely impacts on their energy budgets and predation risk. But also in Svalbard, where large areas have not had regular seasonal sea ice since 2006, an interdecadal synthesis of several vital rates indices found no clear pattern consistent with climate-related hypotheses (Andersen et al. 2021); the study acknowledged that small-scale variations in breeding habitat could allow suitable habitat to remain in the particular area where the hunted samples were collected. Life history plasticity—in other words, shifts in the ringed seals' behavior around crucial life history events such as whelping and pup rearing—could not be ruled out but no evidence has been presented to document that such a shift has occurred.

Around Alaska and the western Canadian Arctic, ringed seal vital rates or condition have not been directly compared to snow depth on sea ice, though some studies have made comparisons to ice concentration or area, the length of the ice-covered period, or other statistics that may be related to spring snow depth and other climatic factors in ringed seal demography. Crawford et al. (2015) concluded that young ringed seals in the Chukchi and northern Bering seas grew faster during 2003–2012, which the authors characterized as a period of reduced sea ice, compared to an earlier period, 1974–1984. Ringed seals harvested at four northern Bering Sea villages included higher proportions of pups during the recent period, as well. A continuation of the study, comparing the period 2000–2015 with 2016–2020 (Quakenbush et al. 2020a), found that growth of ringed seals born in the most recent period was good except for 2017, and that blubber thickness (i.e., body condition) was below average in 2017–2018. Those years were extremely warm and low in sea ice, with impacts documented throughout the Pacific Arctic ecosystem (Huntington et al. 2020; Boveng et al. 2020).

Also in the Bering and Chukchi seas, as part of a study on polar bear body condition and recruitment, Rode et al. (2021) assessed patterns in a subset of the ringed seal harvest data or the years of 2007–2010, 2012, and 2014–2016 from 11 coastal villages in northwestern Alaska. They found that body condition of non-pup ringed seals in the fall was negatively correlated with June-November sea ice cover over the Chukchi and Bering seas continental shelf, suggesting that to some extent, reductions in sea ice cover may benefit ringed seal body condition. Together with the poor ringed seal body condition observed in 2017–2018 (Quakenbush et al. 2020a) during anomalously low sea ice conditions, it remains unclear what amount of sea ice coverage is optimal for ringed seals.

In the western Canadian Arctic, ringed seals were monitored in the eastern Amundsen Gulf and western Prince Albert Sound during 36 years between 1971 and 2019 (Harwood et al. 2012b, 2020). These areas were characterized as prime habitat, with sea ice that typically persists well beyond the ringed seal pup rearing period. The poorest body condition and lowest indices of reproduction occurred in the years with the latest ice break-up. In an overlapping region ranging from Amundsen Gulf to Mackenzie Bay, Nguyen et al. (2017) proposed that a ringed seal tooth measurement could be used as an index of reproductive capacity. Tooth measurements were smaller during years with late sea-ice breakup and colder climate indices, similar to the findings of Harwood et al. (2012; 2020) that late ice breakup may be detrimental to ringed seal reproduction. However, long-term trends toward later autumn freeze-up and earlier spring sea ice clearance in the western Canadian Arctic have coincided with a declining trend in seal body condition (Harwood et al. 2012b, 2020), suggesting more complex processes than a simple directional influence of Arctic warming on the seals' vital rates. A declining trend in ringed seal body condition and other vital rate indices has also been documented farther south in Hudson Bay. Over the period of 2003–2013, ringed seals harvested by Inuit hunters in Hudson Bay showed decreases in blubber mass and increases in cortisol, a hormone associated with stress (Ferguson et al. 2017). Body condition was negatively correlated with the length of the open-water period. Pup survival, as estimated from the percentage of pups in the harvest, exhibited a "marginal" decline. Ovulation rate was highly variable without an apparent trend with respect to year or environmental variables. However, ovulation rates were low in 2011 following a year of high cortisol levels in 2010, suggesting that stress can negatively affect ringed seal reproduction.

Reimer et al. (2019b) produced the first demographic projection model for Arctic ringed seals, formalizing hypotheses about the relationship between environmental conditions and ringed seal vital rates in Amundsen Gulf and Prince Albert Sound in the Canadian Arctic. They first developed a matrix-based population model for a historical period (1971–2011), with the assumption that ringed seal fertility was negatively affected by years with late sea-ice breakup. Baseline ringed seal vital rates were obtained from previous studies (Smith 1987; Kelly 1988; Kelly et al. 2010); however, they found that the parameter for annual adult survival needed to be increased above what was reported in the literature (from 0.86 to 0.92) in order to avoid unrealistic population declines during the historical period.

Using these adjusted vital rates, Reimer et al. (2019b) then developed a forward demographic projection model for 2017–2100. Unlike their historical model, the future model did not include any effects of late sea-ice breakup on fertility. Instead, they assumed that the primary environmental impacts on the population would be reductions in pup survival associated with declining snow depth and early sea-ice breakup. Under their "medium sensitivity" scenario, pup survival was assumed to be unaffected by snow depth when snow depths were ≥ 30 cm, and then decreased linearly to complete pup mortality at less than 20 cm. Similarly, pup survival was assumed to be unaffected by sea-ice breakup date when breakup occurred after 24 May (pup weaning date), and then decreased linearly to complete pup mortality when breakup occurred before 15 April (pupping date). They also considered scenarios where pup survival was more or less sensitive to environmental conditions. Projections of April snow depth and sea-ice breakup dates for the Amundsen Gulf region were obtained from a suite of climate models used in the Intergovernmental Panel on Climate Change's (IPCC's) fifth assessment report produced by Working Group 1 (referred to in this review as 'AR5 WG1'). For each climate model, Reimer et al. (2019b) used projections from RCP8.5 (Representative Concentration Pathway 8.5), the high greenhouse gas (GHG) emissions scenario in AR5 WG1. Population simulations were then performed for combinations of snow and sea ice model sets from the climate models and combinations of low-high pup sensitivity. Under the "medium sensitivity" scenario, ringed seals were predicted to decline to less than 10% of their original population size by 2100. For the "high sensitivity" scenarios, declines were more severe. For the most optimistic "low sensitivity" scenario where pup survival was more robust despite changes in snow depth and sea-ice breakup, the population tended to increase until mid-century and then exhibit mild to moderate declines thereafter. Forecasted reductions in snow depth in the climate models had a greater effect on pup survival than earlier breakup dates.

The Reimer et al. (2019b) population projections also indicated that a declining ringed seal population would show a shift in stage structure, with an increasing proportion of pups and a decreasing proportion of juveniles. They estimated that the power to detect this shift in stage structure, using harvest-based monitoring of 100 harvest ringed seals per year, would reach 0.8 by mid-century. A larger harvest sample would enable changes in stage structure to be detected earlier.

As acknowledged by Reimer et al. (2019b), their forecasting model should be updated when improved information on the relationship between pup survival and environmental conditions becomes available. The authors also did not test how their assumptions of the relationship between pup survival and environmental conditions would have affected population size in the historical period. Less severe emissions scenarios, density dependence, and other factors such as changes in harvest or predation pressure were not considered and could result in different population trends than estimated in Reimer et al. (2019b).

In general, the studies summarized above have examined suites of indices for vital rates but have not had the means to directly measure those rates or to detect overall demographic impacts such as changes in abundance or loss of significant portions of breeding range. Changes in the stage structure of harvested seals may signal population declines (Reimer et al. 2019b), but this approach is sensitive to any trend in age-selectivity of the harvest. While monitoring indices of vital rates or other demographic parameters provides insight about mechanisms of response to environmental variability and climatic trends, sampling considerations are often complex, as are interpretations of the results. The need remains for complementary, direct means of monitoring abundance and distribution of breeding populations, such as count-based surveys.

Okhotsk Ringed Seal

Our review did not identify any new information on demographic features or trends in the Okhotsk seal population. Depleted sea ice will likely impact pup survival similar to that of the Arctic ringed seal.

Baltic Ringed Seal

Kauhala et al. (2019) investigated the reproductive rate and nutritional status of ringed seals in Bothnian Bay from samples collected during 1981–2017. The birth rate (i.e., proportion of females with *corpus albicans* in their ovaries) was 10% at age-3, 17% at age-4, about 65% at ages 5–12, 50% at ages 13–20, and 21% at ages 20+. For females age 5+, the birth rate increased from 29% prior to 1997, to 60% in 1997–2006, to 72% in 2007–2016. The presence of uterine occlusions, which resulted from environmental contaminants and caused sterility to females in the past, declined from 48% prior to 1997, to 23% in 1997–2006, to 6% in 2007–2017. Average blubber thickness declined in subadults (during 1991 to 2007) and adults (during 1986 to 2001), but tended to increase in both age classes thereafter, except in adult females which declined throughout the study period. Blubber thickness correlated positively with average weight and total catch of herring (*Clupea harengus*) and vendace (*Coregonus albula*) suggesting that quality or quantity of important prey species has an effect on the nutritional status of ringed seals. The authors suggested that the continued decline in adult female blubber thickness in spring while herring quality increased may be partly due to stress caused by recent poor ice conditions during the nursing period, and this in turn, may be at least partly responsible for the relatively low birth rate and population growth rate of ringed seals in Bothnian Bay (Kauhala et al. 2019).

This new information indicates that Baltic ringed seals' birth rates in Bothnian Bay have increased by about 12% since the time of the 2010 Status Review. However, population growth rates do not appear to be increasing at the same rate and may be hampered by poor ice conditions during the nursing period. This suggests that the demographic risks associated with productivity, which were previously judged to be low at present but high in the foreseeable future, have not changed substantially since the 2010 Status Review.

Ladoga Ringed Sea

Our review did not identify any new information on demographic features or trends in the Ladoga seal population.

2.3.5. Genetics, genetic variation, or trends in genetic variation (e.g., loss of genetic variation, genetic drift, inbreeding, etc.):

Arctic Ringed Seal

At the time of the listing for Arctic ringed seals, several studies had found no genetic population structure that would indicate discreteness of subgroups within the subspecies *P. h. hispida*. However, detecting demographically important levels of exchange can be difficult in taxa with such high abundance. Because recent developments in genetic technology have enabled sequencing of much larger numbers of genetic markers, Lang et al. (2021)

> used a next-generation sequencing approach (DArTseq) to genotype ~5700 single nucleotide polymorphisms in 79 seals from 4 Pacific Arctic regions. Comparison of the 2 most geographically separated strata (eastern Bering vs. northeastern Chukchi-Beaufort Seas) revealed a statistically significant level of genetic differentiation that, while small, was 1 to 2 orders of magnitude greater than expected based on divergence estimated for similarly sized populations connected by low (1% per year) dispersal. A relatively high proportion (72 to 88%) of individuals within these strata could be genetically assigned to their stratum of origin. These results indicate that demographically important structure may be present among Arctic ringed seals breeding in different areas, increasing the risk that declines in the number of seals breeding in areas most negatively affected by environmental warming could occur.

Although Lang et al. (2021) identified genetic population structure that may indicate the existence of sub-populations of the Arctic ringed seal in the Pacific region of the Arctic, there is currently insufficient information available to evaluate the boundaries and both the discreteness, and ecological significance criteria of the joint NMFS-U.S. Fish and Wildlife Service Policy Regarding the Recognition of Distinct Vertebrate Population Segments Under the Endangered Species Act (61 FR 4722; February 27, 1996). Also, due to the high genetic diversity and very large population size of Arctic ringed seals, these new findings on their own are not expected to alter the genetic diversity-associated demographic risk to Arctic ringed seals, which was judged by the BRT in the 2010 Status Review to be very low for the present and low in the foreseeable future.

A very recent paper scientifically describes a distinct ecotype of ringed seals that has long been known to local Inuit people of the Ilulissat Icefjord in West Greenland (Rosing-Asvid et al. 2023). The ‘Kangia’ ringed seal, as it is known locally, has a population of around 3,000 individuals. It is larger in body size than most other Arctic ringed seals (Kovacs et al. 2021), has unique pelage patterns and behaviors, and is genetically differentiated (Rosing-Asvid et al. 2023). Several candidate genes, possibly under strong selection, were identified that may be associated with these phenotypic differences. The ecotype is estimated to have diverged from other Arctic ringed seals around 240,000 years ago, with secondary contact around the last glacial maximum.

With the application of advanced genetic tools for understanding evolutionary histories and rates of dispersal among populations, new analyses of traditional biological data such as morphometrics, and greater recognition of IK to help guide investigations of diversity, it is possible that significant genetic and demographic structure will eventually be found within the enormous range of the Arctic ringed seal (Kovacs et al. 2021; Lang et al. 2021; Rosing-Asvid et al. 2023). The evidence is just beginning to emerge and is yet insufficient to prompt a formal review for the existence of DPSs within the Arctic ringed seal subspecies, but the topic should be among the high priorities for research in support of ringed seal management and conservation.

Okhotsk Ringed Seal

Our review did not identify any new information about the genetics of Okhotsk ringed seals that became available since the time of listing.

Baltic Ringed Seal

Baltic ringed seals are thought to have originated from the Arctic source population after the Scandinavian Ice Sheet retreated and the Baltic Basin filled with glacial melt water, sometime between 11,600 and 10,200 BP (calibrated years before “present”, which is taken to be 1950; Ukkonen et al. 2014). As noted in the 2010 Status Review, Palo et al. (2001) and (Palo 2003) found relatively little genetic differentiation between Baltic and Arctic ringed seals, possibly indicative of recurrent gene flow. Genetic diversity was lower, but still substantial in the Baltic subspecies, likely maintained by the gene flow and/or—until recently—a large population size (Nyman et al. 2014). A recent paper has complicated the origins and phylogenies of the Baltic, Saimaa, and Ladoga ringed seals; Heino et al. (2023) used mitochondrial control-region haplotypes to show that the clade of Saimaa ringed seals is not nested within the Baltic haplotypes from which they were thought to have originated. Rather, the Saimaa seals are nested more within the Arctic group, particularly those sampled in North America. While this is mostly relevant to the Saimaa ringed seal, which we do not review here, other features of the results suggest that more work is needed for a fully consistent understanding of the biodiversity within and among the closely-situated Baltic, Saimaa, and Ladoga subspecies. We consider it premature to judge whether these new findings alter the genetic diversity-associated demographic risk to Baltic ringed seals, which was judged by the BRT in the 2010 Status Review to be low for the present and moderate in the foreseeable future.

Ladoga Ringed Seal

Valtonen et al. (2012) and Nyman et al. (2014) confirmed that the genetic diversity of ringed seals in Lake Ladoga is nearly as high as that in the Baltic Sea. This adds confidence to, but does not significantly change the demographic risks associated with diversity, which were judged by the BRT in the 2010 Status Review to be moderate for the present and in the foreseeable future.

2.3.6. Spatial distribution, trends in spatial distribution (e.g., increasingly fragmented, increased numbers of corridors, etc.), or historic range (e.g. corrections to the historical range, change in distribution of the species' within its historic range, etc.)

Arctic Ringed Seal

Recently, Fisheries and Oceans Canada initiated a science program aimed to characterize the remote multiyear sea ice ecosystem in the northern Canadian Arctic Archipelago, where the Canadian government designated the Tuvaijuittuq Marine Protected Area in 2019 off the northwest coast of Ellesmere Island. An aerial survey conducted as part of this program around northern Ellesmere Island in Archer Fjord-Lady Franklin Bay, Nares Strait, and the Lincoln Sea in mid-August of 2019, documented some ringed seals outside of Archer Fjord, but there were relatively few ringed seals recorded for that large area as compared to the 30 ringed seals detected within the fjord (Carlyle et al. 2021). During an icebreaker expedition during August 2015 in the region of Petermann Fjord in northwest Greenland and adjacent Nares Strait, ringed seals were observed in areas with an average of about 40% ice coverage and most ringed seals were in water versus hauled out (Lomac-MacNair et al. 2018). Sightings per unit effort within the fjord increased in front of the Petermann Glacier ice-tongue margin and outlet glaciers, as well as along the prominent bathymetric sill at the entrance to the fjord, while in the Nares Strait, ringed seal sightings per unit effort were highest in Hall Basin and near the entrance to Bessel Fjord (Lomac-MacNair et al. 2018).

Ringed seal densities estimated from aerial surveys completed in this high Arctic region during early to mid-June (2018 and 2019) were approximately an order of magnitude lower than in the intermediate Arctic (Eclipse Sound on northern Baffin Island; surveys flown early to mid-

June, 2016 and 2017) and low Arctic (western Hudson Bay; surveys flown late May to early June, 2017), although the surveys in the high Arctic may have occurred before the peak haul-out period for ringed seals in this region (Carlyle 2022). This observed latitudinal decrease in ringed seal density from the low and intermediate Arctic to the high Arctic coincided with a decrease in first-year ice and an increase in multiyear ice from the low to high Arctic (Carlyle 2022).

Okhotsk Ringed Seal

Haul-out timing and behavior of Okhotsk ringed seals at Sakhalin Island in the Sea of Okhotsk was studied from 2014–2017, to examine seasonal and annual variations in ringed seal numbers at the haulout in the mouth of Piltun Bay (Trukhin and Permyakov 2021). This is the largest multispecies haul-out group of phocid seals at Sakhalin Island; ringed, spotted, and bearded seals all use this site, and as many as 2,500 seals could be there at one time. The site is used by ringed seals throughout the ice-free period from June through October. The arrival of large numbers of ringed seals in the nearshore waters in June coincided with spawning migrations of small to medium sized fish, including herring, pond smelt, big-scaled redfin, capelin, three-spined stickleback, and other marine fishes. Annually, the seasonal maximum number of ringed seals occurred from the last 10 days of August to the first 10 days of October, for all the years studied. The large number of phocids and the long occupancy during the year at this haul-out site indicate that environmental conditions in the mouth of Piltun Bay are favorable for phocid seals during their feeding season in the summer (Trukhin and Permyakov 2021).

Baltic Ringed Seal

HELCOM (2023b) evaluated the breeding distribution, molting distribution, and area of occupancy (i.e., areas used for foraging and transit) of ringed seals in the Baltic Sea during 2016–2021 based on comparisons to “pristine conditions” (e.g., distributions from 100 years ago) or, where appropriate, to a modern baseline where all currently available haul-out sites are occupied and no decrease in the area of occupation occurs. Although interannual variation remains high, there has been a significant reduction in sea ice extent and concentration in the Baltic Sea since the 1970s which has limited the breeding and molting distributions of ringed seals in all subpopulations. When the Bothnian Bay ice field broke up earlier in the molt season, ringed seals showed a new pattern of gathering in large groups along ice cracks or leads, and when ice was scarce (as has become more common in recent years), ringed seals hauled out on rocks to molt. In the southern subpopulations (Gulf of Finland and Gulf of Riga), ice is becoming rare during the molting period and land haulouts have become increasingly important. In recent years when ice has broken up particularly early, there have been reports of ringed seals giving birth and nursing their pups on land (Halkka et al. 2017). Compared to the early 1900s, ringed seal distribution is now “clearly more restricted and fragmented” and ringed seals cannot access the same breeding and molting areas they once did (HELCOM 2023b). Recent telemetry studies and limited visual observations suggest there is no evidence that ringed seal movement or foraging areas have been restricted in recent years. Based on these findings, HELCOM (2023b) assessed with moderate confidence that Baltic ringed seals do not meet the thresholds for achieving good status for their distribution indicator.

Ladoga Ringed Seal

Trukhanova et al. (2013) found that water depth, proximity to shore, ice type, and presence of fisheries were among the most important factors influencing ringed seal density and distribution in Lake Ladoga based on a covariate analysis of aerial survey data from April 2012. Ringed seal density was highest in areas that were relatively shallow (< 50 m). Density increased with distance from shore, especially in "ice-edge" zones where large areas of ridges and hummocks formed between the fast ice and drifting ice, but dropped off again towards the center of the lake where ice was beginning to break up. Average density was lower in fast ice than in drifting ice habitats. Within the fast-ice zone, the presence of fisheries had a highly negative effect on seal presence. The authors concluded that disturbance from human activities has become a major factor influencing seal distribution in Lake Ladoga and has likely shifted the core pupping area from the shorefast ice to the central part of the lake (Trukhanova et al. 2013).

It is unknown if this theorized shifting of the core pupping area from the presumably preferred shorefast ice to the presumably less optimal ice-edge zone or drifting ice continued to occur beyond 2012 on a regular or permanent basis. If so, it could plausibly increase the demographic risks associated with the population's spatial structure, which the BRT in the 2010 Status Review judged to be moderate at present and high in the foreseeable future. However, effects, if any, on the population's productivity remain unknown.

2.3.7. Habitat or ecosystem conditions (e.g., amount, distribution, and suitability of the habitat or ecosystem)

A species' habitat comprises both physical and biological components. The relevant scientific disciplines and literature associated with the physical components are often distinct from those pertaining to the biological components and ecosystem conditions. Therefore, we review the new information on physical habitat separately, acknowledging that the sections on ecosystem conditions naturally include physical features and their interactions with the species' biology.

2.3.7.1. Physical components of ringed seal habitat

The 2010 Status Review concluded that diminishing ice and snow cover are the greatest challenges to persistence of all of the ringed seal subspecies. Climate models in broad use at the time of listing projected overall diminishing ice and snow cover during the critical winter-spring period for ringed seal whelping and nursing, at least through the current century, with regional variation in the timing and severity of those losses. Increasing atmospheric concentrations of GHGs, including carbon dioxide (CO_2), were anticipated to drive climate warming and increase acidification of the ringed seal's ocean and lake habitats. Warming causes sea and lake ice to diminish in extent, thickness, and duration of cover, reducing the availability of snow-covered ice that ringed seals need for whelping and rearing pups. Acidification portends changes in prey communities on which ringed seals depend. This 5-year review must therefore address questions about whether the best available information about ringed seals' primary threats has changed or been updated in ways that would prompt NMFS to change the ESA status of any of the four listed subspecies being reviewed.

Since these four ringed seal subspecies were first listed in 2012, the United Nations' IPCC has produced its fifth and sixth comprehensive assessments of the physical science basis of climate change (IPCC 2013a, 2021, respectively). These reports comprise the consensus findings by the world's leading authorities on the earth's processes that influence the climate. In generating these reports, the IPCC considered the myriad empirical and modeling studies completed since the listings. Because the IPCC assessment process is cumulative, and aims to progressively refine the consensus view among the world's climate experts, we focused our review of ringed seal habitat primarily on the most recent assessment report (IPCC 2021) rather than the previous reports. This sixth assessment was authored by hundreds of scientists. They cited 13,500 references published by 39,000 authors prior to the report cycle cutoff date of 31 January 2021. Because new information continues to be produced rapidly we also considered related reports, and peer-reviewed studies published more recently that extend our understanding of ringed seal habitat and ecosystem changes. For brevity in citing material from the sixth assessment report on the physical science basis of climate change, produced by Working Group 1, we refer to it hereafter simply as 'AR6 WG1'. For convenience, we occasionally also provide pointers to specific parts of the 2,409-page report as, for example, 'SPM' (Summary for Policy Makers), 'TS' (Technical Summary), 'Figure TS.9' (Figure 9 in the Technical Summary), or '9.3' for a chapter and section number of the document. Similarly, we also make occasional reference to the fifth assessment report on the physical science basis (IPCC 2013a) as 'AR5 WG1', and the fourth assessment report (IPCC 2007) as 'AR4 WG1'.

In consideration of the new information that has become available since the listings, two overarching questions to be addressed by this review are: (1) Has the consensus among the world's climate scientists changed about the *observed* rates and magnitudes of warming and loss of sea ice and lake ice?; and (2) Has there been any change since the listings in how much reduction of ice on Arctic seas and lakes—and snow cover on that ice—can reasonably be *expected within the foreseeable future*?

Changes in the observed rates and magnitudes of climatic warming and loss of sea ice could arise from actual, recent changes in the processes of warming and sea ice loss, or from refinements in the methods for measuring and documenting those changes. Changes in the consensus about rates and magnitudes of expected future change could stem from new information about the underlying geochemical, geophysical, or ecological processes; advances in capabilities to model those processes; or information that changes the range or likelihood of plausible future scenarios. We considered new information about both the observed and the expected (i.e., projected) future changes in the main factors affecting ringed seal habitat and ecosystems as a key part of our basis for evaluating whether the listing statuses of ringed seals remain appropriate.

2.3.7.1.1. Observed changes in physical components of habitat and ecosystems

The AR6 WG1 cited improvements in observations and paleoclimate archives that provide a more comprehensive view of the earth's climate system, its variability and trends, and the human influence on climate extremes. A primary conclusion of the report was that, "It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred." (AR6 WG1 SPM A.1). The statement reflects an increase in confidence about the role of human activity, compared to the two previous assessments: The AR5 WG1 concluded, "It is *extremely likely*[4] more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together." And the AR4 WG1 conclusion was that, "Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations." This increase in confidence among the large body of climate experts that authored the IPCC reports—from at least 90% in AR4 WG1, to at least 95% in AR5 WG1, to 'unequivocal' in AR6 WG1—reflects a progression of advances in capabilities to observe and predict features of the climate and a growing body of support that stems from agreement between multiple independent lines of evidence (e.g., Sherwood et al. 2020).

The level of well-mixed greenhouse gases (WMGHGs) in the atmosphere increased strongly since the 19th century, such that the CO_2 concentration is the highest it has been in at least the past 2 million years; the effective radiative forcing—the power to heat the atmosphere—due to

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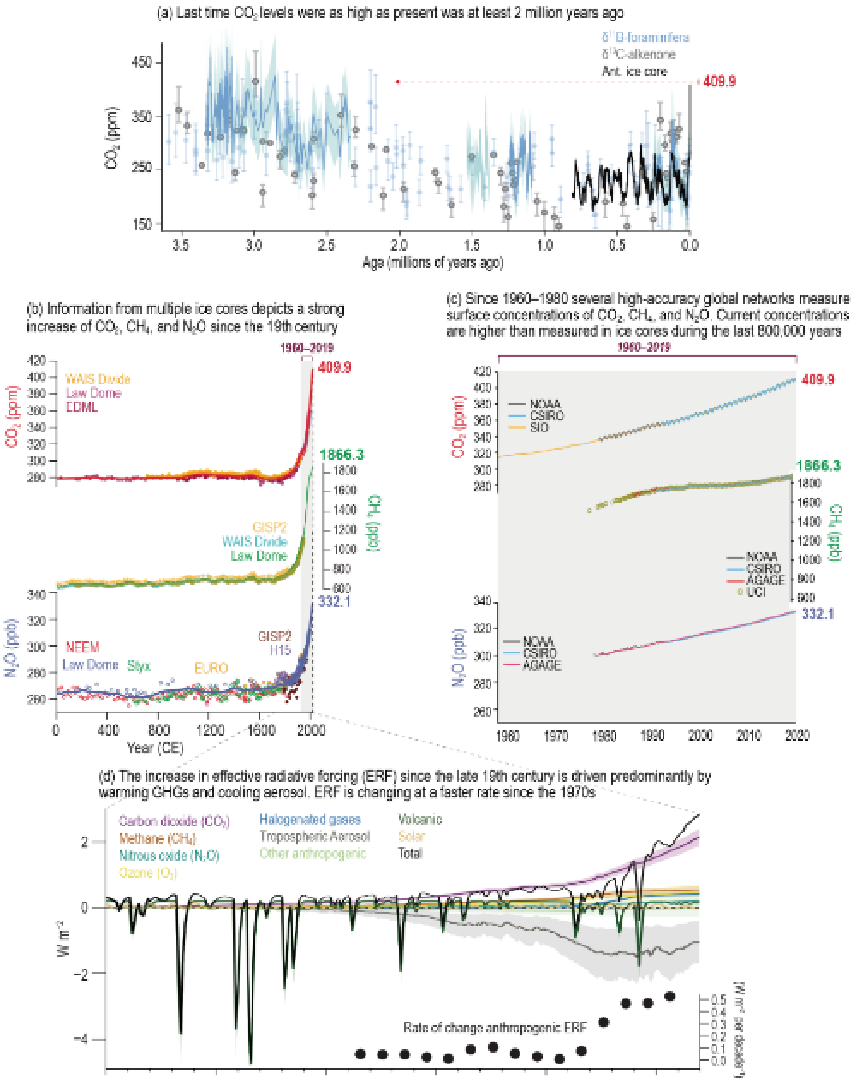
[4] In the IPCC reports, "Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, for example, *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or result: virtually certain 99–100% probability; very likely 90–100%; likely 66–100%; about as likely as not 33–66%; unlikely 0–33%; very unlikely 0–10%; and exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%; more likely than not >50–100%; and extremely unlikely 0–5%) are also used when appropriate. Assessed likelihood is typeset in italics, for example, *very likely*." (e.g., AR6 WG1 SPM Introduction)

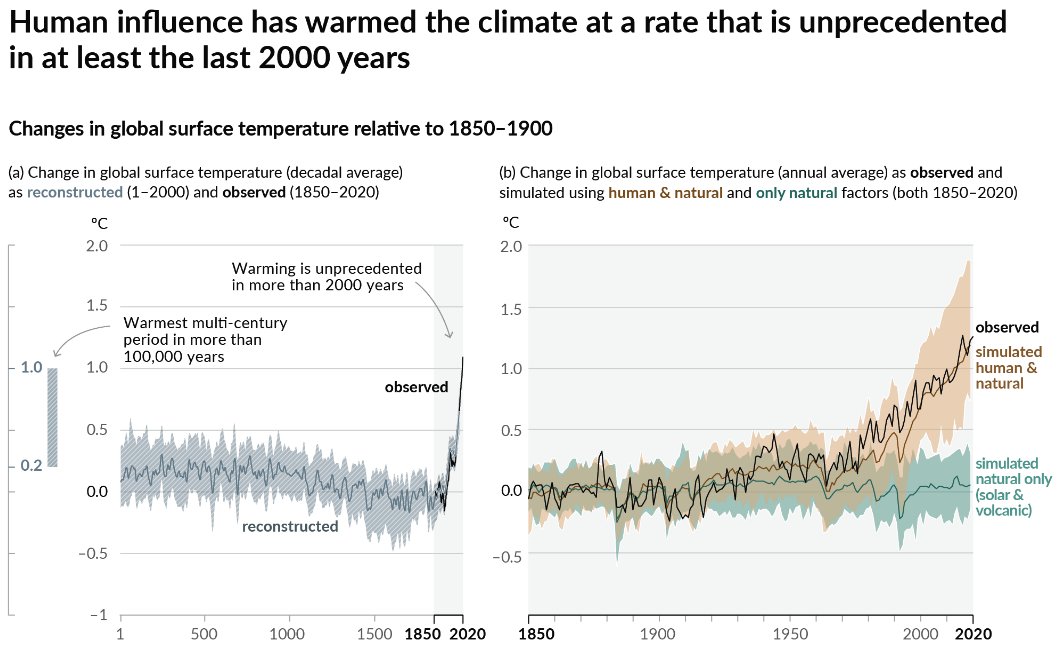
anthropogenic factors accelerated strongly in the 1970s (Figure 3). The increases in GHGs have produced a rate of global warming that is unprecedented in at least the last 2,000 years (Figure 4). Temperatures now exceed the range of any multi-century period in at least the past 6,500 years and there is no other candidate for a warmer multi-century period since the last interglacial period, around 125,000 years ago; both of those warm periods developed slowly (over thousands of years) due to orbital variations rather than natural earth systems-caused or human-caused changes (IPCC 2021). In contrast, the vast majority of warming from human-caused radiative forcing has taken place over a period of less than 200 years, accelerating markedly in the 1970s (Figure 4).

In 2012 when the four subspecies of ringed seals were listed, the global average surface temperature for the preceding decade of 2003–2012 was 0.78 °C above the pre-industrial baseline period of 1850–1900 (IPCC 2013b). For comparison, in 2013–2022 the average increase in surface temperature from the pre-industrial baseline period was 1.15 °C (Forster et al. 2023), including an increase of 0.06 °C within just 2 years from the value reported by the IPCC (2021) for 2011–2020.



Changes in well-mixed greenhouse gas (WMGHG) concentrations and effective radiative forcing (EFR). *The intent of this figure is to show that the changes of the main drivers of climate system over the industrial period are exceptional in a long-term context.* (a) Changes in carbon dioxide (CO2) from proxy records over the past 3.5 million years. (b) Changes in all three WMGHGs from ice core records over the Common Era. (c) Directly observed WMGHG changes since the mid-20th century. (d) Evolution of ERF and components since 1750. Further details on data sources and processing are available in the associated FAIR data table

Figure 3. (Reproduced with full caption from AR6 WG1 Figure TS.9) CO_2 in the atmosphere is higher than at any time in more than 2 million years. Concentrations of greenhouse gases have risen dramatically since the 19th century, with extremely rapid increases since 1970.



Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years

Changes in global surface temperature relative to 1850–1900

(a) Change in global surface temperature (decadal average) as reconstructed (1–2000) and observed (1850–2020)

(b) Change in global surface temperature (annual average) as observed and simulated using human & natural and only natural factors (both 1850–2020)

IPCC (2021) Figure SPM.1 | History of global temperature change and causes of recent warming

Panel (a) Changes in global surface temperature reconstructed from paleoclimate archives (solid grey line, years 1–2000) **and from direct observations**(solid black line, 1850–2020), both relative to 1850–1900 and decadally averaged. The vertical bar on the left shows the estimated temperature (*very likely* range) during the warmest multi-century period in at least the last 100,000 years, which occurred around 6500 years ago during the current interglacial period (Holocene). The Last Interglacial, around 125,000 years ago, is the next most recent candidate for a period of higher temperature. These past warm periods were caused by slow (multi-millennial) orbital variations. The grey shading with white diagonal lines shows the *very likely* ranges for the temperature reconstructions.
Panel (b) Changes in global surface temperature over the past 170 years (black line) relative to 1850–1900 and annually averaged, compared to Coupled Model Intercomparison Project Phase 6 (CMIP6) climate model simulations (see Box SPM.1) of the temperature response to both human and natural drivers (brown) and to only natural drivers (solar and volcanic activity, green). Solid coloured lines show the multi-model average, and coloured shades show the *very likely* range of simulations.

Figure 4. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2021) documented continued improvement in the understanding of recent climate warming in the contexts of past patterns and human influence.

Arctic Ringed Seal

Temperature—The conclusions cited above from the AR6 WG1 represent the prevailing view among the world's climate scientists about the recent and current changes in the *global* climate. Arctic ringed seals are denizens of *the Arctic*, a region where warming and its effects are amplified—relative to the global average—in paleoclimatic records, present-day observations, and climate model projections of the future (Previdi et al. 2021). Due to this amplification, the AR6 WG1 concluded that, "It is *virtually certain* that the Arctic will continue to warm more than global surface temperature, with high confidence above two times the rate of global warming." (IPCC 2021; SPM B.2.1). More recent studies suggest that amplification may be even stronger, with the Arctic having warmed four times as fast as the rest of the globe since 1979 (Rantanen et al. 2022), and more than four times as fast during the first decade of the 21st century (Chylek et al. 2022). Observed Arctic temperatures are already about 2 °C higher than the average for the period 1981–2010 (Figure 5). It remains unclear whether the unexpected stronger Arctic amplification was driven by external forcing (i.e., GHGs) or internal climate variability; the former would indicate that current climate models may underestimate the amplification, and the latter would mean that recent strengthened amplification is a random occurrence within the natural climate variability (Chylek et al. 2022; Rantanen et al. 2022).

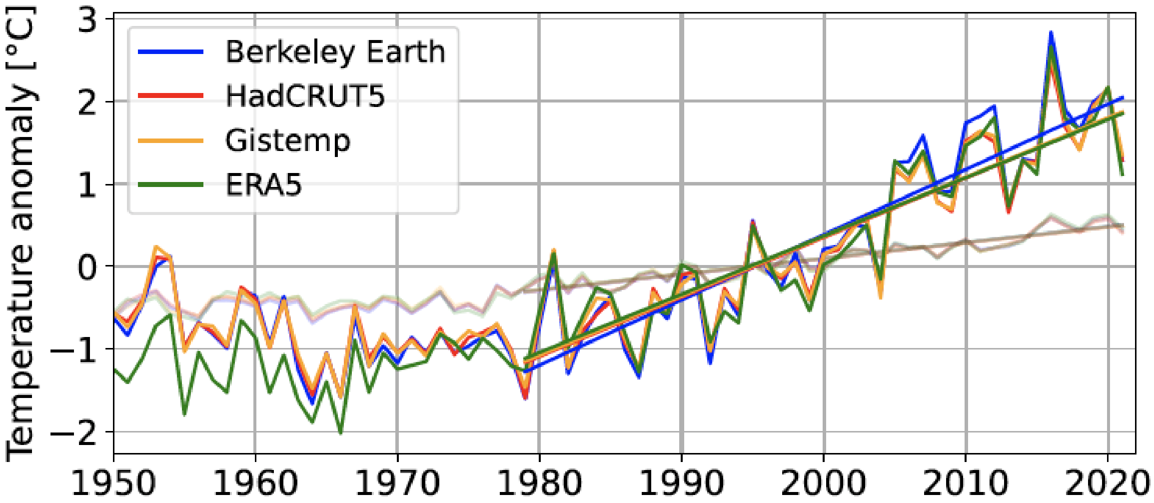


Figure 5. Arctic temperatures have risen 4X faster than the global average since 1979. Illustration from Rantanen et al. (2022): "Annual mean temperature anomalies in the Arctic (66.5°–90°N) (dark colours) and globally (light colours) during 1950–2021 derived from the various observational datasets. Temperature anomalies have been calculated relative to the standard 30-year period of 1981–2010. Shown are also the linear temperature trends for 1979–2021." Used under the Creative Commons Attribution 4.0 International License.

In addition to the observed increases in average temperatures globally and in the Arctic, marine heatwaves (MHWs) have become more frequent and stronger. "There is *high confidence* that MHWs have increased in frequency over the 20th century, with an approximate doubling from 1982 to 2016, and *medium confidence* that they have become more intense and longer since the 1980s." (AR6 WG1 Box 9.2). For each of the five years 2014–2018, Arctic annual surface air temperature exceeded that of any year since 1900. During the winters (January to March) of 2016 and 2018, surface temperatures in the central Arctic were 6 ºC above the 1981–2010 average (IPCC 2019).

Sea ice—Arctic ringed seals, as well as the other marine ringed seal subspecies (*P. h. ochotensis, and P. h. botnica*) are strongly associated with and dependent on sea ice during winter and spring for resting, whelping and nursing pups, and molting their coats annually.

Declines in the area[5], thickness, and volume of northern hemisphere sea ice (IPCC 2019) are some of the most prominent signs of the warming global climate. A decline in Arctic sea ice is one of the "impact-relevant" changes that has emerged from its range of natural variability as a result of human-driven climate change (AR6 WG1 TS.1.2.3). Coinciding with the accelerated warming due to Arctic amplification, "Decadal ice loss during winter months has accelerated from −2.4%/decade from 1979 to 1999 to −3.4%/decade from 2000 onwards" (Stroeve and Notz 2018). "Sea ice area has decreased in every month of the year from 1979 to the present (*very high confidence*)" (IPCC 2021; Section 9.3.1 and Figure 9.13). The sea ice has declined at an average rate of about 36,400 km^2/year in the months of March, April, and May, when ringed seals are most strongly associated with the ice for their critical life history functions (Figure 6) (Parkinson 2022).

The diminished Arctic ice is unprecedented in history going back centuries:

> Current Arctic sea ice coverage levels (both annual and late summer) are at their lowest since at least 1850 (*high confidence*), and for late summer for the past 1000 years (*medium confidence*). Since the late 1970s, Arctic sea ice area and thickness have decreased in both summer and winter, with sea ice becoming younger, thinner and more dynamic (*very high confidence*). It is very likely that anthropogenic forcing, mainly due to greenhouse gas increases, was the main driver of this loss . . . (AR6 WG1 TS 2.5)

The human-forced component of Arctic sea ice loss accounts for nearly all of the observed loss of about 2 million km^2 up to 2014 (IPCC 2021; Figure TS2.7). There has been a linear decline in the area of Arctic sea ice extent with cumulative anthropogenic CO_2 emissions that ranges from 1.2 m^2/ton in March, to 3.2 m^2/ton in August (Notz and Stroeve 2016; Stroeve and Notz 2018).

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[5] Analyses of sea ice often focus on ice area or ice extent. "Sea ice area is the total region covered by ice. Extent is the total region with at least 15 percent sea ice cover." (Scott 2022). Both measures are typically expressed in km^2. For the Arctic, they differ somewhat due to both fixed and variable factors; ice extent gives larger values than ice area. Extent and area are highly correlated and, for analyses of trends and other purposes in this review, the two measures provide similar results (e.g., Comiso et al. 2023).

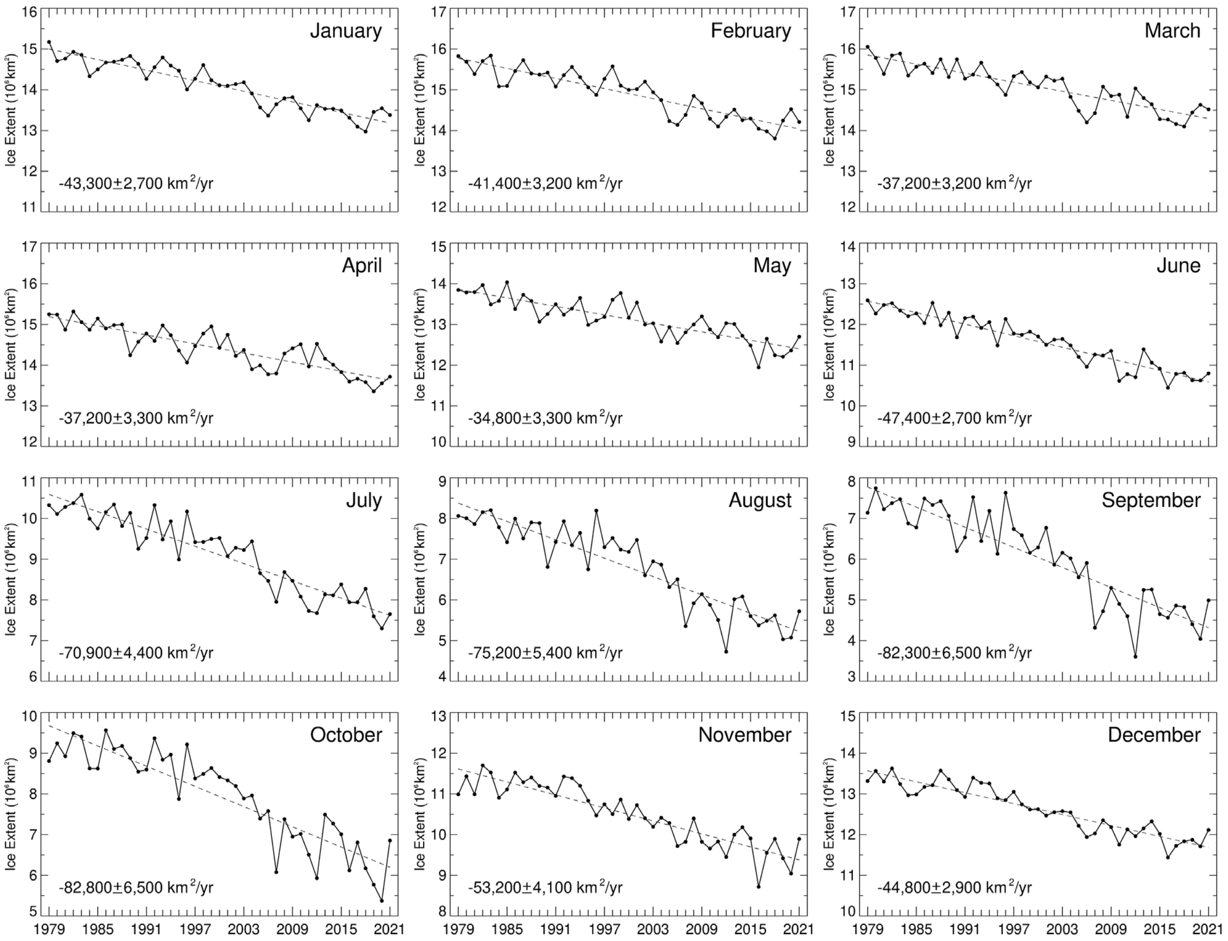

Figure 6. Sea ice has declined in all 12 months of the year. Illustration from Parkinson (2022), "Arctic sea ice extents and trends, 1979–2021, for each of the 12 calendar months. The y-axis values vary for the different months, but in each case there is a range of 5 × 10^6 km^2, to allow ready visual comparison of the trend-line slopes." Used under the Creative Commons Attribution License (CC BY).

Sea ice extent has not changed uniformly over the entire Arctic (e.g., Parkinson 2022) (Figure 7). Typically, the decline in yearly average ice has been larger for regions closer to the outer edge of the seasonal ice cover (Notz and Stroeve 2018), though the pattern is not strictly driven by latitude. It is amplified in the North Atlantic, where the warm Gulf Stream leads to high-latitude ice-free waters (Parkinson 2022), and seasonal landfast ice ceased to form in areas around Svalbard in the Barents Sea since 2006 (Hamilton et al. 2018). The typical pattern is also moderated by a 'continentality effect' in Hudson Bay, where winters are colder than similar latitude oceanic locales (Parkinson 2022). These effects are apparent in sea extents during March, April, and May, the period that is vital for ringed seals: Since the Arctic ringed seal listing in 2012, there have been large overall declines and percentage declines in sea ice present during those months in the north Atlantic regions of the Barents Sea, Baffin Bay, and around Greenland, along with the peripheral Pacific Arctic seas, the Bering and Okhotsk (Table 1).

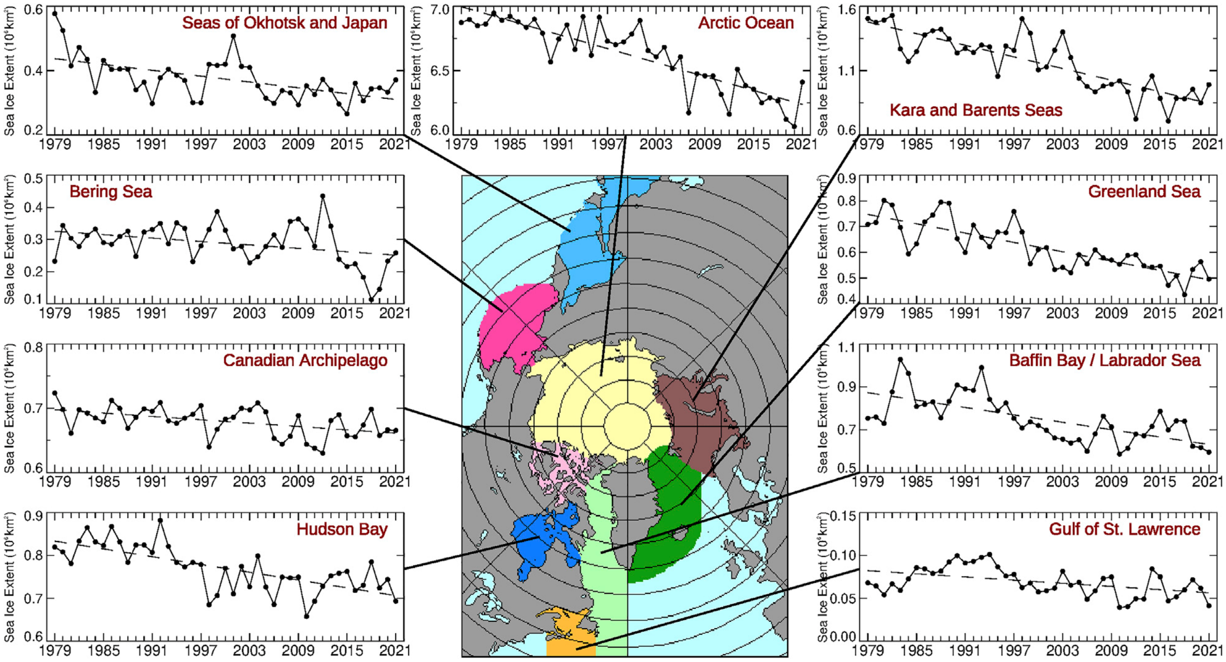

Figure 7. Sea ice has not declined uniformly across Arctic regions. Illustration from Parkinson (2022), "Yearly average sea ice extents and least-square trend lines, 1979–2021, for the following regions: Seas of Okhotsk and Japan; Bering Sea; Canadian Archipelago; Hudson Bay; Arctic Ocean; Kara and Barents Seas; Greenland Sea; Baffin Bay/Labrador Sea; and Gulf of St. Lawrence." Used under the Creative Commons Attribution License (CC BY).

The highest densities of breeding ringed seals during winter and spring are found in areas of landfast ice, which in many areas has historically formed relatively early and dependably. Studies since the listing rule have shown that landfast ice has not been immune to the effects of warming, exhibiting declines in extent, thickness, and duration of coverage (Yu et al. 2014; Mahoney et al. 2014; Li et al. 2020). From 1976–2018, the annual average landfast ice extent in the Arctic declined at an average rate of 10.5% per decade, compared to the overall ice extent decline of 5.2% per decade (Li et al. 2020). The March-April-May declines in Arctic-wide landfast ice extent were statistically significant ($p < 0.01$) and averaged about 6.4%. There were significant declines in the January–May average landfast ice extent in 11 of 17 Arctic subregions; the others had non-significant trends that were all negative except for the Bering Sea, where landfast ice extent was highly variable.

Table 1. Average annual change in March-April-May sea ice extent by region during the satellite record, 1979–2023, based on simple linear regression over the National Snow and Ice Data Center Sea Ice Index v3.0 (Fetterer et al. 2017). The total change for the period and the percent change since 2012, based on the overall average slope are also shown.

Region	Average Annual Change (km^2/year)	Total Change (km^2)	Change Since 2012
Baffin	-5,056	-222,455	-4.8%
Barents	-11,494	-505,715	-20.7%
Beaufort	-132	-5,814	-0.2%
Bering	-3,119	-137,250	-6.6%
Canadian Archipelago	-36	-1,562	-0.1%
Central Arctic	-255	-11,232	-0.1%
Chukchi	-350	-15,399	-0.5%
East Siberian	23	1,014	0%
Greenland	-5,552	-244,271	-8.4%
Hudson	-242	-10,647	-0.2%
Kara	-315	-13,860	-0.4%
Laptev	-60	-2,622	-0.1%
Okhotsk	-6,538	-287,664	-11.5%

The timing of annual freeze-up and melt cycles has also been disrupted, leading to shorter seasonal duration of ice coverage. The length of the open-water period is particularly relevant to habitat quality for Arctic ringed seals, which rely on under-snow lairs on the sea ice, because snow depth and quality is influenced by the ice freeze-up and melt onset dates. “Arctic sea ice retreat includes an earlier onset of surface melt in spring and a later freeze up in autumn, lengthening the open-water season in the seasonal sea ice zone (Stroeve and Notz 2018).” (IPCC 2021; Section 9.3.1.1). Crawford et al. (2021) showed that the length of the open-water period increased in every region of the Arctic except the Bering Sea from 1979–2013; but there has been a long-term decline in Bering Sea March ice extent (e.g., Ballinger et al. 2023) and a marked reduction in sea ice concentration since 2017 (Stabeno and Bell 2019), likely accompanied by a lengthening of the open-water period there, as well. Dauginis and Brown (2021), analyzing ice data from 1997–2019, found that pan-Arctic open-water duration increased by 4.85 days/decade. Regionally, they found that the Bering, Chukchi, and Beaufort seas had the strongest trends toward earlier 'ice-off', with the Bering also having the strongest trend toward later 'ice-on'.

Snow cover on sea ice—Snow depth on sea ice in the Arctic has decreased. Warming in the upper layer of Arctic waters has caused later onset of sea ice formation in autumn that, in turn, reduces snow accumulation on the ice because more snow falls into open water (Webster et al. 2018; Lam et al. 2022). Until recently, it has been difficult to measure changes in snow depth over the Arctic region (Webster et al. 2018). The few examples of *in situ* snow depth monitoring on sea ice have required massive logistical efforts (Warren et al. 1999) or have been quite limited spatially (Lam et al. 2022) or temporally (Haas et al. 2017). Recent research campaigns motivated by the need to account for snow cover when monitoring sea ice thickness—such as Operation Ice Bridge and the IceSat-2 satellite—provided calibration data that greatly advanced the capabilities for Arctic-wide remote sensing of snow depths by passive microwave methods (Lee et al. 2021). The result has been a clear multidecadal decline in average snow depth on sea ice. Webster et al. (2014) found that snow on Chukchi and Beaufort Sea ice in 2009–2013 was about 56% thinner than during the latter half of the 20th century. Lee et al. (2021) found an Arctic-wide average reduction in snow depth from the period 1954–1991 to the period 2003–2020, but with statistically significant positive trends during 2003–2020 on multi-year ice (MYI; ~0.6 cm/yr) and negative trends over mixed and first-year ice (FYI; about −0.4 cm/yr). Stroeve et al. (2020), using a detailed physical model of snow depth driven by weather reanalysis products, estimated declines in March-April-May snow depths over the period 1980–2016 of 1.9–3.0 cm/decade in the Chukchi Sea; 0.5–1.9 cm/decade in the Beaufort Sea; 1.7–3.4 cm/decade in the E. Siberian Sea; 1.8–3.0 cm/decade in the Laptev Sea; 2.9–3.6 cm/decade in the Kara Sea; and 1.9–2.7 cm/decade in the Barents Sea. The central Arctic and east Greenland regions had mixed positive and negative trends for the same months and decadal periods. Most of the recent analyses of snow depth trends have found that snow depth has been increasing on multi-year ice but decreasing on first-year ice (e.g., Stroeve et al. 2020; Lee et al. 2021; Li et al. 2022). Because the multi-year ice area itself has been decreasing and is small relative to the seasonal ice area, the Arctic-wide average snow depth has declined. Also, first-year ice is extremely important to ringed seals, which are found in highest densities on landfast (i.e., first-year) ice.

The clear documentation of declining winter-spring snow depth on Arctic sea ice is perhaps the most significant new finding about ringed seal habitat since the listing decision. At the time of listing, it was understood that later freeze-up and earlier melt would reduce the time available for snow accumulation and persistence on the sea ice. There was a modest amount of CMIP5 model output projecting Arctic-wide declines in snow depth through the end of the century (Hezel et al. 2012). But there was very little observation-based documentation of a trend in snow depth. One example was the 'Warren climatology', the widely-referenced source (Warren et al. 1999) that was, until recently, the primary available means for estimating seasonal snow cover on Arctic sea ice. The Warren climatology was derived from *in situ* snow measurements at Soviet-era drifting ice stations during 1954–1991. The study found weak negative trends of snow depth in all months, “apparently due to a reduction in accumulation-season”. The strongest decline was 8 cm over 37 years, for May, the month of maximum snow depth in the dataset. The new observation-based, Arctic-wide studies provide a much more robust confirmation of an ongoing decline in snow depth on sea ice, and a basis for greater confidence in the model outputs that project the trends into the foreseeable future.

In addition to the effect of later freeze-up on snow depth accumulation, earlier spring warming has also had an effect on the amount of precipitation that falls as rain rather than snow. Increasing rain-on-snow events were documented as threats to ringed seals in the 2010 Status Review (e.g., Hammill and Smith 1991; Stirling and Smith 2004), based on direct observations and on intuition about Arctic warming leading to more rain. For ringed seals, rain can pose threats by melting and collapsing lairs (exposing pups to predation or hypothermia), icing over breathing holes (Furgal et al. 2002), and wetting the coats of pups (compromising thermoregulation). Since the listing, rain-on-snow events have gained greater recognition for their impacts on a variety of Arctic geophysical processes, wildlife, and human livelihoods (Serreze et al. 2021). This recognition has motivated studies that have documented the increasing trend in rain events that was anticipated by the 2010 Status Review and earlier studies. For example, Dou et al. (2021) showed that rain-on-snow events in the ERA5 reanalysis dataset have shifted as much as 4–6 days earlier per decade in some regions; there have been more rain-on-snow events in spring; and the increased rain-on-snow events have caused a reduction of spring snow depth of 0.5 cm per decade over the Arctic Ocean since 1980, and up to 2 cm/decade in the Kara-Barents seas and Canadian Arctic Archipelago.

Okhotsk Ringed Seal

Since the 2010 Status Review, continuing declines in sea ice extent, volume, duration, and production have been documented in the Sea of Okhotsk (Figure 7; Table 1). Annual trends in landfast sea ice extent and duration from 1976 to 2018 were examined throughout the Arctic using satellite data (Li et al. 2020). In the Sea of Okhotsk, landfast sea ice extent and duration during the months of January to May showed decreasing trends over the 40 year period. Landfast ice extent declined by about 100 km^2/year. When compared to a study that examined sea ice data from 1976–2007 (Yu et al. 2014), both landfast ice extent and duration in the Sea of Okhotsk changed from a positive trend through 2007, to a decreasing trend through 2018 (Li et al. 2020). Kashiwase et al. (2014) used satellite data to reconstruct annual ice production in the Sea of Okhotsk from 1974 to 2008. The estimated annual ice production over the 34 years showed a significant decreasing trend of about 11.4%, due to warming in autumn at the land northwest of the Sea of Okhotsk. Satellite data were also used to estimate sea ice volume in the Sea of Okhotsk from 2000 to 2020, during its stage of maximum development (Pishchalnik et al. 2021).

Over the 20 year period, ice volume decreased by 51.9%. The decrease in overall ice volume was mostly due to declines in ice thickness, while declines in ice cover contributed to a lesser extent.

Lozhkin and Shevchenko (2019) used satellite data to estimate sea surface temperatures in the Sea of Okhotsk from 1998 to 2017. They found that the heat content of the surface layer decreased over the 20 year period. The trend was most pronounced in the spring, and they suggested that the cooler waters may be due to a decrease in sea ice cover, which resulted in more significant cooling due to winter convection.

Baltic Ringed Seal

Meier et al. (2022) summarized and assessed the current knowledge of the effects of global warming on past, present, and future changes in climate of the Baltic Sea region. Their study is an update of the *Second Assessment of Climate Change for the Baltic Sea Basin* (BACC II Author Team 2015). Select key messages from this assessment that most directly relate to past or present ringed seal habitat and ecosystem conditions are quoted below, including estimated levels of confidence (based on agreement and evidence) and whether the result was novel since the previous assessment (marked "NEW"):

> – ***Air Temperature.*** Linear trends of the annual mean temperature anomalies during 1878–2020 were +0.10 °C per decade in the Baltic Sea region (high confidence). This is larger than the global mean temperature trend and slightly larger than estimated in the earlier BACC reports (NEW). The warm spell duration index has increased during 1950–2018 (medium confidence). Statistically significant decreases in winter cold spell duration index across the period 1979–2013 have been widespread in Norway and Sweden, but less prevalent in eastern Finland, while changes in summer cold spells have been small in general (medium confidence).
>
> – ***Precipitation.*** Since 1950, annual mean precipitation has generally increased in the northern part of the Baltic Sea region. There is some evidence of a long-term trend during 1950–2018 (low confidence). However, long-term records suffer from inhomogeneity due to the increasing number of rain gauges. The frequency and intensity of heavy precipitation events have increased (medium confidence). Drought frequency has increased across southern Europe and most of central Europe since 1950 but decreased in many parts of northern Europe (low confidence).
>
> – ***Snow.*** The decrease in snow cover[6] has accelerated in recent decades, except in the mountain areas and the northeastern part of the Baltic Sea region (high confidence;

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[6] These findings are likely referring to snow cover in terrestrial areas, which may differ from snow cover on sea ice. We are not aware of any studies that have directly examined snow cover on sea ice in the Baltic Sea region;

> NEW). On average, the number of days with snow cover has declined by 3–5 per decade (high confidence). Mean and maximum snow depth has also decreased, most clearly in the southern and central part of the region (high confidence). Whether sea effect snowfall events have changed is unknown (low confidence).
>
> – ***Sea ice.*** Long-term decreases in sea ice in the Baltic Sea have exceeded the large natural climatological variability and can only be attributed to global climate change (high confidence). In addition, unprecedented mild ice seasons have occurred in the last 10 years, and 100-year trends in sea ice cover showed an accelerated decline in 1921–2020 compared to 1910–2011 (high confidence; NEW).
>
> – ***Water temperature.*** Monitoring data, satellite data, and model-based historical reconstructions indicate an increase in annual mean SST [sea surface temperature] averaged over the Baltic Sea of 0.4–0.6 ºC per decade or ~1–2 ºC since the 1980s (high confidence). During 1856–2005, reconstructed SSTs increased by 0.03 and 0.06 ºC per decade in northeastern and southwestern areas, respectively. Hence, without excluding internal variability, recent warming trends have accelerated 10-fold (NEW). Long-term measurements at Tvärminne, at the northern coast of the Gulf of Finland, indicate that marine heatwaves have increased since 1926 (low confidence). (Meier et al. 2022)

Among their concluding remarks, Meier et al. (2022) stated:

> The climate change signal is still confined to increases in observed air and water temperatures, to decreases in sea and lake ice, snow cover, permafrost, and glacier mass, to the rise in mean sea level, and to variables directly related to temperature and the cryosphere, such as ringed seal habitats. Compared to the previous BACC report, changes in air temperature, sea ice, snow cover, and sea level were shown to have accelerated.

HELCOM and Baltic Earth (2021) also summarized the latest scientific knowledge on how climate change is currently affecting the Baltic Sea and how it is expected to develop in the foreseeable future. They reported that, during the past 100+ years, the Baltic Sea ice season has become shorter (-18 days in the northern Bothnian Bay and -41 days in the central Gulf of Finland) and the maximum ice extent has decreased by about 30%. Indices of total winter ice volume showed a decline of more than 10% per decade during 1985–2015 in many regions (HELCOM and Baltic Earth 2021).

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however, the patterns observed in the Arctic seas (i.e., later freeze-up, earlier melting, and more rain vs. snow during spring leading to less snow cover) likely apply to the Baltic Sea, as well.

Landfast ice in the Baltic Sea during the months of January–May was estimated to have declined at an average rate of 250 km^2/year from 1976–2018 (Li et al. 2020), though the trend was not statistically significant (i.e., $p > 0.01$).

Ladoga Ringed Seal

Imrit and Sharma (2021) examined lake ice phenology on 18 lakes across the Northern Hemisphere over the past ~200 years to investigate impacts of climate change. They showed that 'ice-on' is 11 days later per century, 'ice-off' is 9 days later per century, and ice cover duration is 19 days shorter per century. There were several significant breakpoints—most recently in the mid-1990s—after which changes in ice cover were even faster and associated with changing weather and climate. The authors concluded that their findings "support the assertion that broad-scale climatic changes have led to more rapid lake ice loss in lakes distributed across the Northern Hemisphere, with potential widespread impacts on critical ecosystem services that lake ice provides" (Imrit and Sharma 2021).

Karetnikov et al. (2017) examined Lake Ladoga ice conditions from 1913 to 2015 based on weather data and Finnish ice reports (1913–1937) and Soviet/Russian aerial surveys and satellite imagery (1943–2015). The average dates of first and last ice cover were November 26 and May 15, respectively. Comparing the more recent dataset (1943–2015) versus the earlier dataset (1913–1937), the average date of first ice formation was 2 days later (Nov 28 vs. Nov 26) and the average date of complete ice melt was 5 days earlier (May 13 vs. May 18), making the average ice season 7 days shorter (167 vs. 174 days) between the two periods. The frequency of winters per decade with complete ice cover over Lake Ladoga varied between 80% and 100% from the 1890s to the 1940s, then steadily declined to 50% during the 2010s. The authors noted that the period from 1990 to 2015 was much milder than preceding years. In their conclusions, Karetnikov et al. (2017) warned that climate warming of 1–2 °C in this region could result in only very shallow near-shore areas of the lake freezing over.

Trukhanova (2013) examined Lake Ladoga ice conditions from 1947 to 2012 based primarily on data obtained from aerial surveys and satellite imagery. Ice cover and thickness during 1983–2002 were modeled or calculated to fill data gaps. Based on this dataset, the average date of first ice formation shifted 15 days later (from Dec 2 to Dec 17) and the average date of complete ice melt shifted 13 days earlier (from May 14 to May 1) from 1947 to 2012, resulting in a 13.7% reduction in the average ice season duration. The probability of having a winter with complete ice cover also showed a significant negative trend from 1947 to 2012, declining from about 0.75 to 0.35. The sum of negative air temperatures near the lake declined by an average of 5.56 °C per year (35.2% overall) and mean ice thickness declined by an average of 0.18 cm per year (11.88 cm overall) during 1947–2002, although the coefficients of determination (R^2) for these trends were quite low. The author reported that extremely low ice cover in 2008 resulted in high ringed seal pup mortality and numerous stranded pups that required rehabilitation (Trukhanova 2013).

2.3.7.1.2. Expected future changes in physical components of habitat and ecosystems

Ringed seals were listed under the ESA primarily due to risks from climate-driven trends that are expected to become critical in the future, so it is important to evaluate the best available information about the current consensus on the rates and magnitudes of expected future change. Pertinent new information may include the underlying geochemical, geophysical, or ecological processes; advances in capabilities to model those processes; or information that changes the range or likelihood of plausible future scenarios.

Underlying geochemical, geophysical, or ecological processes—While a full review of improvements in understanding the processes underlying global climate change is beyond the scope and unnecessary for this review, we highlight one example that is central to the concept of uncertainty in future projections. The equilibrium climate sensitivity (ECS) is an important metric used to estimate how the climate responds to radiative forcing. The ECS is defined as the change in the surface temperature after reaching equilibrium, following a doubling of the atmospheric carbon dioxide (CO_2) concentration from the pre-industrial period, which is taken to be the multi-century period prior to the onset of large-scale industrial activity around 1750. The IPCC's reference period of 1850–1900 is used to approximate pre-industrial global mean surface temperature. The IPCC (2021) recognized recent improvements in the understanding of the ECS:

> Since AR5 WG1, substantial quantitative progress has been made in combining new evidence of Earth's climate sensitivity with improvements in the understanding and quantification of Earth's energy imbalance, the instrumental record of global surface temperature change, paleoclimate change from proxy records, climate feedbacks and their dependence on time scale and climate state. A key advance is the broad agreement across these multiple lines of evidence, supporting a best estimate of equilibrium climate sensitivity of 3 °C, with a *very likely* range of 2 °C to 5 °C. (AR6 WG1 TS.3.2.1)

The *likely* range of 2.5 °C to 4 °C is narrower than the *likely* range of 1.5 °C to 4.5 °C used in AR5 WG1, which did not present a best estimate for ECS.

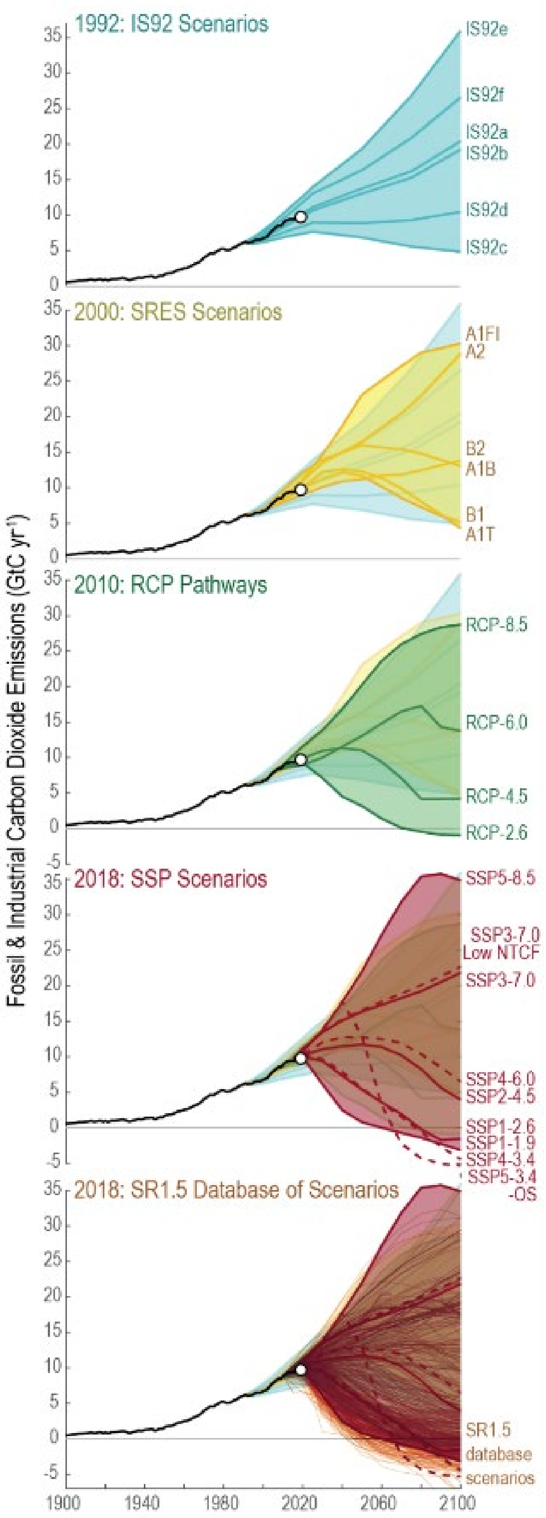
Advances in capabilities to model those processes—The four subspecies of ringed seals that we review here were added to the list of threatened and endangered species based in part on the AR4 WG1 and the CMIP3 climate model intercomparison project. The CMIP3 and earlier climate models, though very simplistic by current standards, were remarkably accurate at projecting the warming that has occurred in the interim (AR6 WG1 1.3.6; Hausfather et al. 2020). Since the listing, the IPCC produced the AR5 WG1 based on updated climate models

(CMIP5) in 2014, and in 2021 released the next report, AR6 WG1, and the outputs from the current generation of models, CMIP6 (IPCC 2021).

The evolution of climate models (also earth system models (ESMs) that include biological and geochemical processes) has naturally involved increased spatial and temporal resolution; better representation of physical, chemical, and biological processes represented in the models; and tuning of model parameters to increase the correspondence between model outputs and observations (AR6 WG1 Box SPM.1). The IPCC (2021) concluded that the CMIP6 models are better than their predecessors at simulating the sensitivity of Arctic sea ice area to anthropogenic CO_2 emissions, and thus are better at capturing the evolution of the satellite-observed Arctic sea ice loss (AR6 WG1 3.4.1.1). "Advances in sea ice models have been made, for example through correcting known shortcomings in CMIP5 simulations, in particular the persistent underestimation of the rapid decline in summer Arctic sea ice extent (Rosenblum and Eisenman 2016, 2017; Turner and Comiso 2017; Notz and Stroeve 2018)." (AR6 WG1 1.5.3.1.2). "The horizontal resolution and the number of vertical levels in ESMs is generally higher in CMIP6 than in CMIP5." (AR6 WG1 1.5.3.1.1). However, there are still shortcomings in the models' capabilities to project certain details about Arctic sea ice. "Despite the documented progress of higher resolution, the model evaluation carried out in subsequent chapters shows that improvements between CMIP5 and CMIP6 remain modest at the global scale." (AR6 WG1 1.5.3.1.1).

CMIP5 and CMIP6 are very similar in representing seasonal cycles and the long-term trend in sea ice extent (Shu et al. 2020; Chen et al. 2021). There was a slightly smaller spread among models in CMIP6 for Arctic summer sea-ice extent, and continued improvement in models' ability to capture the observed seasonal trends. While CMIP5 models substantially underestimated the rates of Arctic sea ice loss trends for individual months, and this bias was reduced in CMIP6, the current models as a group continue to estimate too much sea ice relative to observations (Notz and SIMIP Community 2020). The implication is that projections of future sea ice extent/area based on the entire CMIP6 ensemble will tend to be over-optimistic with respect to the amount and quality of ringed seal habitat in the Arctic.

Future emissions scenarios—Throughout the IPCC's history, scenarios have been used to establish inputs for projecting the consequences of various human actions on the future climate. A primary feature of the scenarios is that they include trajectories or 'pathways' of future GHG emissions. As part of the evolution and advancement of a framework for developing and applying climate models, the scenarios themselves have become more numerous and detailed. They include emissions of CO_2, CH_4, N_2O, and other well-mixed GHGs, prescribed in conjunction with aerosol emissions, ozone changes and effects from human-induced land-cover changes that may be radiatively active. Figure 8, reproduced from AR6 WG1, shows the CO_2 emissions through the 21st century under scenarios used for IPCC assessments since 1992. When the ringed seals that we review in this document were listed, AR4 WG1 was the then-current IPCC assessment. AR4 WG1 was developed using the Special Report on Emissions Scenarios (SRES; Nakicenovic and Swart 2000) (Figure 8, 2nd panel), AR5 WG1 was developed using the Representative Concentration Pathways (RCP; van Vuuren et al. 2011a) (Figure 8, 3rd panel), and AR6 WG1 was developed using the Shared Socioeconomic Pathways (SSP; Riahi et al. 2017) (Figure 8, 4th panel).



Comparison of the range of fossil fuel and industrial CO_2 emissions from scenarios used in previous assessments up to AR6. Previous assessments are the IS92 scenarios from 1992 **(top)**, the Special Report on Emissions Scenarios (SRES) scenarios from the year 2000 **(second panel)**, the Representative Concentration Pathway (RCP) scenarios designed around 2010 **(third panel)** and the Shared Socio-economic Pathways (SSP) scenarios **(fourth panel)**. In addition, historical emissions are shown (black line; Figure 5.5); a more complete set of scenarios is assessed in SR1.5 **(bottom)**; (Huppmann et al., 2018). Further details on data sources and processing are available in the chapter data table (Table 1.SM.1).

Figure 8. (Reproduced with full caption from AR6 WG1 Figure 1.28)

When the four subspecies of ringed seals were listed, the GHG emissions scenarios being considered were mostly limited to future emissions pathways resulting in ‘radiative forcing’ in the year 2100 of at least 4.5 watts per square meter (W/m^2) (van Vuuren et al. 2011b). The warming effect of radiative forcing caused by future emissions results from the well-known physics of GHGs absorbing the sun’s radiation, thereby warming the earth’s atmosphere. Radiative forcing of 4.5 W/m^2 was expected to result in year-2100 warming of about 2.5 °C relative to pre-industrial temperatures. Beginning with the scenarios for AR5 WG1, emissions pathways were named according to the radiative forcing implied by the pathway for the year 2100; e.g., ‘RCP4.5’. The emissions scenarios developed and investigated by scientists prior to AR5 WG1 mostly did not envision climate change mitigation by national policies that might be feasible under a framework such as the Paris Climate Agreement (van Vuuren et al. 2011b). To fill that gap, RCP2.6 was included in AR5 WG1 for exploring what hypothetical global energy system and land use changes would be required to limit warming to 2 °C in 2100 (van Vuuren et al. 2011b). The RCP2.6 scenario would require stringent mitigation to achieve a ‘peak-and-decline’ in radiative forcing, with CO_2 emissions peaking before 2030 and declining through the remainder of the century (van Vuuren et al. 2011a).

The RCPs were developed alongside hypothetical storylines or narratives about how global socio-economic factors might change over the next century. The factors, such as population, economic growth, education, urbanization, and the rate of technological development can, collectively, influence GHG emissions in many ways. A single storyline could lead to multiple GHG emissions pathways (i.e., RCPs), though some would be more plausible than others for any particular storyline. The development of the storylines, now called shared socioeconomic pathways (SSPs; Riahi et al. 2017) lagged behind the development of the RCPs, so AR5 WG1 was developed based mostly on the RCPs themselves, as GHG emissions pathways (Hausfather 2018). After completion of the SSPs, AR6 WG1 was developed with a more internally consistent coupling of the emissions pathways to the underlying socio-economic assumptions. Despite the shift toward more explicit socio-economic underpinnings,

> Many of the SSPs end up being broadly similar in their narratives to the old SRES scenarios, used in the IPCC’s third and fourth assessment reports. For example, the sustainability-focused SSP1 is rather similar to SRES B1, while the more middle-of-the-road SSP2 is similar to SRES B2. The globally fragmented SSP3 is quite similar to SRES A2 and the high fossil-fuel reliant, high-growth SSP5 shares many elements with SRES A1F1. (Hausfather 2018)

There are five SSPs, spanning a range of socioeconomic challenges for mitigation and adaptation to climate change.[7] SSP1 (‘sustainability’) and SSP3 (‘regional rivalry’) describe

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[7] “Socioeconomic challenges to mitigation are defined as consisting of: (1) factors that tend to lead to high *reference emissions* in the absence of climate policy [e.g., carbon intensive energy supplies] because . . . higher

futures in which the level of challenges to mitigation and adaptation are both low and both high, respectively. SSP4 (‘inequality’) envisions low challenges to mitigation and high challenges to adaptation, and SSP5 (‘fossil-fuel intensive’) envisions the opposite. The remaining narrative, SSP2 (‘middle of the road’) is a central case in which both types of challenges are medium (Riahi et al. 2017).

Because each SSP can generate a range of GHG emissions pathways, another layer of models, called Integrated Assessment Models was used to explore the range and plausibility of different RCPs within each SSP. To provide an agreed framework for the IPCC to conduct broad experiments and evaluations of ESMs, a core set of five ‘illustrative’ scenarios was established, composing a range of future development of climate change drivers found in the literature (AR6 WG1 Box SPM.1). In each illustrative scenario, an SSP was associated with an RCP and named in an SSPx-RCPy format, such as SSP2-4.5. The very high and high scenarios (SSP5-8.5 and SSP3-7.0) envision a doubling of CO_2 emissions by 2050 and 2100, respectively. The intermediate scenario (SSP2-4.5) has emissions remaining around current values to mid-century, then declining but not to ‘net zero’ by 2100. The low and very low scenarios (SSP1-2.6 and SSP1-1.9) envision CO_2 emissions declining to net zero in the latter half of this century, and then require negative emissions (e.g., carbon capture and storage) to meet their 2100 targets of radiative forcing. It is important to note that the RCPs used for GHG emissions in AR6 WG1 are roughly similar but not identical to those used in AR5 WG1 and AR4 WG1. For example, in the latter half of the century, SSP5-8.5 has substantially higher CO_2 emissions than RCP8.5, and then it levels and declines, but only to a 2100 level that is still substantially higher than AR5 WG1’s RCP8.5 and the older, very high, AR4 SRES A1FI scenario (Figure 8).

The ESA seeks not only to protect species that are already in danger of extinction, but also to provide protection to those that are likely to become endangered within the foreseeable future. That goal requires consideration of the best available information about what conditions are likely to occur for the species in the future. In AR6 WG1, the IPCC conveys the recent findings and conclusions of the vast majority of the world’s climate scientists about the past and current climate, and about projections of the future climate through the remainder of the 21st century under prescribed scenarios. Although the IPCC has adopted standard terminology for consistent treatment of uncertainties by the lead report authors, including qualitative terms for the validity of a finding and a quantitative scale for the likelihood of an outcome (Mastrandrea et al. 2010), it has refrained from ascribing likelihoods to the various illustrative future climate scenarios used in its analyses (AR6 WG1 1.6.1.1). The scenarios’ purpose is for *projection of what would happen* in the future under specified pathways of GHG emissions rather than *prediction of what*

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reference emissions makes [the] mitigation task larger; and (2) factors that would tend to reduce the inherent *mitigative capacity* of a society [e.g., range of viable technological options]. . . . Socioeconomic challenges to adaptation are defined as societal or environmental conditions that, by making adaptation more difficult, increase the risks associated with any given projection of climate change.” (O’Neill et al. 2014) *will happen* given current conditions. Nevertheless, it is clear that individual experts in climate science and policy do not view the IPCC emissions scenarios as equally likely (e.g., Ho et al. 2019).

In recent years, some have described the highest IPCC emissions scenarios—RCP8.5 in AR5 WG1 and SSP5-8.5 in AR6 WG1—as implausible or misleading ‘business as usual’ scenarios because they would require unrealistic levels of fossil fuel consumption or extreme combinations of socioeconomic factors (e.g., Hausfather and Peters 2020a, 2020b; Burgess et al. 2023). According to IPCC (2022b), “high-end scenarios have become considerably less likely since AR5 but cannot be ruled out.” At the other end of the scenario spectrum, low emissions scenarios—RCP2.6 in AR5 WG1, SSP1-1.9 and SSP1-2.6 in AR6 WG1—were constructed to explore what mitigation measures would be required to meet stringent targets such as those sought under the Paris climate agreement. The near-linear rise in global temperature as a function of cumulative CO_2 emissions (e.g., AR6 WG1 5.5; AR6 WG1 Figure SPM.10) provides a simple conversion between a specified warming limit and a budget for the remaining CO_2 emissions that will cause the limit to be reached. Accounting in that way for the current and near-future emissions levels, the United Nations Environment Programme’s Emissions Gap Report for 2022 (UNEP 2022a) found there is currently no credible pathway for limiting global temperature rise to 1.5 °C above pre-industrial levels, as portrayed in SSP1-1.9. A more recent paper that refines the estimation of the remaining carbon budget found that, as of January 2023, the budget for preserving just a 50% likelihood of achieving the 1.5 °C limit affords only 6 years of current CO_2 emissions (Lamboll et al. 2023). UNEP (2022a) reported that the new or updated climate actions that the Paris Agreement parties have determined they could implement on their own to reach the Agreement’s long-term temperature goal (unconditional nationally determined contributions, or NDCs), “point to a 2.6 °C increase in temperatures by 2100, far beyond the goals of the Paris Agreement.” Moreover, UNEP (2022a) found that “Existing policies point to a 2.8 °C increase, highlighting a gap between national commitments and the efforts to enact those commitments.” Assuming that unconditional, as well as conditional NDCs are achieved, along with net zero commitments, global warming is projected to be kept to 1.8 °C (UNEP 2022a) (in line with global temperature increase under SSP1-2.6). “However, this scenario is currently not credible” given current emissions, highly insufficient near-term NDC targets, and highly uncertain net-zero targets (UNEP 2022a).

Some recent papers (Pielke Jr et al. 2022; Burgess et al. 2023) assert that a middle-of-the-road scenario similar to SSP2-4.5 is the most plausible outlook because of similarity to ‘existing policies’ projections mentioned above, or the ‘Stated Policies’ scenario of the International Energy Agency (IEA 2021). These assertions, however, reflect a lack of consideration for—or a willingness to discount—the risk of failures by nations to implement and maintain current policies. A willingness to discount that risk may be founded on optimism that additional policies and technological solutions will be forthcoming and adequate to offset the risk of policy failures.

The IEA Stated Policies scenario also appears to lack a realistic consideration of policy setbacks such as supply chain disruptions in renewable energy development. Current and recent events, however, indicate that the risk of climate policy failures is real, as are supply chain disruptions with potential to slow or derail progress on a global transition toward renewable energy (e.g., Chestney 2023).

As an example of uncertainty and risk in domestic climate mitigation policy, the United States, over a recent period of just 4 years, withdrew from the Paris Agreement and rolled back many of the federal government's emissions mitigation policies (e.g., Pitt et al. 2020). Subsequently, the United States returned to the Paris Agreement and the federal government re-engaged on efforts to achieve the goals of the Agreement. Executive Orders on climate goals or activities affecting GHG emissions are readily replaced by U.S. federal administrations with differing views from those of their predecessors, and frequent changes in legislative control among closely-divided political parties pose risks for continuity of laws and regulations to mitigate climate disruption.

In the United Kingdom, which has been one of the leading nations in commitments to net zero targets, the Climate Change Committee (UKCCC) is a statutory body established to advise the UK on emissions targets and to report to Parliament on progress made in reducing GHG emissions. In its most recent progress report, the UKCCC found that, through failures to act and backtracking on fossil fuel commitments, "The UK has lost its clear global leadership position on climate action." The report also noted that the UKCCC's confidence in the UK meeting its medium-term targets has decreased in the past year. "Continued delays in policy development and implementation mean that the NDC's achievement is increasingly challenging" (Climate Change Committee 2023).

Beyond domestic challenges in maintaining progress on climate goals, global geopolitical forces can also cause setbacks in energy policies, as in the unexpected rise in use of coal to replace natural gas supplies disrupted by the Russian invasion of Ukraine. The most recent World Energy Outlook published by the International Energy Agency (IEA 2022a) opens by emphasizing that "the world is in the midst of the first truly global energy crisis, with impacts that will be felt for years to come", and shows that the crisis stems directly from the invasion. The term 'energy crisis' appears 270 times in the 524-page report, demonstrating the prominence of this factor in the IEA's current assessment of the global energy and emissions outlook. The report cites numerous examples of how this shock has caused or exacerbated mismatches between plans for fossil fuel development and current climate mitigation policies. Extreme policy mismatches are also evident in current governments' plans "to produce more than double the amount of fossil fuels in 2030 than would be consistent with limiting warming to 1.5 °C. The persistence of the global production gap puts a well-managed and equitable energy transition at risk." (SEI et al. 2023). Even if setbacks like these turn out to be temporary, they permanently alter the trajectory of cumulative GHG emissions, which is nearly linearly related to total warming (AR6 WG1 5.5).

Recent and current geopolitical events underscore the notion that evaluation of future emissions likelihood for purposes of this 5-year review should include consideration of the plausibility of the socioeconomic pathways that underlie the IPCC scenarios. The coupling of the emissions pathways to socioeconomic storylines provides a basis on which to elaborate a rationale for climate-dependent decision-making (e.g., ESA decisions). Because GHG emissions stem from human socio-economic processes, choosing a scenario or range of scenarios as a 'most likely' basis for ESA decision-making is more transparent and relatable than choosing an emissions pathway detached from its human-activity underpinnings.

A broadly-based expert assessment of the global strategic outlook for the next couple of decades (The National Intelligence Council 2021) that envisions "a more contested world" has many similarities to the narratives of SSP3 ("Regional Rivalry–A Rocky Road") and SSP4 ("Inequality - A Road Divided") (Riahi et al. 2017). The storyline of SSP3 envisions a future for the remainder of this century in which,

> A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. Policies shift over time to become increasingly oriented toward national and regional security issues. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time. Population growth is low in industrialized and high in developing countries. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions. (Riahi et al. 2017)

These socioeconomic conditions arise from high challenges to climate-change mitigation and adaptation, alike, from features such as high dependence on fossil fuels and slow technological development.

The storyline of SSP4 envisions a future for the remainder of this century in which, challenges to adaptation are high, but challenges to mitigation are low:

> Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly

> educated societies that work in a labor intensive, low-tech economy. Social cohesion degrades and conflict and unrest become increasingly common. Technology development is high in the high-tech economy and sectors. The globally connected energy sector diversifies, with investments in both carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources. Environmental policies focus on local issues around middle and high income areas. (Riahi et al. 2017)

The National Intelligence Council (NIC) report echoed many of the same themes as SSP3 and SSP4, but it represents an outlook, rather than the hypothetical scenario of the SSPs. The NIC concluded that,

> In coming years and decades, the world will face more intense and cascading global challenges ranging from disease to climate change to the disruptions from new technologies and financial crises. These challenges will repeatedly test the resilience and adaptability of communities, states, and the international system, often exceeding the capacity of existing systems and models. This looming disequilibrium between existing and future challenges and the ability of institutions and systems to respond is likely to grow and produce greater contestation at every level. In this more contested world, communities are increasingly fractured as people seek security with like-minded groups based on established and newly prominent identities; states of all types and in all regions are struggling to meet the needs and expectations of more connected, more urban, and more empowered populations; and the international system is more competitive—shaped in part by challenges from a rising China—and at greater risk of conflict as states and nonstate actors exploit new sources of power and erode longstanding norms and institutions that have provided some stability in past decades. (The National Intelligence Council 2021)

The NIC report is an assessment of the global strategic outlook that is prepared early in each new U.S. federal administration to assess “the key trends and uncertainties that will shape the strategic environment for the United States during the next two decades.” Although it does not represent official U.S. policy, the report represents the NIC’s expert analysis and judgment based on consultation with government, academia, the private sector, and civil society. Despite similarities of the NIC outlook to both SSP3 and SSP4, the underlying assumption of low socioeconomic challenges to mitigation in SSP4 is inconsistent with the recent history of nations’ struggles in forming, implementing, and maintaining the climate policies required to put the world on a path toward the outcomes of SSP4-6.0 or lower-impact scenarios. The parallels between the NIC outlook, the SSP3 narrative, and its underlying assumption of high challenges to both mitigation and adaptation are more supportive of SSP3 and its associated emissions pathway, RCP7.0, as the most plausible among the 5 IPCC illustrative scenarios at this time.

The recently-released White House Office of Science and Technology Policy guidance on selecting climate information to use in climate risk and impact assessments acknowledges that various factors influence the selection of climate scenarios, including risk tolerance:

> The societal value of the asset at risk should be considered by decision-makers when including scenarios on the higher end of potential impacts (e.g., SSP3-7.0 or RCP8.5), especially when planning for critical or long-lived assets or natural resources (e.g., critical infrastructure, endangered species, etc.). (OSTP 2023)

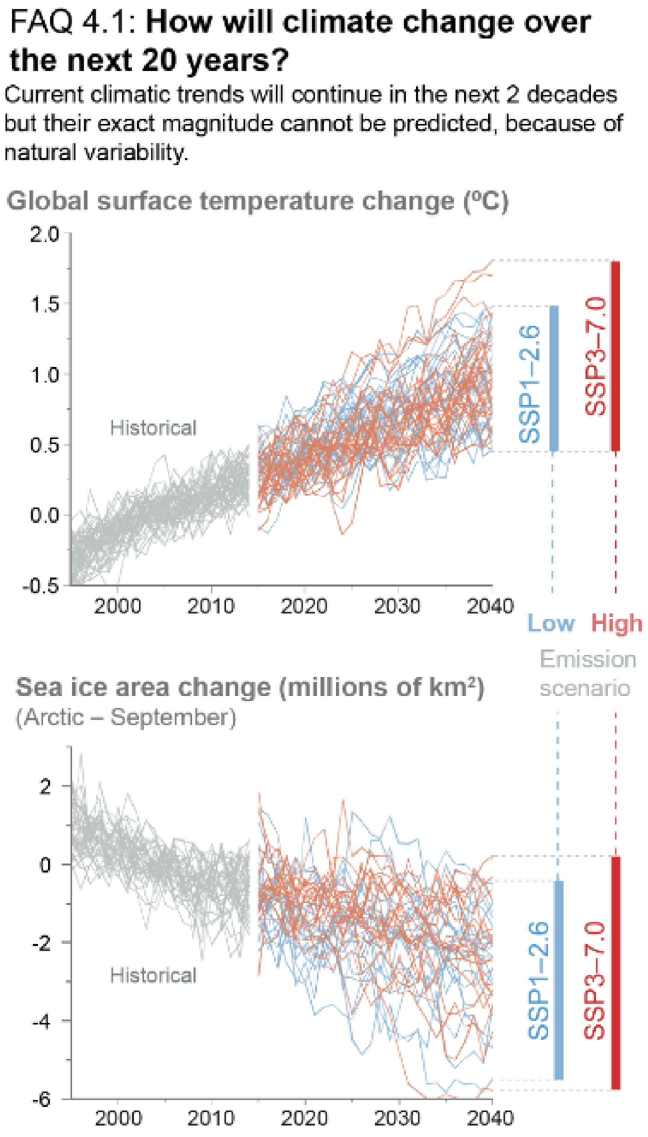
Following this guidance, the risk of failures to exercise and maintain emissions policies should be part of the broad suite of risks and uncertainties considered and accounted for in ESA assessments and decisions. In order to account for uncertainty, decision makers could consider a scenario with a higher and broader distribution of year-2100 global warming levels than SSP4-6.0 and SSP2-4.5 (the IPCC defines 'global warming level', or GWL, as a global surface temperature increase in 2100, relative to the mean of the preindustrial years 1850–1900; AR6 WG1 TS.1.3.2). The most likely GWL under SSP2-4.5 is 2.9 °C, versus 3.9 °C under SSP3-7.0 (AR6 WG1 Table 4.2). However, the 90% confidence ranges overlap within 2.8–4.0 °C, indicating that many of the plausible outcomes are similar between the two scenarios.

SSP3-7.0 is a 'no-additional-climate-policy' scenario, meaning that it does not rely on mitigation policies beyond those already included in the Paris Agreement. As a default outlook for the future, a no-additional-policy assumption is rational in the sense that it does not rest on arbitrary assumptions about the establishment, timing, or effectiveness of any future policies. Alternatively, it may be viewed as equivalent to a recognition that any future policy implementations have the potential to be offset by cancelations or failures to implement existing policies.

The OSTP guidance and several of the other points made above are among the reasons that NMFS has recently updated its own guidance for treatment of climate change in ESA decisions; the current guidance is to

> use climate indicator values projected under the IPCC's Shared Socioeconomic Pathway (SSP) 3-7.0 when data are available. When data specific to that pathway are not available, we will use the best available science that is as consistent as possible with SSP3-7.0. (NMFS 2023b)

The 2010 Status Review assessed the threat of climate-driven destruction or modification of the seals' sea-ice habitat primarily under two scenarios in use at the time, SRES A1B and SRES A2; the CO_2 emissions pathway in SSP3-7.0 lies about midway between them (Figure 8). As was the case at the time of listing, due to natural short-term variability in the climate it will remain difficult to discern what future pathway we are on (Figure 9). There is no guarantee that the future pathway will resemble any particular illustrative scenarios, but GHG emissions over the next couple of decades may demonstrate certain pathways are unlikely or unattainable, as is currently the case for SSP1-1.9 and SSP2-2.6. The highest warming scenario, SSP5-8.5, seems avoidable based on progress toward slowing global emissions growth.


FAQ 4.1: **How will climate change over the next 20 years?**

Current climatic trends will continue in the next 2 decades but their exact magnitude cannot be predicted, because of natural variability.

Simulations over the period 1995–2040, encompassing the recent past and the next twenty years, of two important indicators of global climate change. (Top) Global surface temperature, and **(bottom)**, the area of Arctic sea ice in September. Both quantities are shown as deviations from the average over the period 1995–2014. The grey curves are for the historical period ending in 2014; the blue curves represent a low-emissions scenario (SSP1-2.6) and the red curves one high-emissions scenario (SSP3-7.0).

Figure 9. (Reproduced with full caption from AR6 WG1 FAQ 4.1, Figure 1)

Although NMFS has selected SSP3-7.0 as the default scenario for ESA assessments at present, the climate outlook for ringed seals is not particularly sensitive to the chosen scenario, as was the case at the time of listing. Figure 10 shows that a broad range of scenarios project a large amount of warming and loss of sea ice within this century. Even the low and very low emissions scenarios, SSP1-2.6 and SSP1-1.9, deemed to be currently not credible (UNEP 2022a), portend substantial additional warming before very slight cooling trends late in the century. Massive declines in September Arctic sea ice are projected under SSP3-7.0 and SSP2-4.5, leaving the Arctic ‘practically ice free’ on average after mid-century. Even SSP1-2.6 would lead to a loss of half of present-day ice extent in September. As Overland et al. (2019) characterized it, no matter which emissions scenario is followed over the next few decades, the Arctic will be a substantially different environment at mid-century than at present (less snow and sea ice, melted permafrost, different ecosystems), and will be perhaps unrecognizable by the end of the 21st century. “There is no uncertainty about the sign of future Arctic change. There is uncertainty regarding the pace of change in the second half of the century, as well as its impacts on local and remote regions” (Overland et al. 2019).

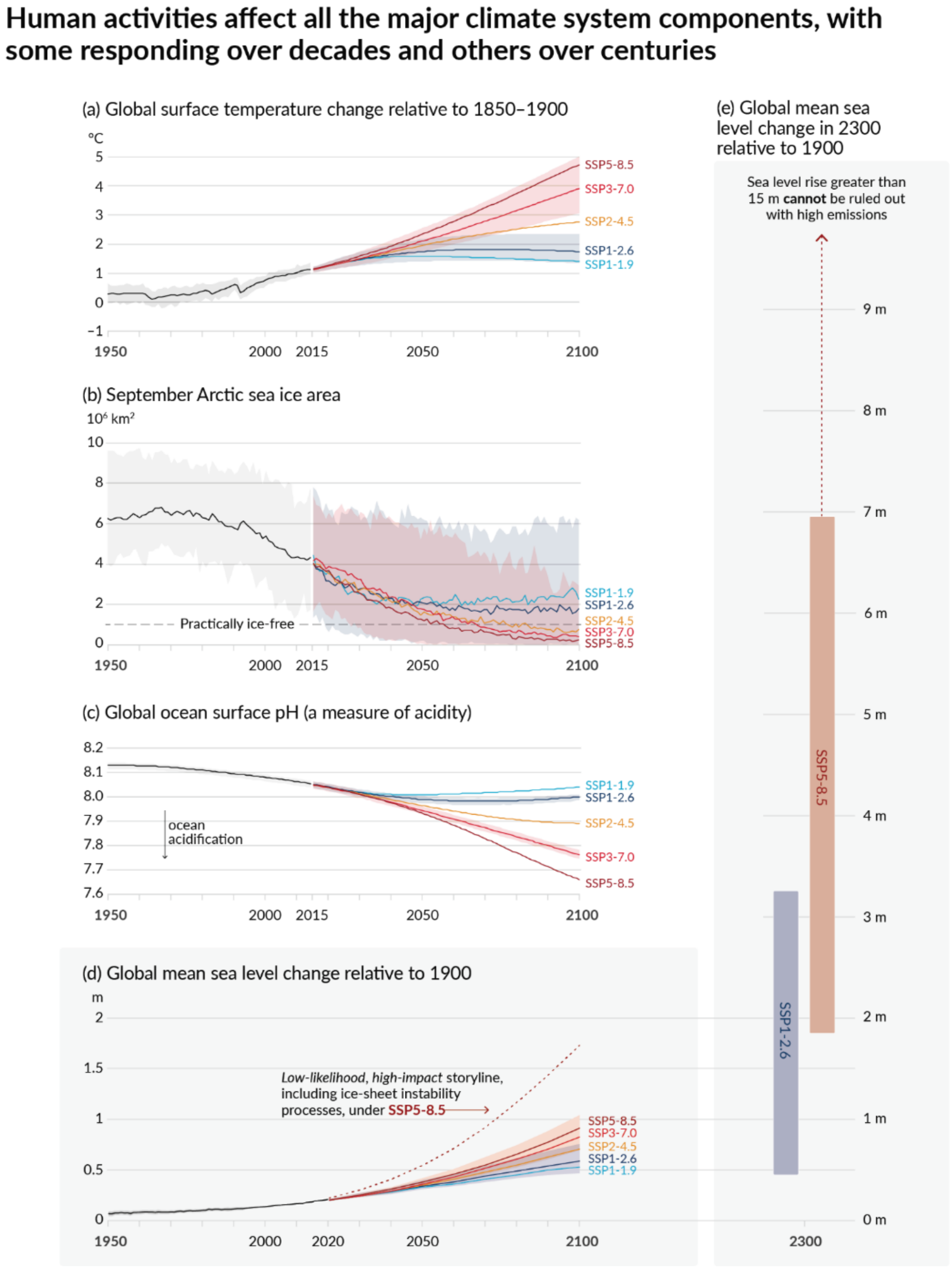


Figure 10. (Reproduced with full caption from AR6 WG1 Figure SPM.8)

Selected indicators of global climate change under the five illustrative scenarios used in this Report. The projections for each of the five scenarios are shown in colour. Shades represent uncertainty ranges – more detail is provided for each panel below. The black curves represent the historical simulations (panels a, b, c) or the observations (panel d). Historical values are included in all graphs to provide context for the projected future changes.

Panel (a) Global surface temperature changes in °C relative to 1850–1900. These changes were obtained by combining Coupled Model Intercomparison Project Phase 6 (CMIP6) model simulations with observational constraints based on past

simulated warming, as well as an updated assessment of equilibrium climate sensitivity (see Box SPM.1). Changes relative to 1850–1900 based on 20-year averaging periods are calculated by adding 0.85°C (the observed global surface temperature increase from 1850–1900 to 1995–2014) to simulated changes relative to 1995–2014. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0.
Panel (b) September Arctic sea ice area in $10^6 km^2$ based on CMIP6 model simulations. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0. The Arctic is projected to be practically ice-free near mid-century under intermediate and high GHG emissions scenarios.
Panel (c) Global ocean surface pH (a measure of acidity) based on CMIP6 model simulations. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0.
Panel (d) Global mean sea level change in metres, relative to 1900. The historical changes are observed (from tide gauges before 1992 and altimeters afterwards), and the future changes are assessed consistently with observational constraints based on emulation of CMIP, ice-sheet, and glacier models. *Likely* ranges are shown for SSP1-2.6 and SSP3-7.0. Only *likely* ranges are assessed for sea level changes due to difficulties in estimating the distribution of deeply uncertain processes. The dashed curve indicates the potential impact of these deeply uncertain processes. It shows the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice-sheet processes that cannot be ruled out; because of *low confidence* in projections of these processes, this curve does not constitute part of a *likely* range. Changes relative to 1900 are calculated by adding 0.158 m (observed global mean sea level rise from 1900 to 1995–2014) to simulated and observed changes relative to 1995–2014.
Panel (e) Global mean sea level change at 2300 in metres relative to 1900. Only SSP1-2.6 and SSP5-8.5 are projected at 2300, as simulations that extend beyond 2100 for the other scenarios are too few for robust results. The 17th–83rd percentile ranges are shaded. The dashed arrow illustrates the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice-sheet processes that cannot be ruled out.
Panels (b) and (c) are based on single simulations from each model, and so include a component of internal variability. Panels (a), (d) and (e) are based on long-term averages, and hence the contributions from internal variability are small. {4.3; Figures 4.2, 4.8, 4.11; 9.6; Figure 9.27; Figures TS.8 and TS.11; Box TS.4 Figure 1}

Arctic Ringed Seal

Future temperatures in the Arctic—The World Meteorological Organization (WMO) is the United Nations System's authoritative voice on weather, climate, and water. The most recent WMO global annual update (WMO 2023a) concluded:

- The annual mean global near-surface temperature for each year between 2023 and 2027 is predicted to be between 1.1 °C and 1.8 °C higher than the 1850-1900 average.
- There is a 98% chance of at least one in the next five years beating the temperature record set in 2016, when there was an exceptionally strong El Niño.
- The chance of the five-year mean for 2023-2027 being higher than the last five years is also 98%.
- Arctic warming is disproportionately high. Compared to the 1991-2020 average, the temperature anomaly is predicted to be more than three times as large as the global mean anomaly when averaged over the next five northern hemisphere extended winters. (WMO 2023b)

The CMIP6 models project that the Arctic mean surface temperature in 2100 will be about 5 °C warmer relative to 1981-2011 under the SSP2-2.6 scenario and about 9.5 °C warmer under the SSP5-8.5 scenario (Hu et al. 2021). The projected warming under our assumed scenario of

SSP3-7.0 would lie between those values. These are massive increases in temperature but it is important to note that they are values for the year-round average; Arctic amplification is greatest in the autumn–winter months and April (Rantanen et al. 2022), which are all important times for the formation and persistence of snow on sea ice that is crucial for ringed seals.

The projected increases in future average temperatures are accompanied by expectations that the observed trend toward more frequent and stronger extreme warm events in the oceans will continue in the future under the scenarios with GWLs above 1.5 °C:

> This trend will continue, with marine heatwaves at global scale becoming four times [2 to 9, *likely* range] more frequent in 2081–2100 compared to 1995–2014 under SSP1-2.6, and eight times [3 to 15, *likely range*] more frequent under SSP5-8.5. The largest changes will occur in the tropical ocean and the Arctic (*medium confidence*). (AR6 WG1 9 Executive Summary; AR6 WG1 Table TS.2; AR6 WG1 Box 9.2)

Future sea ice conditions—Arctic sea ice is projected to continue to decline substantially, even under the most optimistic of the illustrative scenarios, SSP1-1.9 (Figure 8), which is unachievable given the historical GHG emissions, as described above. The Arctic is likely to be practically sea ice-free in September at least once before 2050 under all five illustrative scenarios considered in the AR6 WG1, with more frequent occurrences for higher warming levels. A report from the Sea-Ice Model Intercomparison Project found that:

> In the vast majority of the available CMIP6 simulations, the Arctic Ocean becomes practically sea-ice free (sea-ice area $< 1 \times 10^6$ km^2) in September for the first time before the Year 2050 in each of the four emission scenarios SSP1-1.9, SSP1-2.6, SSP2-4.5, and SSP5-8.5. (Notz and SIMIP Community 2020)

A more recent analysis (Kim et al. 2023), however, used the observed record of sea ice area to constrain the CMIP6 models, thereby improving the models' response to greenhouse gases, and reducing the tendency of those models as a group to overestimate future sea ice area . The constrained models project a practically ice-free Arctic during September, on average, in this century under all IPCC scenarios.

Later freeze-up and earlier melt onset naturally cause an increase in the open-water duration of seasonally ice-covered waters that form ringed seal habitat. Crawford et al. (2021) projected 21st century trends in open-water duration, by Arctic region. All regions of Arctic ringed seal range show substantial increases in the expected open-water period by mid-century under SSP1-2.6, SSP2-4.5, and SSP5-8.5, with comparable rate of change for all three scenarios. After mid-century, the rate of increase in the expected open-water period slows under SSP1-2.6, persists under SSP2-4.5, and accelerates under SSP5-8.5. Increased open-water duration is an important factor in the accumulation of snow on Arctic sea ice because autumn snowfall prior to freeze-up falls into the water rather than onto the sea ice, causing reduced snow depth, a key consideration in the analysis of threats that supported the ESA listing of Arctic ringed seals.

Future snow cover on sea ice—Chen et al. (2021) compared CMIP6 model snow depths on Arctic sea ice with satellite-retrieved observations during 1993–2014 to evaluate the models' skill. The observed variability was in the middle of the models' simulation range but there were notable discrepancies in the seasonal timing, spatial distribution, and other aspects of the modeled snow depths. Nonetheless, future projections suggest continued decreases in snow depths through the end of the century, and certain model features were identified that might provide insight for selection of a subgroup of models that can project snow depths more accurately than the complete CMIP6 ensemble.

Continued warming in the Arctic is expected to result in increased precipitation, but the precipitation over oceans and lakes will increasingly fall as rain. Several studies have projected future trends in Arctic precipitation (e.g., Bintanja and Andry 2017; McCrystall et al. 2021; Dou et al. 2022) and concluded that rain will become the dominant form of Arctic precipitation by late in this century (Bintanja and Andry 2017). The timing of when that might occur is dependent on factors such as latitude, regional differences, and the GHG emissions pathway; these studies relied primarily on the very high emissions CMIP5 RCP8.5 or CMIP6 SSP5-8.5 pathways. A recent study of the hydrological cycle in the CMIP6 models concluded that

> Arctic precipitation (rainfall) increases more rapidly in CMIP6 than in CMIP5 due to greater global warming and poleward moisture transport, greater Arctic amplification and sea-ice loss and increased sensitivity of precipitation to Arctic warming. The transition from a snow- to rain-dominated Arctic in the summer and autumn is projected to occur decades earlier and at a lower level of global warming, potentially under 1.5 °C, with profound climatic, ecosystem and socio-economic impacts. (McCrystall et al. 2021)

Increasing rain-on-snow events were anticipated as threats in the 2010 Status Review based on observations and intuition about Arctic warming leading to more rain. It is difficult to judge whether the recent modeling studies that project the frequency and strength of rain events imply a change in the strength of threats vs. a change in the ability of models to project these kinds of climatic details.

Okhotsk Ringed Seal

Our review found relatively little new information about expected future changes in the physical components of the habitat or ecosystem of Okhotsk ringed seals that became available since the time of listing. Yamanaka et al. (2021) projected sea ice extent using CMIP5 models under the RCP2.6 and RCP8.5 scenarios, finding 28% and 70% declines, respectively, over the

21st century.[8] Despite the limited information specific to the Sea of Okhotsk, the expected effects of a warming climate on Okhotsk ringed seals will likely include many similarities to those described for Arctic ringed seals, above.

Baltic Ringed Seal

Meier et al. (2022) summarized and assessed the current knowledge of the effects of global warming on past, present, and future changes in climate of the Baltic Sea region. Select key messages from this assessment that most directly relate to future ringed seal habitat and ecosystem conditions are quoted below, including estimated levels of confidence (based on agreement and evidence) and whether the result was novel since the previous assessment (marked “NEW”):

- ***Air temperature.*** Coupled atmosphere–ocean regional climate models project an increase in annual mean air temperature by between 1.5 and 4.3 ºC over the Baltic Sea catchment area at the end of the century. The range indicates ensemble mean values for RCP2.6 and RCP8.5 scenarios.[9] On average, air over surrounding land will warm about 0.1 to 0.4 ºC more than the air over the Baltic Sea (high confidence; NEW). A bias-adjusted median estimate of increase in warm spell duration index in Scandinavia for the period 2071–2100, compared to 1981–2010, was about 15 days under RCP8.5, with an uncertainty range of about 5–20 d (medium confidence). The cold spell duration index in northern Europe is projected to decrease in the future, with a likely range of from -5 to -8 d yr^{-1} by 2071–2100, compared to 1971–2000 (medium confidence).
- ***Precipitation.*** Annual mean precipitation is projected to increase over the entire Baltic Sea catchment at the end of the century (medium confidence). The signal is robust for winter among the various regional climate models but is highly uncertain for summer in the south. The intensity and frequency of heavy rainfall events are projected to increase. These increases are even larger for convection-resolving models (high confidence; NEW). Projections show that the number of dry days in the southern and central parts of the Baltic Sea basin increases mainly in summer (low confidence).
- ***Snow.*** Projections under RCP8.5 suggest a reduction in the average snow amount between 1981–2010 and 2071–2100 by more than 70% for most areas[10], with the exception of the high Scandinavian mountains, where the warming temperature

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[8] Projected warming under our assumed scenario of SSP3-7.0 lies between RCP2.6 and RCP8.5.

[9] The projected warming under our assumed scenario of SSP3-7.0 would lie between those values.

[10] These findings are likely referring to snow cover in terrestrial areas, which may differ from snow cover on sea ice. We are not aware of any studies that have used models to project snow cover on sea ice in the Baltic Sea region; however, the patterns projected for Arctic seas (i.e., later freeze-up, earlier melting, and more rain vs. snow during spring leading to less snow cover) likely apply to the Baltic Sea, as well.

does not reach the freezing point as often as in lower-lying regions (high confidence). Sea effect snowfall events in future climate have not been investigated yet.

– ***Sea ice.*** Regional climate projections consistently project shrinking and thinning of Baltic Sea ice cover (high confidence) but still estimate that some ice will be formed even in mildest future winters. However, those estimates are based on a limited number of ensemble members and may not represent future climate variability correctly.

– ***Water temperature.*** Coupled atmosphere-ocean regional climate models project an increase in annual mean SST of between 1.1 and 3.2 ºC, averaged for the Baltic Sea at the end of the century. The range indicates ensemble mean values for RCP2.6 and RCP8.5 scenarios.[9] Warming will be largest in summer in the northern Baltic Sea (high confidence). Under both RCP4.5 and RCP8.5, record-breaking summer mean SSTs were projected to increase at the end of the century (medium confidence; NEW). However, due to the pronounced internal variability, there might be decades in the near future without record-breaking events. (Meier et al. 2022)

HELCOM and Baltic Earth (2021) also summarized the latest scientific knowledge on how climate change is currently affecting the Baltic Sea and how it is expected to develop in the foreseeable future. They reported that, in the future, it is very likely that the maximum ice extent and (non-rafted) ice thickness will decrease. The number of days with ice and length of the ice season will also likely decrease, but with considerable regional differences in magnitude (HELCOM and Baltic Earth 2021).

Ladoga Ringed Seal

Meier et al. (2022) summarized and assessed the current knowledge of the effects of global warming on past, present, and future changes in climate of the Baltic Sea region, which includes Lake Ladoga. In their key messages on the expected future changes in lake ice, the authors stated

> The observed trends of earlier ice break-up, later freeze-up, and shorter ice cover duration on lakes in the region are projected to continue with future warming, and lakes with intermittent winter ice will consequently become increasingly abundant. (Meier et al. 2022)

2.3.7.1.3. Summary of new information about physical habitat

In summary, we found no evidence for a consensus among climate experts that foreseeable-future conditions of physical habitat for the persistence of any of the four subspecies of ringed seals are likely to be better than those projected at the time of listing.

Although considerable uncertainty remains about the full magnitude of future warming, loss of sea and lake ice coverage, and reduction in snow cover on ice, no scenario in the IPCC 6th Assessment Report and the 2022 UNEP Emission Gap Report that is considered to be currently credible points to a GWL of less than 2.9 and 2.8 °C, respectively; the GWL for the scenario selected by NMFS for ESA assessments, based on SSP3-7.0, is 3.9 °C. Given the observed and expected future Arctic amplification, any level of global warming within that range is expected to cause massive modification of the physical habitats for all four ringed seal subspecies (summarized individually, below).

Two cycles of climate assessment by the IPCC—since the four subspecies of ringed seals were listed—encapsulate a massive amount of monitoring, research, and synthesis that substantially improves our understanding and reduces uncertainty about climate-driven processes that underpin the main threats to ringed seals (Zhou 2021). Key improvements stem from 1) more accurate records of historical warming; 2) alignment of multiple independent lines of evidence to quantify the attribution of warming to human activities and to improve accuracy of future projections; 3) reduced uncertainty in the amount of warming from a doubling of CO_2; and 4) greater confidence in the range of plausible scenarios for the foreseeable future, in which the lower impact scenarios are confirmed to be currently not credible given warming due to emissions that have already occurred, and the highest impact scenario seems avoidable based on progress toward slowing global emissions growth.

In addition to the ‘high-level’ improvements in global climate assessment noted above, there have been specific improvements in understanding of the specific, regional processes that influence the suitability of each subspecies’ physical habitat, summarized below.

Arctic Ringed Seal

The well-documented phenomena of Arctic amplification and the long residence time of CO_2 in the atmosphere assure that substantially more Arctic warming and its consequential effects will occur during this century. Even in the exceedingly unlikely event that global warming can be held to 1.5°C, amplified temperatures in the Arctic will be much higher than today and very much higher than they were prior to the industrial period that initiated the human-caused climate disruption. These conclusions, based on new information since the listing, are similar to those reached in the 2010 Status Review that informed the listing rule. At that time, it was also apparent that there was little or no uncertainty about the direction of future Arctic temperature trends and their impact on the availability of suitable reproductive habitat for Arctic ringed seals. Presently, these conclusions are underpinned by greater understanding of climate drivers and processes, providing greater confidence in the projections.

Okhotsk Ringed Seal

In the Sea of Okhotsk, landfast ice extent and duration have changed to show declining trends in recent years, a shift from the results of a study of earlier years, during which the trends of both were positive. Sea ice production declined steadily from 1974 to 2008, and sea ice volume significantly declined during 2000–2020 in the Sea of Okhotsk. Changes in sea surface temperatures have also indicated that sea ice cover has been decreasing. As several aspects of sea ice have been observed to decrease in the Sea of Okhotsk over recent years, it appears that the declining trends of sea ice are likely to continue in the future.

Our review identified relatively little new information about expected future changes in the physical components of the habitat or ecosystem of Okhotsk ringed seals that became available since the time of listing. Because the trends in Sea of Okhotsk sea ice are expected to be qualitatively similar to those driven by warming throughout high latitudes in the northern hemisphere, where further loss of sea ice is virtually certain, it is reasonable to assume that Okhotsk ringed seal breeding habitat will continue to deteriorate.

Baltic Ringed Seal

Several changes have been observed in the physical components of the Baltic ringed seal's habitat and ecosystem. Annual mean air temperature increases were higher in the Baltic Sea region compared to global trends. Annual mean sea surface temperature averaged over the Baltic Sea has increased ~0.5 ºC per decade or ~1–2 ºC since the 1980s. Long-term decreases in sea ice have continued and accelerated. Exceptionally mild sea ice seasons have occurred in the last decade. The frequency and intensity of heavy precipitation events have increased. Mean and maximum snow depth[11] have declined, especially in the southern and central parts of the Baltic Sea region.

Many of the observed changes in the Baltic ringed seal's physical habitat and ecosystem are expected to continue or intensify with future climate warming. Regional climate models project an increase in annual mean air temperature ranging between 1.5 and 4.3 ºC and an increase in annual mean sea surface temperature ranging between 1.1 and 3.2 ºC over the Baltic Sea region at the end of the century, based on RCP2.6 and RCP8.5 scenarios, respectively. The projected warming under our assumed scenario of SSP3-7.0 would lie between those values. Regional

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[11] We assume that these observations are primarily or entirely of snow depth on land. Because snow depth on sea ice tends to be lower than on land due to early-season snowfall into the water, we also assume that snow depth on Baltic sea ice has declined.

models consistently project shrinking and thinning of Baltic Sea ice cover, though some ice may still form in the northernmost regions even in the mildest future winters. Annual mean precipitation is projected to increase over the entire Baltic Sea region at the end of the century; this signal is particularly strong for winter. The frequency and intensity of heavy rainfall events are projected to continue increasing. For most areas (except for the high mountains), average snow cover is projected to decline[12] by more than 70% by 2071–2100 under the RCP8.5 scenario.

While this new information is, in most cases, not directly comparable to the observations or projections for the Baltic Sea cited in the 2010 Status Review, it indicates that the ringed seals' physical habitat and ecosystem conditions have continued to decline and are projected to get worse with future climate warming. This aligns with and supports the previous assessment in the 2010 Status Review.

Ladoga Ringed Seal

The studies we reviewed that examined observed changes in the physical components of ringed seals' habitat in Lake Ladoga were largely in agreement. They found that the lake ice is forming later in the fall and melting earlier in the spring, resulting in a shorter ice season. The frequency of winters with complete ice cover declined from 75–100% in the mid-1900s to less than 50% in the 2010s. There is some evidence that mean ice thickness declined during this period as well. The consensus among regional experts is that these trends are expected to continue with future climate warming, and intermittent ice during winter will become increasingly common in Lake Ladoga and other lakes in the Baltic region. Similarly to Baltic ringed seals above, this new information is not directly comparable with the predictions made in the 2010 Status Review. However, the finding that physical habitat for ringed seals is declining in Lake Ladoga is consistent with the 2010 Status Review's assessment.

2.3.7.2. Biological components of the habitat or ecosystem (e.g., changes to the prey community, altered benthic-pelagic coupling)

Many or all of the climate-driven changes to ringed seals' physical habitat that we reviewed above have the potential to cascade into the seals' biological habitat, particularly through changes to the seals' prey species and the primary production systems on which they depend. The responses of the biological components of ringed seals' habitat are typically more difficult to monitor and project into the future than the underlying physical attributes of the climate, due to the complexity and variability of ecosystems. In this section we make frequent references to the

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[12] We assume that these projections are for the entire Baltic region, though it is unclear whether the projection model included processes such as early-season snowfall into open water. Based on the observations and on projections for warming and increased heavy rainfall events, we also assume that snow depth on Baltic sea ice can be expected to decline through the foreseeable future.

second major contribution to the IPCC's Sixth Assessment Report, *Climate Change 2022: Impacts, Adaptation and Vulnerability* (IPCC 2022a), which focuses on the impacts of climate change on nature. For brevity, we refer to that report as AR6 WG2, and to specific portions by appending the report's section nomenclature such as CCP6 for the "Cross-Chapter Paper 6: Polar Regions" (Constable et al. 2022).

We include in this section consideration of ocean and lake acidification, a physical process that is driven by atmospheric CO_2 concentrations and is therefore related to climate change. The acidification of waters in which ringed seals swim, however, is not known to pose a threat directly to the seals themselves. Rather, the ramifications of more acidic waters stem from impacts on the organisms that support and compose the seals' prey species.

In this section, we review recent literature on the ecosystems that Arctic, Okhotsk, Baltic, and Ladoga ringed seals inhabit, and comment on the potential implications for ecological threats to each subspecies, when those are possible to assess with reasonable confidence.

2.3.7.2.1. Observed changes in biological components of habitat and ecosystems

Arctic Ringed Seal

Increased primary production—Sea ice loss, leading to a greater area of open water and a longer growing season for phytoplankton, has fueled an increase in Arctic primary productivity (Zhang 2010; Kahru et al. 2011; Arrigo and van Dijken 2011, 2015; AR6 WG2 CCP6.2.1.2). The productivity increase of 57% between 1998 and 2018 was, for about the first decade, a response to sea ice loss. Subsequently, the increase has likely been due to higher phytoplankton biomass sustained by an influx of nutrients over the Pacific and Atlantic inflow shelves. The increase in Arctic primary productivity has occurred despite the loss of vast areas of ice that have traditionally supported production by sympagic, underice algal communities. The sources of carbon—phytoplankton in the pelagic zone versus sea-ice algae in the sympagic zone—utilized by grazers and higher-trophic consumers can be traced by compound-specific stable isotope analyses (Wang et al. 2016b; Kunisch et al. 2021; Carlyle et al. 2022; Desforges et al. 2022). Kunisch et al. (2021) noted,

> In the Eurasian Basin, which is partially covered by sea ice year-round, sympagic carbon contributed as much as 92% to the diets of various underice and pelagic zooplankton and between 34 and 65% for various tissues of polar cod *Boreogadus saida* (Kohlbach et al. 2016, 2017). In the seasonally ice-covered Bering Sea, sympagic primary production has also been shown to make high contributions to the diets of ice-associated seals, with estimates ranging from 62 to 80% for bearded seals *Erignathus barbatus*, 21 to 60% for ringed seals, and 51 to 62% for spotted seals *Phoca largha* (Wang et al. 2016b).

In the European Arctic, Kunisch et al. (2021) found that the relative contributions of sympagic and pelagic sources of carbon in ringed seal blubber were 72% and 28%, respectively, indicating that carbon sourced from seasonal sea-ice contributed substantially to the seals' diet. Similarly, Desforges et al. (2022) found that 80% of the diet of ringed seals in Nunavut, Canadian Arctic was from sympagic carbon sources. These studies sampled ringed seals during 2015–2017, after the shift from sympagic toward pelagic primary production was well underway. That the seals' diet continued to comprise a high proportion of carbon fixed by underice algae may indicate a reliance on sea ice and vulnerability to its further loss. As both studies concluded, however, it remains difficult to predict whether ringed seals will have the flexibility to adapt their diet to the changing prey community supported by a more open-water system of productivity. The results from Wang et al. (2016b), who found unexpectedly low proportions of ice-algal carbon in ringed seals—sampled in 2003–2010—that foraged in the northern Bering Sea, may provide insight: The diets of ringed seals in that region have been shown to be high in saffron cod and various shrimps that may not be tightly coupled to sympagic carbon. If this regional dietary flexibility is widespread in Arctic ringed seals it could contribute resilience to some of the ecosystem shifts that are taking place.

Borealization of Arctic marine ecosystems—A recurring theme across recent studies of Arctic marine ecology is the expansion of many sub-Arctic (i.e., boreal) species' ranges into the Arctic, and contraction of some key Arctic species' ranges; the phenomenon is widely termed 'borealization' (Hop and Gjøsæter 2013; Fossheim et al. 2015; Polyakov et al. 2020; Mueter et al. 2021b, 2021a; Geoffroy et al. 2023). The Arctic is warming faster than the rest of the planet and one of the main effects of the warming conditions has been a northward movement of species as the thermal habitat suitable for boreal species has shifted north (Eriksen et al. 2020; Stafford et al. 2022a). Borealization of fish communities in the Arctic has been the focus of many recent studies due to northward shifts in commercial fish species and because fish support many important and iconic top trophic consumers such as marine birds and mammals. The northward shift has resulted in changes in the distribution and abundance of many prey species for ringed seals in Arctic waters (Drinkwater 2009; Renaud et al. 2012; Haug et al. 2017; Ingvaldsen et al. 2017; Siddon et al. 2020; Mueter et al. 2021a; Stafford et al. 2022a; Levine et al. 2023). The inflow shelves of both the Pacific and Atlantic sectors of the Arctic have been subject to borealization.

Surveys of fish communities have clearly documented the process of borealization in the Pacific Arctic. Arctic cod have typically dominated the pelagic fish communities of the western Beaufort and eastern Chukchi seas and were prevalent in all habitats (Logerwell et al. 2015; De Robertis et al. 2017; Levine et al. 2023). In the eastern Chukchi Sea in 2012 and 2013, age-0 Arctic cod dominated the pelagic fish community in summer. Surveys in the same area in 2017 and 2019 determined that age-0 Arctic cod were still the most abundant pelagic fish, but age-0 walleye pollock (*Gadus chalcogrammus*), which had been scarce and found only in the southern

Chukchi during 2012 and 2013, were observed throughout the Chukchi shelf in high abundance in 2017 and 2019 (Levine et al. 2023). Juvenile pollock have become widespread and highly abundant in the eastern Chukchi, and in the western Chukchi, abundance of both juvenile and mature pollock have increased substantially (Levine et al. 2021, 2023; Orlov et al. 2021). The changes in relative abundance of Arctic cod and walleye pollock in the Chukchi between 2012 and 2019 were closely related to changes in sea ice (e.g., decreased extent, earlier ice retreat), higher sea surface temperature, and increasing movement of Bering Sea waters into the Chukchi, indicating that environmental conditions are allowing walleye pollock to extend their northern range into the central Chukchi (Levine et al. 2023). Cold bottom water on the Bering Sea shelf typically restricts the northward extent of mature walleye pollock, but the recent reduction in the size of the cold pool has allowed them to shift northward (Stevenson and Lauth 2019; Eisner et al. 2020; Stafford et al. 2022a). If the Bering Sea ‘cold pool’ fails to persist due to continued warming and a reduction in sea ice extent, mature walleye pollock could establish a permanent presence in the northern Bering and the Chukchi seas.

After Arctic cod, the most abundant fish species in the northern Bering and Chukchi Seas in surveys in the early 2010s were saffron cod, capelin and Pacific herring (De Robertis et al. 2017). Small pelagic fishes in the Bering Sea are important prey for marine mammals (Sinclair 1994), and their distributions are also changing with warming temperatures. During years with warmer sea surface temperatures, capelin and juvenile sockeye salmon were found farther north, and juvenile sockeye salmon also moved farther west (offshore) than during cold years (Yasumiishi et al. 2020). The dominant species by biomass was also different in cold and warm years. In warm years, the biomass of age-0 pollock, Pacific herring, and juvenile sockeye salmon (*Oncorhynchus nerka*) increased, but capelin biomass was significantly lower (Andrews et al. 2016; Yasumiishi et al. 2020).

Distributions of larger fish, such as adult salmonids, have also changed in recent years. Chinook salmon (*Oncorhynchus tshawytscha*) have rarely been seen in the Arctic, but they were one of the salmonids found in both the Chukchi and Beaufort Seas during surveys in 2007–2012, lending support to speculation that chinook may be moving into the Arctic (Logerwell et al. 2015; Yasumiishi et al. 2020). Pink salmon (*Oncorhynchus gorbuscha*) are the most abundant salmonid in the North Pacific (Ruggerone and Irvine 2018), and adult pink salmon have become more abundant in subsistence catches in the Arctic (Dunmall et al. 2013), indicating that pink salmon stocks in the north are increasing. Salmon have not typically been documented as ringed seal prey (Kelly et al. 2010). Given the typical absence of large fish from ringed seal diets in the Pacific Arctic, it seems unlikely that increased presence of adult salmon will benefit ringed seals as new prey species. It remains uncertain whether juvenile salmon in the Arctic would benefit ringed seals as new prey, or impact them as competitors for prey, or predators on lower trophic species.

As in the Pacific Arctic, there is now ample documentation of borealization in the Atlantic Arctic. Over the last few decades, water temperatures in the Barents Sea have increased, sea ice has retreated, and the area covered by warmer Atlantic water has expanded (Johannesen et al. 2012; Comiso 2012; Smedsrud et al. 2013). The warming temperatures have resulted in the borealization of species of all trophic levels in the Barents Sea. The blooms of the phytoplankton species, *Emiliania huxleyi,* now occur five degrees farther north of the first reported bloom in the Barents Sea (Neukermans et al. 2018). Temperate zooplankton species such as the large euphausiid, *Meganyctiphanes norvegica*, have moved north and are now common in the Barents Sea (Dalpadado et al. 2012). Borealization of the copepod community in the Barents Sea has been documented with a declining proportion of the larger, high-lipid copepod *Calanus glacialis*, which dominates in Arctic waters, and increasing numbers of *Calanus finmarchicus*, an Atlantic boreal species with lower lipid content (Aarflot et al. 2018; Mueter et al. 2021b). A potential reason for changes in zooplankton communities is that the reduction of sea ice is associated with a shift in primary production, with considerable decreases in ice algae and increases in open-water phytoplankton production. This transition affects the sizes and species composition of zooplankton communities, causing a shift from large-bodied, lipid-rich zooplankton to smaller, less nutritious zooplankton species (Hunt et al. 2011, 2020; Aarflot et al. 2018).

The distributions of many Atlantic fish species, including mackerel (*Scomber scombrus*), blue whiting (*Micromesistius poutassou*), Atlantic herring (*Clupea harengus*), haddock (*Melanogrammus aeglefinus*), and Atlantic cod (*Gadus morhua*), have also expanded north and into new habitats (Drinkwater 2009; Renaud et al. 2012; Fossheim et al. 2015; Haug et al. 2017; Ingvaldsen et al. 2017). In the Barents Sea, during a warm period in the 1990s–2000s, the spawning stock biomass of Atlantic cod increased, recruitment increased, and the distribution extended farther north (Drinkwater 2009). Atlantic cod in the Barents Sea are a demersal species that generally stay close to the seabed, but recent surveys that used acoustics and stomach content data to investigate their movements indicated that cod leave the shallow Barents Sea shelf to feed on mesopelagic prey in the deep waters of Fram Strait (Ingvaldsen et al. 2017). A greater abundance of large, predatory, boreal species (e.g., cod, haddock) in the Barents Sea suggests that increased predation pressure on small Arctic fish species and intensified competition for other large Arctic predators will likely occur (Fossheim et al. 2015). The changing spatial distributions of fish communities in the Barents Sea will change the ecological interactions of Arctic fish species. As Arctic fish communities are forced to move to the coldest waters and their habitat becomes restricted due to the spread of boreal species, the risk that Arctic species could become locally extinct escalates (Fossheim et al. 2015).

The 2010 Status Review documented the beginnings of most of the ecosystem and prey community changes mentioned above, and anticipated further changes consistent with the new information that has since become available (see 4.2.1.1.3.3 of Kelly et al. 2010). For example, shrinking of the cold pool of bottom water, and range expansion of walleye pollock and contraction of Arctic cod, were already evident in the Bering Sea. In the North Atlantic, many demersal fish species in the North Sea had shifted northward in response to post-1980s rapid warming, and the ecosystem changed from one dominated by cold-water species to one dominated by (relatively) warm-water species. Much like the situation with climate-driven changes to ringed seals' physical habitat, the new information provides more abundant documentation and more details about the processes underlying the changes. However, it is also apparent that the changes documented in the Bering Sea and North Sea prior to the listing rule are now evident substantially farther north, on the inflow shelves of both the Pacific and Atlantic gateways to the Arctic basin. The ongoing changes are associated with myriad interrelated changes in the dynamics of food webs upon which ringed seals depend.

Ocean acidification—It has been well documented that Arctic waters are especially susceptible to ocean acidification (OA: Kelly et al. 2010; AMAP 2018; Terhaar et al. 2020), particularly in the western region (Mathis et al. 2011b) and upper water column (Qi et al. 2017). Generally, as sea ice declines, and more water is exposed, there has been increased uptake of atmospheric CO_2 from anthropogenic activities (Mathis et al. 2015; AMAP 2018), leading to lower pH levels and seasonally low calcium carbonate saturation levels (Kelly et al. 2010; Mathis et al. 2011b). Globally, ocean acidification is one of the "impact-relevant" changes that has emerged from its range of natural variability as a result of human-driven climate change (AR6 WG1 TS.1.2.3). Acidification in the Arctic is happening three to four times faster than the other ocean basins (Qi et al. 2022). While CO_2 uptake is the main driver of OA, it is only one of the many processes that influence the reduction of pH in high-latitude waters. Other processes include organic matter respiration, freshening from ice melt and terrestrial river runoff, and upwelling (Mathis et al. 2011a, 2012, 2015). Collectively, these processes are thought to amplify OA as the Arctic continues to rapidly change (Terhaar et al. 2020). We are not aware of evidence that OA poses threats directly to ringed seals; the potential threats arise from impacts of OA on the food web, i.e., the ringed seals' prey.

Multiple investigations have shown potential impacts from OA to the Arctic food web at multiple trophic levels (Comeau et al. 2010; Munday et al. 2010; Tatters et al. 2012). For example, increased dissolved CO_2 levels have been shown to affect shell production in Thecosome pteropods, a food source for higher Arctic predators (Comeau et al. 2010), including Arctic cod (Falk-Petersen et al. 2008; Walkusz et al. 2013). Munday et al. (2010) found that dissolved CO_2 levels impacted non-calcifying species as well, where behavioral predator avoidance of fish larvae was altered such that it "decreased survival during recruitment to adult populations." Although several groups of Arctic marine species have been tested for sensitivity to acidified waters, there are many more species whose sensitivities may not be apparent until and unless they are being studied as pH begins to drop below their tolerance ranges. The implications of OA for dynamics of food webs that include ringed seals remain difficult to assess and predict, much as they were at the time of listing. Aside from food web dynamics, Tatters et al. (2012) demonstrated that the response of *Pseudo-nitzschia* diatoms (a key species responsible for harmful algal blooms) to OA showed a strong relationship between increased CO_2 levels and silicate-limited growth, which is known to increase cellular toxicity.

Changing food web dynamics—Emergent themes among recent studies of changing Arctic marine food webs include shifts in sizes of plankton, increases in species diversity, altered efficiency of energy transfer to higher trophic levels, and shifts toward fish assemblies composed of larger, more mobile, and more predatory species. These are also among the factors recognized in the AR6 WG2 section on observed and projected impacts of climate change on polar seas:

> climate warming influences key mechanisms determining energy transfer between trophic levels including (a) altered size spectra, (b) shifts in trophic pathways, (c) phenological mismatches and (d) increased top-down trophic regulation (AR6 WG2 Table 3.15); however, the scale of impacts from changes in these mechanisms on ecosystem productivity in warming polar oceans remains unresolved and is hence assigned *low confidence*. (AR6 WG2 3.4.2.10)

Mueter et al. (2021b) reviewed modeling and observational studies of shifts in zooplankton composition and size structure in both the Pacific and Atlantic Arctic gateways, as well as western Greenland. Warm water advected into the Barents Sea, and reduced sea ice in Disko Bay, western Greenland, were both associated with increased abundance of a *Calanus* copepod that is smaller and less lipid rich than two Arctic congeners that it replaced; the result was less efficient energy transfer to upper trophic levels. However, there are few examples of upper trophic impacts except for the well-documented situation with walleye pollock in the Bering Sea (Mueter et al. 2021b).

Phenology (i.e., timing) mismatches have also been associated with a cascade of disruptions in food web dynamics. In the northern Bering Sea, distributions of fish and zooplankton changed significantly the year after the northern Bering had the lowest sea ice extent on record (Siddon et al. 2020). In 2018, sea ice did not form in the northern Bering Sea until March, and it disappeared in April. After this year of record low sea ice, changes recorded in the northern Bering that could affect ringed seals' prey included: a delayed phytoplankton bloom after a reduced availability of ice algae (Duffy-Anderson et al. 2019; Kikuchi et al. 2020; Siddon et al. 2020); low numbers of large, lipid-rich copepods and above average numbers of small, low-lipid copepods (Kimmel et al. 2018; Duffy-Anderson et al. 2019); greater numbers of walleye pollock and Pacific cod than seen before (Ianelli et al. 2017; Stevenson and Lauth 2019); an increase in biomass of juvenile sockeye salmon (Siddon et al. 2020); and a decrease in juvenile forage fish (capelin, Pacific herring) over the northern portion of the shelf (Duffy-Anderson et al. 2019; Siddon et al. 2020). This chain of events has elements of altered size spectra, shifts in trophic pathways, phenological mismatches, and increased top-down trophic regulation—in other words, all of the key mechanisms determining energy transfer between trophic levels that were identified in AR6 WG2 3.4.2.10 as being influenced by climate warming.

In summary, a large body of new information has been developed since the listing decision, about ecological processes and changes that have potential to impact ringed seals.

Okhotsk Ringed Seal

A review of ecosystem studies that examined biological resources in the Sea of Okhotsk conducted by Pacific Research Fisheries Center (TINRO-Center) provided biomass estimates for zooplankton, zoobenthos, fish, squid, marine mammals, and birds in the Sea of Okhotsk from surveys conducted from the 1980s to the 2000s (Shuntov et al. 2019). Although ringed seal numbers were not specifically reported, the number of pinnipeds in the Sea of Okhotsk has increased over the last 40 years due to the lack of large-scale harvesting of marine mammals in the last quarter of the 20th century. The overall conclusion was that the biological resources in the Sea of Okhotsk were in good or satisfactory status (Shuntov et al. 2019).

Baltic Ringed Seal

Meier et al. (2022) summarized and assessed the current knowledge of the effects of global warming on past, present, and future changes in climate of the Baltic Sea region. Select key messages from this assessment that most directly relate to past or present ringed seal habitat and ecosystem conditions are quoted below, including estimated levels of confidence (based on agreement and evidence) and whether the result was novel since the previous assessment (marked “NEW”):

> – ***Marine CO_2 system – alkalinity*.** During 1900–2015, a long-term trend in alkalinity was observed, with the largest increases in the Gulf of Bothnia, where it almost entirely canceled the pH decrease expected from rising atmospheric pCO_2. The smaller alkalinity increase in the southern Baltic Sea compensated ocean acidification by about 50%. Due to the high seasonal variability in pH, large inter-annual variability in productivity, and the identified alkalinity trend, no acidification was measurable in the central and northern Baltic Sea (medium confidence; NEW).
>
> – ***Fish*.** Changes in temperature, salinity, and species interactions can affect the stocks of cod, sprat, and herring. However, the dominant driver is the fishery. For coastal fish, the distribution of pikeperch expanded northwards along the coasts of the Bothnian Sea, apparently due to the warming waters. For many coastal fish species, eutrophication is, however, equally or more important than climate change (low confidence; NEW).

- ***Marine food webs.*** Significant alterations in food web structure and functioning such as the shift from early diatom to later dinoflagellate dominated blooms have been observed. However, the causes of these changes are unknown (low confidence). (Meier et al. 2022)

Understanding ecosystem level impacts of ocean acidification (OA) to Baltic Sea species has been difficult. Most studies select a single species and assess single-factor stressors, therefore it is challenging to project how multiple stressors may impact multiple species and trophic levels. There have not been any studies directly investigating the impacts of OA to ringed seals in the Baltic Sea. Havenhand (2012) suggests that the ecosystem response to OA will depend on species interactions, plasticity and the capacity for genetic change to multiple abiotic factors, not solely to OA.

Ladoga Ringed Seal

Gbagir and Colpaert (2020) examined the trophic state of Lake Ladoga during 1997–2019 using chlorophyll-a levels observed by satellite. Their results showed that seasonal chlorophyll-a concentration varied spatially within the lake: the shallow southern regions had higher concentrations and did not show any changes over time while the deeper regions in the north were much improved. Overall, seasonal chlorophyll-a concentration gradually decreased during 1997–2019, indicating a moderate improvement in the lake's trophic state. The authors suggested, however, that climate warming and ice reduction could contribute to eutrophication of the lake, potentially offsetting the gains made through reduced nutrient load (Gbagir and Colpaert 2020).

2.3.7.2.2. Expected future changes in biological components of habitat and ecosystems

Projecting the future states of ringed seals' biological habitat remains as difficult as it was when the seals were listed. Even primary production, the foundation of the food web, is difficult to foresee under intensifying climate change, despite many examples of observed changes in the altered 'biogeochemical landscape' of the Arctic (Ardyna and Arrigo 2020). The future states of consumers and higher trophic levels that constitute ringed seals' prey are even more difficult to project. Here, we highlight a few emergent ecosystem trends that could be impactful to ringed seals if the trends continue into the future.

Arctic Ringed Seal

Future primary production—As discussed above, higher phytoplankton biomass in the Arctic Ocean in recent years is likely being sustained by a larger supply of nutrients to the system from increased advection of water from the Atlantic and Pacific Oceans, suggesting that the Arctic Ocean could become more productive for higher trophic-level organisms, including ringed seals (Lewis et al. 2020). Constable et al. (2022) came to similar conclusions, but with a caveat about the potential for nutrient limitation:

> In the future Arctic Ocean, higher light availability in response to further sea ice decline and reduced deep mixing is projected to generally increase primary productivity (medium confidence), leading to an increase in phytoplankton biomass from 2000 to 2100 by ~20% for SSP1-2.6 and ~30–40% for SSP5-8.5 (Chapter 3) (Kwiatkowski et al. 2020). However, productivity may increase less than predicted and eventually even decrease once nutrient limitation outweighs the benefits of higher light availability (low confidence) (Randelhoff et al. 2020; Seifert et al. 2020). (AR6 WG2 CCP6.2.1.2)

However, increased primary production would likely also coincide with a shift to smaller phytoplankton and zooplankton sizes, which can alter food web dynamics, as discussed below.

Future borealization—The changing distributions of fish species across the Arctic could have significant effects on ringed seal energy intake. Arctic cod is the most abundant forage fish in the Arctic Ocean (Geoffroy et al. 2023) and is a key node in the energy flow to top trophic levels in much of the Arctic (Hop and Gjøsæter 2013). A recent, extensive review of Arctic cod habitats, distribution, ecology, and physiology predicted an overall decrease in suitable habitat through 2050 due to climate change, and an associated decline in Arctic cod biomass, particularly in areas characterized by advection of warmer Atlantic and Pacific waters (Geoffroy et al. 2023). Similarly, Alabia et al. (2023) suggested that the expansion of larger generalist predators to the Arctic shelves could reduce the biomass of typically smaller and less fecund Arctic species which, presumably, would include Arctic cod.

Future food web dynamics—Warming climate conditions are predicted to cause a shift to smaller average body sizes within species of ectotherms; changes in size composition can occur across communities from phytoplankton to fish (Daufresne et al. 2009; Li et al. 2009). A transition to smaller phytoplankton and zooplankton sizes can directly affect trophic transfer efficiencies and the number of trophic levels in marine ecosystems, which could lead to cascading effects on food webs and potentially serious impacts on upper trophic levels. For example, smaller, lower lipid content zooplankton in warm conditions can lead to longer, less efficient chains from phytoplankton to upper trophic species (Mueter et al. 2021b). The smaller size structures of phytoplankton and zooplankton communities implies that less energy will be available through the food web and ultimately for upper trophic level species, such as fish and marine mammals (Barnes et al. 2010; Fossheim et al. 2015; Mueter et al. 2021b). Mueter et al. (2021b) concluded,

> In summary, changes in the size structure of lower trophic levels have been documented in both Arctic gateways and are supported by laboratory studies and

> models. These changes can have cascading effects on upper trophic levels including fishes. . . and seabirds. The observed trends suggest future changes in plankton size composition will further alter the community composition at higher trophic levels with potentially negative impacts on production. However, current projections are highly uncertain due to model limitations.

The changing distributions of fish species across the Arctic could have significant effects on ringed seal energy intake. Arctic cod is the most abundant forage fish in the Arctic Ocean (Geoffroy et al. 2023) and is a key node in the energy flow to top trophic levels in much of the Arctic (Hop and Gjøsæter 2013). A recent, extensive review of Arctic cod habitats, distribution, ecology, and physiology to assess how climate change will affect this key species through 2050 predicted an overall decrease in suitable habitat, and associated decline in Arctic cod biomass, particularly in areas characterized by advection of warmer Atlantic and Pacific waters (Geoffroy et al. 2023). Similarly, Alabia et al. (2023) suggested that the expansion of larger generalist predators to the Arctic shelves could reduce the biomass of typically smaller and less fecund Arctic species which, presumably, would include Arctic cod.

Arctic cod and capelin are energetically valuable prey because they contain large amounts of lipids (Hop and Gjøsæter 2013; Florko et al. 2021a). Capelin has also been one of the most abundant species in the northern Bering and Chukchi (De Robertis et al. 2017); however, in warm years, the abundance of capelin in the Bering Sea was much lower compared to cold years (Andrews et al. 2016; Duffy-Anderson et al. 2019; Siddon et al. 2020; Yasumiishi et al. 2020). The northward movement of walleye pollock during warm years, potentially replacing Arctic cod and capelin as a major prey item, indicates that the quality of prey available to ringed seals could be reduced under these conditions (Copeman et al. 2017).

Multiple climate change scenarios have been used in models to examine future ecological responses to climate change in the Arctic. In one example, the prey base of ringed seals in Hudson Bay was modeled using low and high greenhouse gas emission scenarios from 1950–2100 (Florko et al. 2021a). In a high-emission scenario, Arctic cod, which are the most energetically valuable prey species, are expected to decline in abundance by 50%, while smaller forage fish (capelin, sand lance) will increase in biomass but become more concentrated in southern and coastal areas, which could lead to more competition among ringed seals if prey are not as widely distributed (Florko et al. 2021a). These changes in abundance and distributions of ringed seal prey species will have direct and indirect effects on foraging behavior and body condition of ringed seals. Multiple climate change projections from 2026–2100 were used to model effects on marine biodiversity in the eastern Bering and Chukchi Seas (Alabia et al. 2020). Overall the models predicted poleward increases in boreal species, which provides potential for larger, longer-lived taxa to expand north. Boreal species expected to move north are more phylogenetically and functionally similar compared to current Arctic species, which would result in homogenization of species in the Arctic (Vincent et al. 2011). Based on evidence from other Arctic regions, these changes are predicted to increase the vulnerability of Arctic ecosystems to climate and environmental perturbations (Alabia et al. 2020).

Future ocean acidification—Modeled OA levels must typically incorporate a variety of projected future physical and chemical changes to the Arctic (Mueter et al. 2021b). Processes included can range from projected snowfall, rain, terrestrial river runoff, organic matter respiration, sea ice coverage, wind, storm events, upwelling, etc., each of which can provide some avenue to increase atmospheric CO_2 absorption in localized regions of the Arctic (Fransson et al. 2017; Drinkwater et al. 2021; Mueter et al. 2021b). Model predictions suggest pH levels will decrease by 0.1–0.4 units by 2100 in surface levels of the Arctic (Drinkwater et al. 2021). These predictions will likely have an impact on the food web dynamics for a variety of species and age classes as previously discussed, however it is challenging to specifically predict exactly how future OA will impact ringed seals.

The Fourth National Climate Assessment, Chapter 26, Alaska concluded,

> More recent research suggests that corrosive conditions have been expanding deeper into the Arctic Basin over the last several decades [(Qi et al. 2017)]. The annual average aragonite saturation state (a metric used to assess ocean acidification) for the Beaufort Sea surface waters likely crossed the saturation horizon near 2001) [(Mathis et al. 2015)], meaning that the Beaufort Sea is undersaturated (lacking sufficient concentrations of aragonite) most of the year—a condition that limits the ability of many marine species to form shells or skeletons (Figure 26.3). Under the higher scenario (RCP8.5), the Chukchi Sea is projected to first cross this threshold around 2030 and then remain under the threshold after the early 2040s, and the Bering Sea will likely cross and remain under the threshold around 2065 (Figure 26.3) [(Mathis et al. 2015)]. (Markon et al. 2018)

Okhotsk Ringed Seal

Our review did not identify any new information about expected future changes in the biological components of the habitat or ecosystem of Okhotsk ringed seals that became available since the time of listing. However, the effects of a warming climate in the Sea of Okhotsk are likely to be similar to changes that have been predicted to occur in the Bering Sea, such as shifts in chlorophyll-a concentrations as sea ice decreases and changes in the abundance and distribution of ringed seal prey species.

Baltic Ringed Seal

Meier et al. (2022) summarized and assessed the current knowledge of the effects of global warming on past, present, and future changes in climate of the Baltic Sea region. Select key messages from this assessment that most directly relate to future ringed seal habitat and ecosystem conditions are quoted below, including estimated levels of confidence (based on agreement and evidence) and whether the result was novel since the previous assessment (marked "NEW"):

> – ***Marine CO_2 system.*** Due to anthropogenic emissions, atmospheric pCO_2 and, consequently, also the mean pCO_2 of Baltic surface seawater will rise, which has the potential to lower pH (high confidence). However, the magnitude of the pH change also depends on alkalinity trends, which are highly uncertain (low confidence). Hence, projections for the Baltic Sea are different from the global ocean.
>
> – ***Zooplankton.*** Experimental studies suggested improved conditions for micro-zooplankton due to warming but negative effects on some larger zooplankton species (low confidence; NEW).
>
> – ***Fish.*** Projected changes in temperature and salinity will affect the stocks of cod, sprat, and herring. However, nutrient loads and especially fishing mortality are also important drivers. Although multi-driver modeling studies have been performed, the impact of climate change is unknown (low confidence; NEW).
>
> – ***Marine mammals.*** Mild winters are known to negatively affect Baltic ringed seals (*Phoca hispida botnica*) because, without their sea ice lair, the pups are more vulnerable to weather and predators, and it has been projected that the growth rates of ringed seal populations will decline in the next 90 years. Also, for grey seals, it has been suggested that reduced ice cover in combination with (partly climate-driven) changes in the food web, may affect their body condition and birth rate (low confidence).
>
> – ***Marine food webs.*** Significant alterations in food web structure and functioning can be expected, since species distributions and abundances are expected to change with warming seawater. The consequences are difficult to project, as research into the long-term dynamics of food webs is still scarce (low confidence). (Meier et al. 2022)

Ladoga Ringed Seal

Our review did not identify any new information about expected future changes in the biological components of the habitat or ecosystem of Ladoga ringed seals that became available since the time of listing.

2.3.8. Utilization for commercial, recreational, scientific, or educational purposes

2.3.8.1. Commercial, subsistence, and illegal harvest

Arctic Ringed Seal

Our review identified updated information on harvest of ringed seals in a few parts of the Arctic:

- Alaska – Using household survey data collected between 1992 and 2014 for 41 of the 55 communities that regularly hunt ice-associated seals for subsistence in Alaska, Nelson et al. (2019) estimated that the statewide removal of ringed seals by subsistence hunters (including both harvested seals and seals struck and lost) in 2015 was 6,454 seals, and they found that trends in the annual subsistence removal of ice seals were stable or decreasing. In the Yukon-Kuskokwim Delta region, household survey data for three communities indicates declining trends in subsistence harvest of ringed seals from 1988 to 2018, likely due to changing sea ice conditions altering access to seals by hunters, among other factors (Olnes et al. 2022).
- Greenland – The reported annual catch of ringed seals in Greenland averaged 50,853 (range: 40,633–64,930) during 2013–2020, as compared to an annual average of 71,575 (range: 60,656–87,782) during 1994–2012 (NAMMCO 2023).
- Svalbard and Norway – During 2013–2022, the reported annual catch of ringed seals in Svalbard (the majority of the reported annual catch) and on the Norwegian coast combined averaged 57 (range: 40–73), as compared to an annual average of 48 (range: 31–80) during 2003–2012 (NAMMCO 2023).

Okhotsk Ringed Seal

As discussed in the 2010 Status Review, large-scale ship-based commercial harvests of ringed seals ended in the Sea of Okhotsk in 1994. Trukhanova et al. (2017) described the commercial harvest of ice-associated seals in the Sea of Okhotsk between 1972 and 1994, including harvest rates, species composition (which in most years was predominantly represented by ringed seals), and related parameters, based on unpublished data recorded in sealing log books of harvest vessels during this period. They reported that the annual total allowable catch set by the Russian Federation for ringed seals in the Sea of Okhotsk was reduced to 2,100–2,200 in 2009–2012, after which this species was shifted to “a less strict system used for less commercially valuable species with low harvest interest.” The annual harvest level in the Sea of Okhotsk in recent years is believed to be 1,000–2,000 ringed seals (Zagrebelny et al. 2020).

Baltic Ringed Seal

During 2011–2014, a small number of ringed seals (8–12) were reported taken by hunters annually in the northern Baltic Sea, mainly in Bothnian Bay (HELCOM 2017). As a result of conflicts with human fishing activities, hunting of ringed seals has more recently increased in the Bothnian Bay management unit (HELCOM 2018). Annual quotas for ringed seals in the last few years have been set in Sweden (protective hunt) at 420 seals and in Finland (quota-based regular hunt) at 375 seals (HELCOM 2023c). A total of 2,463 ringed seals were reported taken by Swedish and Finnish hunters during 2016–2021, with annual totals ranging from 176–337 seals during 2016–2018, and from 538–568 seals during 2019–2021 (HELCOM 2023d).

In Estonia, Halkka et al. (2017) noted that the grey seal hunting season introduced there in 2015 includes habitats where both ringed seals and grey seals are present, which in the case of inexperienced hunters has introduced the risk of ringed seals being shot should they be misidentified as grey seals.

Ladoga Ringed Seal

Hunting of Ladoga ringed seals had been prohibited since at least the 1980s (Kelly et al. 2010). According to Trukhanova et al. (2021), there has been continuing pressure from groups of fishers in the region, albeit unsuccessful thus far, to resume ringed seal harvest and allow protective culling of individual seals who feed on netted fish.

2.3.8.2. Scientific and educational utilization

Scientific research activities include capturing and handling ringed seals for tagging, measuring, and biological sampling. Ringed seals have also been occasionally placed in captive facilities (e.g., Mizuguchi et al. 2015; Rosen et al. 2021). For all the ringed seal subspecies the available information continues to support the conclusion in the 2010 Status Review that the total numbers of ringed seals used for scientific or educational purposes are small.

2.3.9. Disease, parasites, or predation

Arctic Ringed Seal

Kelly et al. (2010) provided a comprehensive description of diseases, parasites, and predation in ringed seals. Since 2010, several studies have added information about some of these factors in ringed seals.

Protozoa—Ringed seals from the Canadian Arctic have been screened for the protozoan parasites, *Toxoplasma gondii*, *Sarcocystis* spp., and *Neospora* spp., using serology and polymerase chain reaction (PCR) to look for antibodies and DNA of these protozoa. Serology was used to test for exposure to *T. gondii* in ringed seals from communities across northern and eastern Canada, and 10.2% (80/788) of ringed seals tested were seropositive (Simon et al. 2011). This seropositive rate in ringed seals from the Canadian Arctic was similar to prevalence rates of *T. gondii* in studies of ringed seals in Alaska (Dubey et al. 2003) and Svalbard (Jensen et al. 2010). *Toxoplasma gondii* DNA was detected by PCR in 26% (6/23) of ringed seals in one study (Reiling et al. 2019), but Simon et al. (2011) did not find *T. gondii* DNA in any tissues tested by PCR.

Reiling et al. (2019) also detected DNA from *Sarcocystis* spp. in 9% (2/23) of ringed seals; and they found *Neospora caninum*-like DNA in 26% (6/23) of ringed seals that were sampled from Hudson Bay. This is the first report of *Sarcocystis* spp. in ringed seals from Canada. Ringed seals from Alaska have previously tested seropositive for *N. caninum* antibodies (Dubey et al. 2003), but this is a new record of *N. caninum*-like antibodies in ringed seals from Canada (Reiling et al. 2019). Results from both studies suggest that consuming raw or undercooked seal meat may be a significant source of infection for Inuit in Canadian Arctic communities who harvest and often consume uncooked seal meat (Simon et al. 2011; Reiling et al. 2019).

A novel parasite, *Sarcocystis pinnipedi*, which is closely related to *S. canis*, caused epizootic disease in a colony of grey seals in Nova Scotia in 2012. Screening of apparently healthy, harvested Arctic pinnipeds found that 22% of ringed seals, collected from across their range, were infected with *S. pinnipedi* (Haman et al. 2015). *S. pinnipedi* appears to be enzootic in ringed seals and does not cause morbidity or mortality, but it caused liver failure and high mortality in grey seals in 2012 (Haman et al. 2015).

Bacteria—Ringed seals from Alaska were screened for antibodies to *Brucella* spp. in a large study that examined four phocid species (ringed, harbor, spotted, ribbon seals) and two otariid species (Steller sea lions, *Eumetopias jubatus* and Northern fur seals, *Callorhinus ursinus*). This study found that all four phocid species were seropositive for *Brucella* spp., and 14% (21/150) of ringed seals were seropositive (Nymo et al. 2018). Ringed seal juveniles had a higher probability of being seropositive than pups and adults, but the difference was not significant (Nymo et al. 2018). *Brucella* spp. antibodies have also been detected in ringed seals from Canada and Svalbard (Nielsen et al. 1996; Tryland et al. 1999), but pathological signs or symptoms have not been observed in seropositive ringed seals.

Viruses—Serological and molecular evidence has now shown that phocine distemper (PDV)-like viruses are widespread in pinnipeds in the North Pacific (Duignan et al. 2014; VanWormer et al. 2019). A large scale study examined pinniped species from across the North Pacific to look for exposure to and infection with PDV in samples collected from 2001–2016 (VanWormer et al. 2019). Serology and PCR methods were used to test for exposure or presence of PDV in phocids (ringed, bearded, ribbon, spotted seals) and otariids (Steller sea lions, northern fur seals, northern sea otters). Viral transmission across species and widespread PDV exposure and infection were documented in all species beginning in 2003. The authors also found evidence of PDV viral infection in apparently healthy pinnipeds, indicating that PDV may be able to persist in Arctic and sub-Arctic species in the North Pacific without causing widespread disease. Peaks of PDV exposure and infection in North Pacific pinnipeds occurred after years with reduced Arctic sea ice extent (VanWormer et al. 2019).

A novel gammaherpesvirus was detected in ringed seals from Canada (Bellehumeur et al. 2016). The herpesvirus was isolated and partially sequenced from 12.5% (2/16) of ringed seals tested as part of a disease surveillance program. The sequence of the herpesviruses in the two ringed seals was identical, and it was most similar to the sequence of phocid herpesvirus-2. The infected seals did not display signs of clinical disease, except both showed reduced body condition. This is the first report of herpesvirus in ringed seals from Canada (Bellehumeur et al. 2016).

Algal toxins—Two of the most harmful algal bloom (HAB) toxins are domoic acid and saxitoxin. Warming climate trends and increasing water temperatures have led to concerns that these HABs could expand north. A study tested 13 marine mammal species from Alaska for domoic acid and saxitoxin. Ringed seals from the Alaskan subsistence harvest were tested, and 17% of ringed seals were positive for domoic acid, while 14% were positive for saxitoxin. This broad-scale study showed that HAB toxins are present throughout Alaskan waters and could affect marine mammal health in the Arctic environment (Lefebvre et al. 2016).

Helminths—Since the 2010 Status Review, several studies have found helminth parasites in ringed seals from the Bering and Chukchi Seas and Canada. Two new species were documented in the studies since 2010, and both new species were anisakid nematodes. *Pseudoterranova bulbosa* was found in one ringed seal from Hudson Bay, Canada (Karpiej et al. 2014), and *Pseudoterranova decipiens* complex helminths were found in ringed seals from the Bering and Chukchi Seas (Walden et al. 2020), and from Hudson Bay, Canada (Soltysiak et al. 2013). Since 2010, a variety of nematode, cestode, trematode, and acanthocephalan species were found in studies of ringed seals from the Bering and Chukchi Seas (Seymour et al. 2014a; Walden et al. 2020) and from Hudson Bay, Canada (Karpiej et al. 2014); all of these species had been documented in ringed seals previously (Kelly et al. 2010). None of the recent studies found high rates of infection or evidence of mortality due to helminth infection. Lesions caused by two species of anisakid nematodes were reported in ringed seals from Hudson Bay, Canada (Soltysiak et al. 2013). The lesions caused ulcerative gastritis in areas that were adjacent to the parasite, but the inflammation was limited to the mucosa and submucosa of the stomach, and no damage to the muscle was observed. Overall, the anisakid infection was moderate, and mortality was not observed (Soltysiak et al. 2013).

A literature review of the incidence of anisakid nematodes in fishes from across the world, from 1978 to 2015, found a 283-fold increase in abundance of Anisakis spp., but there was no change in abundance of *Pseudoterranova* spp. (Fiorenza et al. 2020). Although only two new helminth species have been documented in ringed seals since 2010, abundance of helminths in fish species across the world may be increasing.

Predation—Polar bears are a primary predator of ringed seals across their range, and in the Canadian Arctic, polar bears have been observed to kill 8–44% of the estimated annual ringed seal pup production (Hammill and Smith 1991). Pilfold et al. (2012) examined polar bear predation attempts on ringed seals in the Eastern Beaufort Sea; they compared age and sex composition of seals killed by polar bears in years of high and low pup productivity. The proportion of ringed seal pups killed was highest during years of high pup productivity. In years of low pup productivity, polar bears killed a higher proportion of older adult ringed seals (Pilfold et al. 2012). Pilfold et al. (2014) found that in the Canadian Beaufort Sea, observations of ringed seal pups killed by polar bears collected from April to mid-May were located farther offshore during years of high ringed seal reproduction (2007–2014) when compared to years of low ringed seal natality (2003–2006). Pup kills were found as frequently in pack ice as in fast ice in years of high ringed seal natality whereas they were predominantly located in fast ice in the years of low ringed seal natality (Pilfold et al. 2014).

Reimer et al. (2019a) created population models to address the same question of whether intraspecific prey switching by polar bears occurs during years of varying ringed seal productivity. Their models supported the results of Pilfold et al. (2012), finding that polar bears typically select for ringed seal pups, but in years with low pup productivity and availability, bears switch and select older seals (Reimer et al. 2019a). Changing to preying more often on older seals in years of low pup production does not appear to affect ringed seal population growth (Reimer et al. 2019a). Additionally, the polar bear population in the southern Beaufort Sea has declined, which would potentially lead to reduced predation pressure on ringed seals (Bromaghin et al. 2015; Reimer et al. 2019a).

Cherry et al. (2009) previously reported that the proportion of sampled polar bears that were in a physiological fasting state in the Beaufort Sea more than doubled between 1985–1986 and 2005–2006. Pilfold et al. (2015) compared polar bear predation events on ringed seals between these two periods using kill observations from Pilfold et al. (2012). Kill rates, calculated as the number of ringed seal kills observed per hour of survey effort, were similar between the two periods. However, the seals killed in the later period consisted of more pups and fewer juveniles than the earlier period, despite both periods being characterized as having low pup productivity. The unusually rough sea ice that formed in the Beaufort Sea during 2005–2006 may have limited polar bears' ability to access older ringed seal age classes (Pilfold et al. 2015).

Several studies since the 2010 Status Review have shown that polar bear predation on ringed seals can also vary with environmental conditions. In the Bering and Chukchi seas, Rode et al. (2021) found that ringed seal pups comprised a higher percentage of polar bear diet (compared to ringed seal non-pups and other prey species) during years with greater March–May sea ice cover. Similarly, polar bears consumed more ringed seals during years with heavier sea ice conditions and/or colder climate indices in the Eastern Beaufort Sea (Pilfold et al. 2015), Southern Beaufort Sea (McKinney et al. 2017), Viscount Melville Sound in the Canadian High Arctic (female bears only; Florko et al. 2021b), and East Greenland (McKinney et al. 2013). In contrast, polar bears consumed more ringed seals during years with lighter sea ice conditions in the Northern Beaufort Sea and Viscount Melville Sound (male bears only; Florko et al. 2021b), and in western Hudson Bay (adult female bears with dependent young; Sciullo et al. 2017). Long-term trends have also been documented: in East Greenland, polar bear consumption of ringed seals declined by 14%/decade over 1984–2011, with concurrent increases in consumption of hooded seals (*Cystophora cristata*) and/or harp seals (McKinney et al. 2013). In the Southern Beaufort Sea, no persistent trend in polar bear consumption of ringed seals was identified from 2004-2016 (Bourque et al. 2020), and the predator-prey relationship between polar bears and ringed seals appears to still be strong in the Beaufort Sea as a whole (Rode et al. 2023). Changes in sea ice and climate conditions may affect both the abundance and accessibility of ringed seals as prey items for polar bears, and patterns may differ between regions and between polar bear sex and age classes.

In Svalbard, movements of polar bears and ringed seals were tracked with satellite tags during years before and after a sudden decline in sea ice (Hamilton et al. 2017a). Linear mixed-effects models were used to examine polar bear and ringed seal associations with environmental features and areas to investigate changes in spatial overlap between the species before and after the sea ice decline. After the years of sea ice reduction, polar bears spent less time close to tidal glacier fronts in the summer and autumn, but ringed seals spent the same amount of time near glacial fronts in the summer both before and after the sea ice decline. Thus, there was a significant decrease in spatial overlap between these species during the summer in years following a decline in sea ice (Hamilton et al. 2017a). As the spatial overlap between these species decreases, the strength of their predator-prey relationship would also decline, suggesting that if sea ice in the area continues to decline, the impact of polar bear predation on ringed seals in Svalbard could be reduced (Hamilton et al. 2017a).

As described in the 2010 Status Review, Arctic foxes are also an important predator of Arctic ringed seals. Previously unpublished data on predator activity at ringed seal lairs on the landfast ice in Ledyard Bay and southern Kotzebue Sound during spring 1983 and 1984 were reported by Hauser et al. (2022). They found that the pup predation rate was considerably higher in Ledyard Bay than it was to the south in Kotzebue Sound, where all of the documented predation was by Arctic foxes (*Vulpes lagopus*). Although both polar bears (*Ursus maritimus*) and Arctic foxes preyed on ringed seal pups in lairs in Ledyard Bay, the pup predation rate there was higher for Arctic foxes than for polar bears.

Stable isotope analysis of Pacific walrus (*Odobenus rosmarus divergens*) tissues collected from Alaska and Russia found that walrus consume more higher trophic-level prey than has been indicated from stomach content analyses (Seymour et al. 2014b). This suggests that walrus may change to foraging on higher trophic level prey, including pinnipeds and seabirds, during stressful times when their usual prey of benthic invertebrates may not be available (Seymour et al. 2014b).

The presence of killer whales (*Orcinus orca*) in Arctic waters, including the Chukchi Sea and the eastern Canadian Arctic, has been documented with sighting and passive acoustic data in the past decade, and they are now regularly observed in the Arctic (Higdon and Ferguson 2009; Ferguson et al. 2010; Stafford et al. 2022a, 2022b). Killer whale numbers in Hudson Bay have increased exponentially since the mid-1900s, and they are seen in Hudson Bay every year now (Higdon and Ferguson 2009). Killer whales in Hudson Bay primarily prey on marine mammals, both cetaceans (e.g., bowhead whales, beluga whales, narwhals) and phocid seals (e.g., ringed, bearded, harp, hooded seals) (Ferguson et al. 2012). Interviews were conducted with Inuit hunters to develop baseline data on killer whale predation in Hudson Bay, and ringed seals were the most common seal species reported by hunters as being killer whale prey items (Ferguson et al. 2012). Ferguson et al. (2010) used models to estimate the effect of killer whale predation on marine mammals in Hudson Bay. For ringed seals, they estimated that killer whales would take less than 1% of the population of ringed seals in Hudson Bay, and would likely not affect the population growth of ringed seals in the area (Ferguson et al. 2010). In contrast, a recent study used quantitative fatty acid signature analysis to assess the diets of killer whales across the North Atlantic. In whales sampled from the eastern Canadian Arctic, they determined that ringed seals composed over 50% of the diet in about a quarter of the whales sampled (Remili et al. 2023). Thus, killer whale predation on ringed seals may be increasing in some parts of Canada.

Unusual mortality events—Since the listing, ringed seals in Alaska were part of two Unusual Mortality Events (UMEs), which are declared by NOAA Fisheries. The 2011 Arctic Pinniped UME was declared for ringed, bearded, spotted, and ribbon seals in Alaska (NMFS 2011, 2014). In July 2011, high numbers of sick and dead seals were found throughout the Arctic and Bering Strait regions of Alaska. The primary symptoms were skin lesions and ulcers, hair loss, inability to regrow their coat, delayed molting, lethargy, and labored breathing (NMFS 2011; Stimmelmayr 2012). After extensive testing for infectious disease agents and bio-toxins of tissues from the affected seals, no known or new infectious viral or bacterial agents, harmful algal toxins, or industrial pollutants were identified to explain the disease symptoms, and this UME was closed in 2016 (NMFS 2016a). In June 2018, large numbers of dead ringed, bearded, and spotted seals started stranding in the Bering and Chukchi Seas in Alaska, and the 2018–2022

Ice Seal UME was declared for those three species (NMFS 2022a). The cause of this UME is still unknown; samples are being tested for genetics, various pathogen exposure, and harmful algal bloom exposure, and results are pending (NMFS 2022a). Although neither UME is known to have caused major declines in ringed seals in Alaska, the 2011 UME was the first UME that involved subsistence species essential to coastal Alaskan communities (NMFS 2014), and then the occurrence of the second UME with ringed seals just seven years later suggest that conditions in ringed seal habitat in the Bering and Chukchi may be changing and affecting ringed seals in unknown ways (NMFS 2022b).

Baseline data—A couple of studies have provided new baseline data for ringed seals. Baseline data for hematology, serum chemistry, serology, bacterial microbial isolates, and parasites were collected from captive and rehabilitated ringed seals in Alaska; these data provide markers for normal health status and physiology of ringed seals (Goertz et al. 2019). Methods were developed to extract cortisol from blubber and fur of ringed seals to obtain baseline data on cortisol levels; and it was determined that cortisol levels in blubber have the potential to assess changes in chronic stress level (Anderson 2016). In the Canadian Arctic, ringed seals harvested in Hudson Bay showed increasing cortisol levels over 2003–2013, suggesting an increase in chronic stress (Ferguson et al. 2017). Cortisol levels were also measured in ringed seals harvested in Ulukhaktok, but sample sizes were too small to assess whether annual trends were present (Ogloff et al. 2022). In a study that showed that steroid hormones could be measured in mammalian whiskers, cortisol levels and stable isotope values were measured along the length of whiskers of ringed, spotted, and harbor seals from Alaska (Karpovich et al. 2019). In ringed seals, cortisol concentrations were highest near the root and declined moving closer to the tip, and no associations between stable isotope values and cortisol levels were found (Karpovich et al. 2019). Karpovich et al. (2020) developed and validated methods to extract cortisol and progesterone from the claws of adult ringed seals. Ringed seal claws grow continuously and have visibly discernible banding associated with annual growth (McLaren 1958; Benjaminsen 1973), and the methods developed in this study can be used to measure and assess progesterone and cortisol levels from annual bands along the length of the claw. This could provide the ability to examine the history of pregnancy status and changes in physiological stress from many years of a seal’s lifetime (Karpovich et al. 2020).

Okhotsk Ringed Seal

Our review did not identify any new information about disease, parasites, or predation of Okhotsk ringed seals that became available since the time of listing. However, the effects of a warming climate in the Sea of Okhotsk are likely to be similar to changes that have been observed in Arctic waters due to warming temperatures and declining sea ice. Changes in the abundance and distribution of pathogens, parasites, and predators of ringed seals are likely to occur in the Sea of Okhotsk, similar to recent results observed in the Arctic.

Baltic Ringed Seal

Bacteria—Serological analyses were used to screen Baltic ringed seals for antibodies to *Brucella* spp., and 16.7% (2/12) of the seals tested were seropositive (Sonne et al. 2018). This is the first serological study of *Brucella* spp. in Baltic ringed seals that has been published and provides evidence of exposure to *Brucella* spp. in Baltic ringed seals. Although sample size was small, the authors suggest that *Brucella* infections in the northern Baltic Sea should be considered important and monitored.

Helminths—Cestode helminth worms from Ladoga, Saimaa, and Baltic ringed seals were analyzed and identified by DNA sequencing of the cytochrome *c* oxidase 1 barcoding gene (Nyman et al. 2021). Baltic seals are a marine species that live in the Baltic Sea, and the only cestode species found in Baltic seals was *Schistocephalus solidus*. Sequence results showed a deep and well-supported divergence within the *Schistocephalus* clade, suggesting that the currently designated *S. solidus* species may include more than one species (Nyman et al. 2021).

Ladoga Ringed Seal

Helminths—Cestode helminth worms from Ladoga, Saimaa, and Baltic seals were analyzed and identified by DNA sequencing of the cytochrome *c* oxidase 1 barcoding gene (Nyman et al. 2021). Ladoga and Saimaa seals both live in freshwater lakes, and *Ligula intestinalis* was the only cestode species found in them. *Ligula intestinalis* has not been previously reported in seals. The only cestode found in Baltic seals was a different species. The different cestode species identified in marine and landlocked seals in this species are likely related to the different habitat requirements and abundances of the intermediate hosts of each cestode (Nyman et al. 2021).

2.3.10. Changes to regulatory mechanisms

Most key regulatory mechanisms identified in our review as potentially relating directly or indirectly to the conservation of Arctic, Okhotsk, Baltic, and Ladoga ringed seals have remained the same since their listing and are detailed in the 2010 Status Review and listing rule. Updates to that information are summarized below.

2.3.10.1. International regulatory mechanisms

Regulatory mechanisms to limit GHG emissions

In the listing rule, NMFS concluded that existing regulatory mechanisms “do not effectively regulate GHG emissions, which are contributing to global climate change and associated modifications to ringed seal habitat.” Existing regulatory mechanisms addressing GHG emissions include international conventions and agreements, and national laws and regulations.

Because the trajectory of climate change and associated modifications to ringed seal habitat are ultimately linked to global GHG emission rates, we focused our review on existing international mechanisms aimed at addressing global climate change.

The Kyoto Protocol, which was adopted under the United Nations Framework Convention on Climate Change (UNFCCC) in 1997, committed participating industrialized country parties to reducing their GHG emissions during the first commitment period 2008–2012 by an average of five percent against 1990 levels. The United States did not ratify the Protocol and Canada withdrew from the Protocol in 2011. According to IPCC (2022b), "Most studies have concluded that Kyoto did cause emissions reductions." Some of the parties to the Kyoto Protocol, including the European Union, participated in a second commitment period under the Doha Amendment, which committed the parties to reducing their GHG emissions by at least 18 percent below 1990 levels during the period 2013–2020 (UNFCCC 2020).

The Paris Agreement, adopted in 2015 under the UNFCCC, aims to hold global average temperature rise to well below 2 °C above pre-industrial levels and pursue efforts to limit it to 1.5 °C (UNFCCC 2015). The Agreement entered into force in 2016, and has been ratified or otherwise adopted by more than 190 parties. Central to this agreement are procedural requirements that the parties pledge NDCs toward meeting the global temperature goal of the Agreement, with more ambitious targets pledged in successive updated or revised NDCs at least every five years, and that they periodically report on progress in implementing NDCs. Although some progress has been made by parties to the Paris Agreement toward achieving their NDCs for 2030, recent analyses show that those NDCs are highly insufficient for projected global GHG emissions to be on a pathway to meet the goal of the Paris Agreement, even assuming they are fully implemented, and countries are collectively far behind in implementing policies and actions to meet those highly insufficient NDCs (IPCC 2022b; UNEP 2022b).

Agreement to Prevent Unregulated High Sea Fisheries in the Central Arctic Ocean

No commercial fishing occurs in the high seas portion of the Central Arctic Ocean at present, but with declining sea ice in the summer, commercial fishing may become possible in the future. With the aim of managing potential fishing there, the Agreement to Prevent Unregulated High Sea Fisheries in the Central Arctic Ocean was signed by nine countries and the European Union in 2018 and entered into force for the next 16 years in 2021 (Balton 2021). The Agreement provides a framework for establishing a joint research and monitoring program and to prevent unregulated fishing until adequate scientific information is available to inform conservation and management measures.

The Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention)

As described in the 2010 Status Review, countries bordering the Baltic Sea and the European Union are current parties to the Helsinki Convention of 1992, which is aimed at controlling and preventing pollution affecting the Baltic Sea area, and commits the parties to take measures on conserving habitat and biological diversity and for the sustainable use of marine resources. The contracting parties are also members of the Baltic Marine Environment Protection Commission (also known as HELCOM), the governing body of the Helsinki Convention, which adopts recommendations related to the protection of the Baltic Sea and sustainable maritime activities. Parties to the convention are expected to implement HELCOM recommendations through national legislation and environmental programs.

In 2007, HELCOM adopted the Baltic Sea Action Plan (BSAP), which aimed to reduce pollution and eutrophication in the Baltic Sea and to restore and conserve natural resources through an ecosystem-based program of measures and actions (HELCOM 2007). While the overall goal of this plan to reach good environmental status of the Baltic Sea by 2021 was not reached, its implementation contributed to a number of environmental improvements, such as a reduction in nutrient inputs to the sea and a decrease in maritime incidents and spills (HELCOM 2021a). HELCOM adopted an updated BSAP in 2021 that addresses emerging issues in addition to existing commitments from the 2007 BSAP (HELCOM 2021b). As with other plans and recommendations adopted by HELCOM, effectiveness of the 2021 BSAP will depend on follow-up actions by all member countries.

HELCOM established a network of coastal and marine Baltic Sea protected areas (HELCOM marine protected areas; formerly known as Baltic Sea protected areas) in member countries to protect valuable marine and coastal habitats. As of December 2022, there were 178 HELCOM marine protected areas, covering approximately 13.2% of the Baltic Sea, some of which include Baltic ringed seal habitat (HELCOM 2023c). A number of these HELCOM protected areas are also designated as Natura 2000 sites, an ecological network of protected areas for selected habitats and species within the European Union, or Emerald Network sites (an extension of Natura 2000 to include non-member countries). However, HELCOM (2021a) reported that management of existing Baltic Sea marine protected areas and management effectiveness have been identified as issues where significant progress is needed.

As noted in the 2010 Status Review, in 2006 HELCOM adopted Recommendation 27/28-2, which among other actions, calls for the development and implementation of national management plans for Baltic seals. The government of Estonia is revising its management plan for grey and ringed seals every 5 years, and as of 2020, Sweden’s new draft management plan for ringed seals was in review, and update of Finland's seal management plan was in preparation, with the aim of finalizing and implementing the plans in 2023 (HELCOM 2023c).

Other international agreements on contaminants

The Minamata Convention on Mercury (2013), a new global treaty aimed at controlling, reducing, and eliminating anthropogenic emissions and releases of mercury, entered into force in 2017, and has been joined by 146 parties (145 countries and the European Union) as of August 2023. In 2022, the parties agreed to begin the first effectiveness evaluation of this Convention (UNEP 2022b).

As discussed in the 2010 Status Review, the International Convention for the Prevention of Pollution from Ships 1973/78 (MARPOL), which is administered by the International Maritime Organization, is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes. As a result of steps taken by HELCOM countries, the International Maritime Organization amended Annex IV to MARPOL to designate the Baltic Sea as a special area where special mandatory methods for the prevention of sea pollution by sewage from passenger ships came into effect beginning in 2019 (HELCOM 2018). In addition, a nitrogen oxide emission control area for ships built in or after 2021 and operating in the Baltic Sea was adopted by the International Maritime Organization under Annex VI to MARPOL, as proposed by HELCOM countries (HELCOM 2018).

Regulation of the European Parliament and the Council of the European Union on trade in seal products

As described in the 2010 Status Review, a European Union regulation was adopted in 2009 that prohibited the placing of seal products on the European Union market with limited exceptions that included seal products derived from subsistence harvest by Indigenous communities. As a result of the outcome of challenges to the regulation brought before the World Trade Organization, the regulation was amended in 2015 (Regulation 2015/1775). The amended regulation also generally prohibits the placing of seal products on the European Union market. Exceptions to this ban apply for seal products resulting from Indigenous hunts that meet several conditions, and seal products for the personal use of travelers to the European Union. An implementing regulation of the European Union (Regulation 2015/1850) sets out detailed rules for those seal products that can still be placed on the European Union market and for the personal use of travelers.

2.3.10.2. National domestic regulatory mechanisms

Canada

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the status of the Arctic ringed seal in Canada as "Special Concern" in November 2019 on the basis of a projected decline in the Canadian population due to loss of suitable sea ice habitat; it was previously assessed by COSEWIC as "Not at Risk" in 1989 (COSEWIC 2019). In response to the recent assessment, an extended consultation process was announced in December 2020 to inform the government's decision on whether to add the species to the List of Wildlife Species at Risk (Schedule 1) under Canada's Species at Risk Act as "Special Concern" (Government of Canada 2023). For species listed as "Special Concern" under the Species at Risk Act, there is a provision for the preparation of a management plan, but they do not receive the full protections afforded to species listed under the Act as being threatened or endangered (Favaro et al. 2014).

Russian Federation

The Russian Federation government previously approved total allowable catch quotas for ringed seals by geographical region (e.g., Trukhanova et al. 2017). However, since the 2010 Status Review and listing rule, ringed seal harvest has been set under a "less strict system used for less commercially valuable species with low harvest interest" (Trukhanova et al. 2017), and can be easily corrected during the harvest year (V. Burkanov, Kamchatka Branch of the Pacific Institute of Geography, pers. comm., 16 September 2021).

The Ladoga ringed seal, as well as the Baltic ringed seal, are listed in the recently updated Red Data Book of the Russian Federation as rarity status "1" ("Endangered"), threat of extinction status "CR" ("Critically Endangered, and conservation priority "I", for which immediate adoption of comprehensive measures is required, including the development and implementation of a conservation strategy (Ministry of Natural Resources and Ecology of the Russian Federation 2020). Although Trukhanova et al. (2021) reported evidence suggesting a possible decrease in bycatch of Ladoga ringed seals between 2011 and 2019, they concluded that "the bycatch rate is still sufficiently high to remain a threat to the population, and the seal-fisheries requires further mitigation." In December 2017, the Ladoga Skerries National Park was created in northern Lake Ladoga by Decree of the Government of the Russian Federation (Osipov 2023). Osipov (2023) reported that "The fact is that the park exists only on paper, it has no . . . staff … and officially belongs to the Kivach Strict Nature Reserve, which is located 250 km from Ladoga to the east."

2.3.11. Contaminants

Arctic Ringed Seal

Heavy metals—Mercury (Hg) concentrations were measured in ringed seals from Greenland as part of a study that examined mercury levels in phocid species from the northern and southern hemispheres. Ringed and bearded seals had the lowest Hg concentrations out of the five groups of phocids examined from the northern hemisphere (Aubail et al. 2011).

Total mercury (THg) and carbon ($\delta^{13}C$) and nitrogen ($\delta^{13}N$) stable isotopes were measured from ringed seals and polar bears from Hudson Bay. THg and $\delta^{13}C$ both declined in ringed seals, which indicates that ringed seals have likely changed foraging habits to use more pelagic or offshore prey (Houde et al. 2020; Yurkowski et al. 2020). However, $\delta^{13}C$ did not change in polar bears during that time period, which suggests they have not changed their foraging habits. Niche size for each species was estimated also, and niche size significantly decreased for polar bears but did not decrease for ringed seals (Yurkowski et al. 2020). These findings suggest that ringed seals and polar bears are responding differently to the changing environment, and thus, that their predator-prey relationship in western Hudson Bay might be weakening (Yurkowski et al. 2020).

Overall, ringed seals in the Canadian Arctic showed limited declines in Hg concentrations over 45 years of sampling (Houde et al. 2020). Another study found that, although ringed seals were in a lower risk category compared to other Arctic species, the overall risk of Hg exposure and toxicity in ringed seals in the Arctic has increased since the 2000s (Pinzone et al. 2019).

Organochlorine pollutants (OCs)—Temporal trends of a suite of persistent organic pollutants (POPs) were measured in ringed seals from the Canadian Arctic (Vorkamp et al. 2011, 2012; Houde et al. 2017, 2019; Addison et al. 2020). Overall, most POPs that were measured showed a significant general decline in ringed seals, which suggests that regulations to ban and limit their production have led to long-term reductions in POPs in ringed seals (Houde et al. 2019). Ringed seals from the eastern and southern Canadian Arctic showed declining trends in polybrominated diphenyl ethers (PBDEs) after 2008 (Houde et al. 2017, 2019). However, the overall decline in POPs was not consistent throughout the Canadian Arctic. In the western and northern Canadian Arctic, PBDE concentrations increased in both male and female ringed seals through 2010, but appeared to level off or just slowly increase after 2010 (Houde et al. 2017, 2019; Addison et al. 2020).

A study of ringed seals from the Canadian Arctic indicated that levels of PCBs, PBDE, and OCPs that were transferred from mother to fetus were very low. The average percent transferred to the fetus was less than 0.02% for each of the compounds (Brown et al. 2016).

Concentrations of polychlorinated biphenyls (PCBs) in juvenile ringed seals and PBDE levels in adult seals from east Greenland also decreased through 2008 (Vorkamp et al. 2011). However, PCB levels in seals from east Greenland were measured at a relatively high level from 1986–2008; and some of these cases probably exceeded the tolerable daily intake rate for seal blubber as traditional Arctic food (Vorkamp et al. 2011). Ringed seals from east Greenland also showed a significant increase in hexabromocyclododecane (HBCD) levels between 1986 and 2010 (Vorkamp et al. 2012). POPs were measured in ringed seals from west Greenland, as well, and all of the POPs examined decreased from the 1990s through 2010 (Riget et al. 2013; Law 2014).

In the early 2000s, many PBDEs were banned or phased out of production, and the different trends in POP and PBDE concentrations in ringed seals throughout the Canadian Arctic and Greenland indicate that the processes and dynamics of transporting POPs to the Arctic are complex and affect ringed seals throughout the Arctic in different ways (Brown et al. 2018; Houde et al. 2019; Addison et al. 2020). The rapid changes in the environment likely also affect how POPs are spreading in the Arctic. POP levels in seals from west Greenland were examined in relation to the number of days of sea-ice cover, and years with more sea-ice days correlated with relatively lower PCB levels in seals (Riget et al. 2013). The differences in PCB levels may be related to differences in prey availability in years of different sea-ice cover. The finding that years with more sea-ice were related to relatively lower PCB levels in seals is important to consider with the current warming conditions in the Arctic (Riget et al. 2013).

PCB and fatty acid profiles of ringed seals from a bay in Labrador that was contaminated by a PCB spill were compared with ringed seals from uncontaminated waters (Brown et al. 2015). Seals from the contaminated waters had higher PCB levels, and fatty acid profiles indicated that the difference in PCB levels was due to different habitat use, rather than differences in prey types. Prey items in the two areas were similar, but prey in the contaminated bay had higher levels of more heavily chlorinated congeners (Brown et al. 2015). Satellite tracking of seals also indicated that seals around the contaminated bay had a reduced home range and core area that were concentrated around the bay (Brown et al. 2014b).

Ringed seals from four areas of the Russian Arctic (White Sea, Barents Sea, Kara Sea, Chukchi Sea) were analyzed for several POPs. Levels of DDT and PCBs in these seals were higher compared to seals from other Arctic regions, including Svalbard, Alaska, the Canadian Arctic, and Greenland. However, PBDE concentrations in seals from the Chukchi Sea were 30–50 times lower than in seals from the other Russian locations (Savinov et al. 2011). POPs were also measured in subsistence species from coastal Chukotka; and POP levels in ringed seals from Chukotka were lower than levels found in ringed seals from Alaska (Quakenbush et al. 2016; Dudarev et al. 2019).

Perflourinated contaminants (PFCs)—Perfluorinated alkylated substances (PFASs) were examined in ringed seals from east and west Greenland and from Svalbard, and perfluorooctane sulfonate (PFOS) was the most dominant compound found in all locations (Riget et al. 2013; Routti et al. 2016). In the Greenland seals, levels of PFOS increased until 2006, but rapidly decreased after that (Riget et al. 2013); and in the seals from Svalbard, PFOS concentrations declined from 1990–2010 (Routti et al. 2016). Another study found that PFOS concentrations in ringed seals from west Greenland and the north Atlantic stayed level, but long-chain perfluorinated carboxylic acids (PFCAs) increased from 1984 to 2009 (Rotander et al. 2012; Law 2014). The largest yearly increases in PFCA levels occurred during the most recent years of testing, which indicates that these compounds are still increasing in the Arctic by some mechanism (Rotander et al. 2012).

Other contaminants—In 2012, a ringed seal and two spotted seals were harvested in Alaska with visible signs of oil fouling. The oiled seals had higher polycyclic aromatic hydrocarbon (PAH) concentrations in tissues compared to unoiled seals, but in bile analyses, the levels of PAH metabolites in the oiled seals were lower than levels measured in unoiled seals (Stimmelmayr et al. 2018). These seals provided the first report of baseline data for tissue and bile PAH concentrations and pathologic findings of oiled seals from the U.S. Arctic.

Okhotsk Ringed Seal

Our review did not identify any new information about contaminants in Okhotsk ringed seals that became available since the time of listing. The effects of a warming climate in the Sea of Okhotsk are likely to be similar to effects that have occurred in Arctic waters due to warming temperatures and declining sea ice. In the Arctic, however, overall contaminants in ringed seals have declined in the past decades. Declines in contaminant levels in ringed seals are closely related to policies that have banned or restricted the use of many contaminants, so it is difficult to assess if changes in contaminant levels in Okhotsk seals would be comparable to Arctic ringed seals.

Baltic Ringed Seal

***Heavy metals*—**Mean concentrations of total mercury measured in Baltic ringed seals sampled in 2018-2019 were five times lower than in Baltic ringed seals that were sampled in 1995-1996, and lower than in Baltic grey and harbor seals (Boyi et al. 2022). Total mercury concentrations seem to be declining in Baltic ringed seals, but it is still a major contaminant of concern with a history of high levels in Baltic ringed seals and other biota in the region.

Organochlorine pollutants (OCs)—A study compared POPs and hormone levels in ringed seals from a polluted area of the Baltic Sea with seals from a less polluted area of Svalbard. They found that levels of thyroid hormones that could disrupt endocrine functions were associated with higher POP concentrations, and seals from the polluted Baltic Sea had higher levels of POPs than seals from the less polluted area (Routti et al. 2010). Another study of Baltic ringed seals found that temporal trends and concentrations of POPs examined declined between 1974 and 2015 (Bjurlid et al. 2018). Concentrations of POPs in Baltic ringed seals that were sampled in 2018-2019 showed an overall decline compared to levels that were recorded in previous decades (Boyi et al. 2022).

Other—In a recent study, transcription profiles of health-related target genes were measured in three different tissues from Baltic ringed seals to obtain baseline levels of the different genes in the tissues. Concentrations of total mercury and POPs were also measured in different tissues to compare with the mRNA transcript levels (Boyi et al. 2022). They found that endocrine related genes were associated with POPs, and the thyroid hormone receptor alpha gene (*TRα*) is associated with total mercury. The baseline data of the gene transcript levels in different tissues and the relationships with contaminants will provide information for determining optimal tissue sampling for different biomarkers (Boyi et al. 2022).

Ladoga Ringed Seal

Moiseenko and Sharov (2019) presented a review and retrospective analysis of long-term changes in the aquatic ecosystems of Lakes Ladoga, Onega, and Imandra in northwest Russia. In the early 1900s, the lakes were oligotrophic and considered relatively “natural” in condition. Large amounts of pollutants (e.g., copper, nickel, phosphorus, phenols, oil, and lignosulfonates) were input into the lakes between 1930 and 1990, and the catchment areas were also polluted with airborne contaminants. Contamination of several bays of the lakes with toxic substances and nutrients peaked during the 1970s. This resulted in significant changes to the planktonic, benthic, and fish communities within the lakes during this period. Pollution in the lakes has decreased since 1990 as a result of the economic downturn and suspension of industrial production in Russia. Even during the more recent economic recovery, pollution levels have remained lower due to technological modernization and tighter controls on emissions into the lakes and atmosphere. The authors suggested the lakes are experiencing a period of revitalization now (Moiseenko and Sharov 2019).

Hair samples of 14 Ladoga ringed seals (newborn pups, molted pups, adults) were collected in 2020 and 2021, and analyzed for concentrations of 14 trace elements (Trukhanova et al. 2022). Aluminum had the highest concentration of the toxic elements, followed by mercury and lead. Overall, trace element concentration levels in Ladoga ringed seals were relatively low; and concentrations of mercury, cadmium, lead, and copper were significantly lower than in the 1990s, and lead and copper continued to decline in the 2000s. Compared to trace element levels in other seal species, Ladoga seals in this study did not show substantially elevated levels or deficiencies (Trukhanova et al. 2022).

2.3.12. Fishery interactions and bycatch

Arctic Ringed Seal

As noted in the 2010 Status Review, direct interactions of ringed seals with U.S. commercial fisheries appear to be relatively infrequent, with mean annual incidental takes in Bering Sea/Aleutian Islands (BSAI) fisheries at or near zero for the early 1990s to 2006. The most recent estimates of incidental take (2014–2018), for the BSAI flatfish and pollock fisheries, averaged nearly 5 seals per year, with takes in the last two years of 8 and 14, respectively. It is unknown if this increase relates to a greater overlap between the fisheries and seal distributions, or an increase in observer coverage to near 100% from 10–82%, depending on the fishery (Muto et al. 2022).

Recent reports from elsewhere in the Arctic shed light on incidental takes of ringed seals in various fisheries. With 15–20% observer coverage, averaged over time and space, mean annual takes in Icelandic lumpsucker gillnets (non-stratified; 2014–2017) were estimated at 53 (±75) seals (Marine and Freshwater Research Institute 2018). Also in Icelandic waters, from 2014 to 2016, Sigurdsson (2017) estimated the number of ringed seals taken in cod gillnets ranged from 0 to 38. In 2021, summarizing across fisheries in the NE Atlantic, as far north as the Barents Sea and Arctic Ocean, ringed seal takes were not reported anywhere except the Baltic Sea (ICES 2022). Ringed seal bycatch in the Canadian Arctic is virtually undocumented, though a recent status report on the species suggests that “commercial fisheries may impact” the population (COSEWIC 2019).

One of the results of the changing fish distributions in the Arctic is an increased presence of commercially important fish species. Walleye pollock, Pacific cod, flatfishes (Pleuronectidae), and sockeye salmon have been documented in the Chukchi and Beaufort Seas in recent years (Logerwell et al. 2015; Yasumiishi et al. 2020; Levine et al. 2023). There has been no evidence that these species are spawning in the Arctic yet, and the fish were not large enough to be commercially valuable; however, the northward movement of these species into Arctic waters indicates that commercial fishing in the Arctic could increase with warming temperatures. In the Chukchi Sea, bottom-trawl surveys in 2019–2020 indicated that abundances of walleye pollock were large enough to support commercial fishing (Maznikova et al. 2023). Currently, ringed seal interactions with commercial fisheries in the Arctic seem to be relatively infrequent. However, the potential for commercial fishing in the Arctic appears to be growing, which could lead to greater risks for ringed seal populations from fishery interactions. Within the U.S. portion of the subspecies’ range, federal waters of the Chukchi and Beaufort Seas are currently closed to nearly all commercial fishing due to insufficient data to support the sustainable management of a commercial fishery there (North Pacific Fishery Management Council 2009).

Okhotsk Ringed Seal

Bycatch in the Sea of Okhotsk still remains essentially unreported, but, as suggested in the 2010 Status Review, intensive commercial fishing makes some level of bycatch likely, and it may be substantial. The UNEP (2006) indicated that vessels deploying salmon drift nets can kill "several seals in a year", though species were not specified.

Baltic Ringed Seal

Although bycatch monitoring in the northern Baltic fisheries, in coastal Sweden and Finland (Bothnian Bay), has historically been underreported and incomplete, recent studies point to contemporary mortality rates and new mitigation efforts. Oksanen et al. (2015a) observed 103 ringed seals entangled in a segment of the fyke net fishery off the Finnish coast from 2008 to 2013. All 63 seals entangled were drowned in the first 3 years, prior to modifying nets with a "seal sock", whereupon in the final three years survival increased from zero to 70%, with 12 seals drowning out of 40 entangled. Unpublished bycatch estimates from the 1980s and 1990s in Finnish territorial waters cite similar ranges of 30–70 ringed seals killed annually (Finnish Ministry of Agriculture and Forestry 2007), which is believed to represent as much as 5% of the estimated annual pup production (Helle and Stenman 1990; from Finnish Ministry of Agriculture and Forestry 2007). In the southern Baltic, in conjunction with Swedish coastal fisheries, Lunneryd et al. (2005) estimated from fisher surveys that 52 ringed seals (95% CI: 34–70) were killed in 2002 in an unknown segment of the gillnet and trap net fisheries.

Ladoga Ringed Seal

With annual bycatch of ringed seals likely persisting as some hundreds of animals for decades, seal-fishery conflicts in Lake Ladoga—in conjunction with extensive hunting and culling—have been significant sources of seal mortality since the early 1900s, with recent abundance estimates (2,000–5,000 seals) representing as low as 1–5% of historical estimates (Sipilä et al. 1996; Härkönen et al. 1998; Trukhanova et al. 2021). Despite recent fisher surveys (2007 to 2019) suggesting a sizable decline in bycatch of ringed seals (from ~800 to 250 per year) coinciding with a change to less lethal fishing gear and some population rebound (Trukhanova et al. 2013), the Russian Federation in 2020 designated the seals as critically endangered. These fisher surveys also revealed a high frequency of seal depredation on economically important but declining commercial species, a rationale used by fishers to petition the government to resume seal culling (Trukhanova et al. 2021). At present, despite uncertainty about actual seal bycatch and trends in abundance, the current reproductive rate of the population, and the status and location of commercial fisheries in the lake, there have been no regular seal monitoring efforts since 2012 (Trukhanova et al. 2013). Trukhanova (2021) cautioned that bycatch estimates may be biased low due to under-reporting, and that fisheries bycatch continues to be a significant threat to the Ladoga subspecies.

2.3.13. Shipping and transportation

2.3.13.1. The Arctic

2.3.13.1.1. Current shipping activity

As noted in the 2010 Status Review, the most comprehensive baseline for Arctic shipping activity was established by the Arctic Marine Shipping Assessment (AMSA; Arctic Council 2009), revealing that in 2004, virtually all commercial shipping was destination-based, rather than trans-Arctic, with no commercial vessels having yet completed a trans-Arctic voyage. The AMSA study projected then that destination shipping would remain the predominant source of traffic through 2020, though at levels 2–3 times higher due to projected loss of sea ice (Arctic Council 2009).

Although a similarly comprehensive survey is not available for the intervening years, regional perspectives using more advanced AIS ("automatic identification system") monitoring to track shipping have substantiated these predictions, if not shown they were underestimates (Figure 11). In the Bering Strait, from 2008 to 2015, yearly ship transits increased 250%, from 220 to 540 (Boylan and Elsberry 2019). In territorial and international waters of the high Arctic, from 2009 to 2018, ship traffic increased more than 3-fold from ca. 1,300 to 4,000 transits (Berkman et al. 2022). Evolving AIS metrics have enabled tracking of other rising trends, such as a 300 km poleward shift in the centroid of Arctic shipping (2009–2016) (NASA 2018a) and a 75% increase in the distance traveled by all ships in the Arctic during 2013–2019 (PAME 2020). In the Canadian Arctic, from 1990–2015, shipping distance more than tripled with two-thirds of that growth since 2006 (Dawson et al. 2018). AIS data has also revealed that the number of unique vessels entering the Arctic is rising, on the order of a 25% increase (1,298 to 1,628) over a six year span (2013–2019) (PAME 2020); the types of ships and number of nations operating those ships has also increased dramatically (3–4 fold; 2008–2019; Berkman et al. 2022). Destination cargo in the Russian Arctic has risen an order of magnitude during 2010–2019 to 25M tonnes and is forecast to continue a steep trajectory to 75M tonnes by 2025. The main driver in this growth is an expanding infrastructure for liquefied natural gas (LNG) plants on the Yamal Peninsula (Goodman et al. 2021), and now realized LNG shipments which account for more than half of all cargo volume on the Northern Sea Route (NSR); crude oil accounts for a quarter (Huntington et al. 2023). This combined with dramatic increases in resource extraction elsewhere in the Arctic (e.g., new mining activity on Baffin Island) has contributed to a 160% increase in occurrence of (i.e., distance traveled by) bulk carriers in the Arctic between 2013 and 2019. Similarly, the occurrence of passenger vessels increased more than 60% over the same period, coinciding with increasing capacity (74K to 91K passengers) and the number of unique vessels (77 to 104) (PAME 2020, 2021a). Similarly to 2004, fishing vessels in 2019 were still the single most predominant vessel type in the Arctic, though declining in prevalence from about 50% to 41% (PAME 2020). Passenger vessels in 2019 comprised 6%, with about one-third of vessels carrying commercial goods and 17% related to research, service, or icebreaking (PAME 2020).

Despite the still large predominance of destination ship traffic, significant milestones in trans-Arctic shipping have occurred in the last decade. In 2017, the first hardened-hull tanker transited the NSR (via Russia) without an ice-breaker escort, and in 2018, the first commercial container ship was escorted along the same route. Also in 2018, a tanker completed the first mid-winter transit of the NSR from South Korea to France (NASA 2018b). Despite traffic increasing on the NSR, with an estimated 220 vessels transiting from 2011 to 2016, most of the growth is attributed to destination shipping with increased resource extraction added to the traditional resupply of coastal communities (Devyatkin 2018). Using monthly AIS data, Eguíluz et al. (2016) documented year-round transits of the Northeast Passage (NEP; the longer route encompassing the NSR) from 2012 to 2014, showing the annual peak in September rising from 31 to 49 ships. Despite similarly remarkable increases in cargo during 2011–2018 (from 111K to 10.2M tonnes), only 5% is estimated to be transported along the entire NSR, further illustrating the predominance of destination shipping (Humpert 2018; van Hussen et al. 2020). The Northwest Passage (NWP) has seen similar growth, again with a predominance of destination shipping, though mostly attributed to increased fishing and tourism combined with long-standing resupplies of remote communities. During 2008–2018, 222 vessel transits of the NWP were recorded of which only 8 were carrying commercial cargo (Boylan and Elsberry 2019). By 2018, tourism, once limited to Russian icebreakers, was being accommodated annually by up to 2–3 dedicated, ice-strengthened cruise ships navigating the NSR and NWP (van Hussen et al. 2020). Also in 2018 was the first near disaster of a cruise vessel transiting the NWP, with a 117-m vessel running aground and requiring passengers to be evacuated (Humpert 2018). Similarly concerning, between 1990 and 2019 in the Canadian Arctic, there was a 25% decline in highly-strengthened ships (PC3) while low (IB) to medium-strengthened (PC7) ships have increased about 2–6 fold, respectively (Dawson et al. 2022). In recent years, though traffic volume in the NWP is still dominated by larger commercial and government ships, the fastest growing maritime sector is pleasure craft (Huntington et al. 2023).

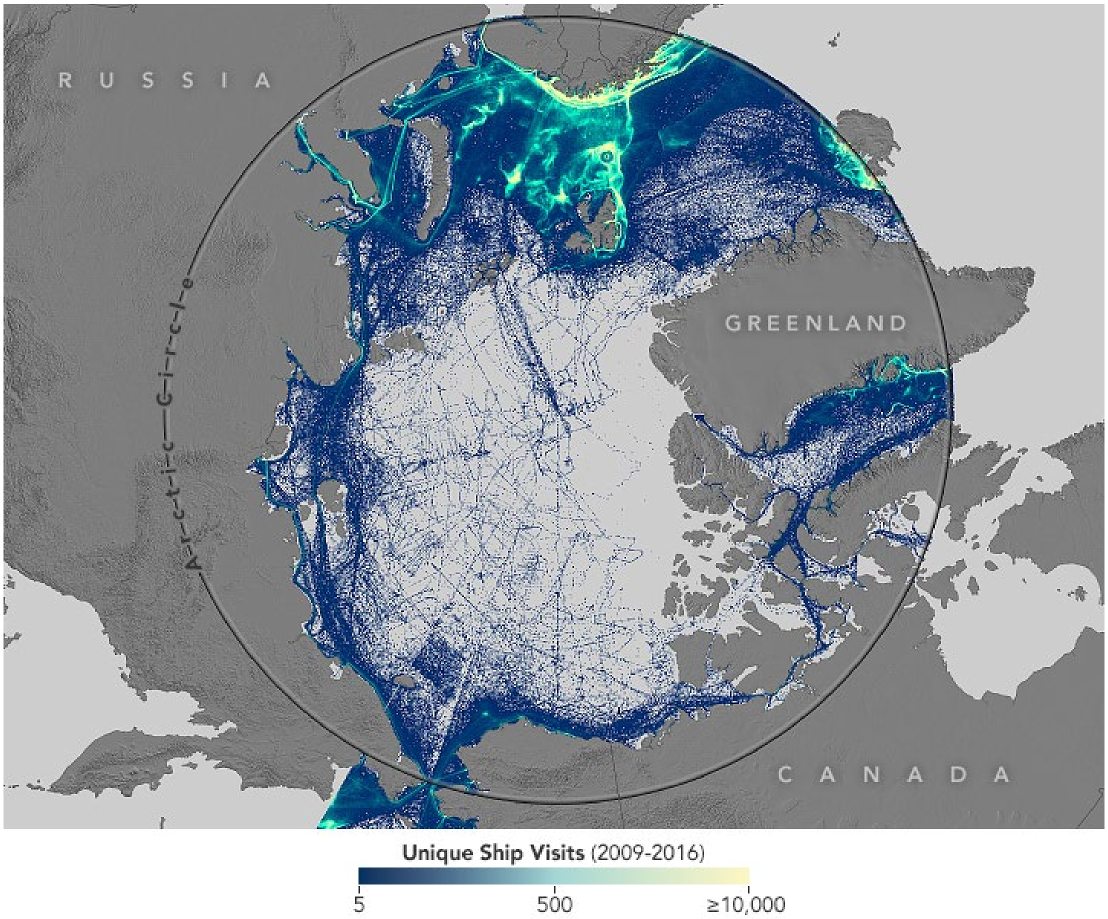

Figure 11. (Reproduced with full caption from NASA et al. (2018b)) Unique ship visits to Arctic waters between September 1, 2009, and December 31, 2016. Dots and lines represent the locations of ships as transmitted by shipboard AIS beacons to satellite receivers. The denser and brighter the coloring of the dots, the greater the number of distinct ship transits reported in that region, with bright yellow and green representing areas with the highest traffic.

2.3.13.1.2. Future shipping activity

While destination ship traffic in distinct sectors of the Arctic stands to continue its upward trajectory, in line with growing human settlements and resource extraction, by far the largest potential growth in ship traffic in the coming decades is in conjunction with greater access to global, trans-Arctic shipping routes. Modeling the evolution of access to these shipping routes in concert with environmental, political, and economic forces has increasingly become a priority over the last decade. As a result, in addition to the already established NWP and NSR, another route only recently considered realistic this century is now being contemplated and studied: the Trans-Polar Sea Route (TSR), which tracks the shortest, most direct path over the pole (Humpert and Raspotnik 2012; Smith and Stephenson 2013; Bennett et al. 2020). Most recent climate and ice modeling predicts the TSR to first be widely navigable between the 2030s and 2070s, depending on the assumed emissions scenario (Bennett et al. 2020). By mid-century, under the low emissions CMIP5 RCP2.6, the TSR could be navigable (> 25% open water) for all vessels for up to 3 months (Sep–Nov); under the very high emissions CMIP5 RCP8.5, the window broadens to 5 months (Aug–Dec; Melia et al. 2016).[13] From 2050-2100, accessibility of the TSR under CMIP5 RCP2.6 is projected to remain fairly consistent; but for CMIP5 RCP8.5 the navigable window is projected to widen to up to 8 months by late-century, with essentially zero ice for 4 months (Aug–Nov; Melia et al. 2016).

Recent modeling of the NWP, assuming CMIP5 RCP2.6, shows a similar progressive opening of shipping lanes, but with the 3-month season occurring a month earlier (Aug–Oct; compared to Sep–Nov for the TSR) and by mid-century being more easily navigable (> 50% open water; Melia et al. 2016). But like the TSR, the NWP under CMIP5 RCP2.6 is not predicted to change much through the end of the century, in this case due to overlap with the Last Ice Area (Mudryk et al. 2021). Still, more current modeling, highlighting 4 distinct Canadian regions of the NWP, predicts a consistent, more linear, and more rapid trend toward longer shipping seasons from the present on (Mudryk et al. 2021). The Arctic Bridge, a 6,700-km Russia-Canada North Atlantic route, and the NWP-south regions are predicted to show similar trends, gaining about 1.5 months of shipping season (across all vessel types) to mid-century (assuming 2° C warming) but with different starting points (5 and 3 months for open-water vessels, respectively; Mudryk et al. 2021). The NWP-north and Beaufort regions are expected to exhibit more rapid changes in access, with a 3-fold widening of the shipping season predicted by mid-century, from the current month-long season to over 3 months for open-water vessels (Mudryk et al. 2021). Year-round access to all Canadian Arctic waters, except the Last Ice Area, would be available to Polar Class 3 (PC3) vessels by mid-century. Despite increasingly longer seasons forecast by this modeling, overall access in the Canadian Arctic is projected to lag behind the other sea routes due to the unpredictability and persistence of multi-year ice and associated hazards in the Last Ice Area (Smith and Stephenson 2013; Melia et al. 2016; Mudryk et al. 2021). Still, if trends in carbon emissions continue unabated, with a +4° C change over pre-industrial levels by 2100, the inevitable disappearance of multi-year ice could further increase shipping seasons for all vessels to 6–10 months, depending on the region. Following this scenario, the vast majority of the Canadian Arctic (except the Last Ice Area) is projected to be open year-round to all polar class vessels by 2100 (Mudryk et al. 2021).

The NSR is currently the most utilized trans-Arctic route, followed by the NWP, a pattern expected to persist and amplify through most of this century. Though the NSR is the shortest established trans-Arctic route it is presently characterized by high volatility in navigability due to a broad, shallow shelf and unpredictable ice massifs—particularly between the Kara Straits and

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[13] Projected warming under our assumed scenario of SSP3-7.0 lies between RCP2.6 and RCP8.5.

the Chukchi—which make the exact route (and timing) unpredictable on any given transit by a particular vessel type and load (van Hussen et al. 2020). This unpredictability, and frequent dependence on ice-breaker convoys, means that the probability of navigating the route in relation to sea ice (i.e., climate change) is only one of a complex of factors that will ultimately determine NSR profitability and thus frequency of future transits. An early freeze in November 2021 along the NSR (in the Laptev Sea) caused at least 18 vessels, including bulk carriers and oil tankers that were spread across five areas, to get trapped in the ice for up to a week, requiring a rescue by two icebreakers (Mathers 2021). Still, modeling of future investments and patterns of global shipping now invariably include rerouting to the NSR, which under a zero-ice scenario (year-round navigability) would serve an estimated 5% of future global trade (Yumashev et al. 2017; van Hussen et al. 2020). Further, Russian authorities are proposing to relax safety precautions in the NSR, and shift from a season- to region-based vessel management system, to broaden and accelerate access to ships with lower ice-class ratings (Humpert 2018). Russia has plans to facilitate NSR vessel transiting year-round by deploying new 120 MW nuclear icebreakers by 2030 (Huntington et al. 2023).

Ice-based modeling of NSR accessibility, using CMIP5 RCP2.6 and RCP8.5, projects suitable conditions for open-water vessels (> 25% open water) typically lasting for 3 months (Aug–Oct) to about mid-century (Figure 12) (Melia et al. 2016), similar to the NWP. Under CMIP5 RCP2.6, by the end of the century, the potential season expands by a month (Nov), and often exceeds 50% open water (Melia et al. 2016). Under CMIP5 RCP8.5, a 4-month season for open-water vessels (> 50% open) is predicted to occur by about 2065, with the same season projected to balloon to 8 months by the end of the century, and the zero-ice season growing to 4 months (Melia et al. 2016). From mid-century on, for both emission models, there is a growing indistinction between the NSR and the TSR, with routes for open-water vessels likely showing a scattered distribution across latitudes (Figure 12) (Melia et al. 2016). Economic modeling combined with navigability projections, even under CMIP5 RCP4.5, estimate the NSR would first become profitable on a very small scale, and only for the smallest tankers (< 50K dead weight tonnage (DWT)), at about 2040, and would be capped below 50% of the potential market for at least 25 years with little change for the foreseeable future (until 2200). At CMIP5 RCP4.5, deeper draft vessels (> 50K DWT) are not projected to become profitable on the NSR until after 2100 due to higher latitude, riskier routes (Yumashev et al. 2017). Under CMIP5 RCP8.5, the timing of first profitability for smaller tankers/container vessels is similar to the timing predicted under CMIP5 RCP4.5 (~2040), but profitability is then projected to exceed 50% of the potential market in less than 20 years and reach 100% by 2150, a few decades after year-round navigability is possible. Under CMIP5 RCP8.5, all but the largest vessel classes (> 2,500 20-foot equivalent units (TEU)) are projected to become profitable by 2060–2090, with the NSR hosting 100% of the market (vs. the SSR; Southern Sea Route) by 2150 (Yumashev et al. 2017).

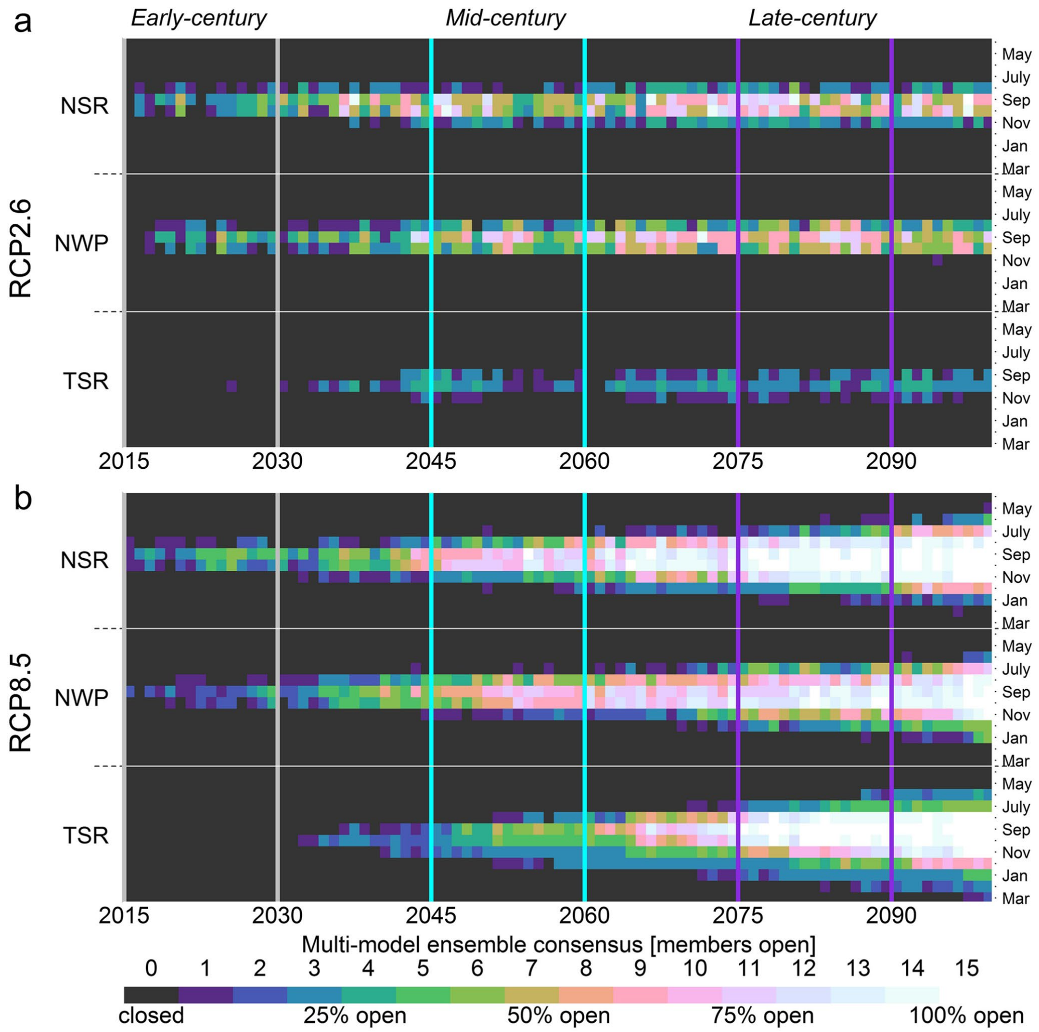


Figure 12. (Reproduced with full caption from Melia et al (2016) Figure 3) Year-round trans-Arctic projections for open-water vessels. The different routes are shown in three horizontal bands for (a) RCP2.6 and (b) RCP8.5. Each route further splits into 12 rows representing each month, starting in April at the top, through to the minimum ice months in the middle, to the maximum ice month of March at the bottom. The colors represent the ensemble consensus or simply the number of ensemble members indicating an open route out of the 15 members available each year (three members × five models) showing substantial interannual variability.

2.3.13.2. Sea of Okhotsk

As in the 2010 Status Review, there is still little quantitative information about the frequency and type of vessel activity in the Sea of Okhotsk. From the extensive oil and gas development that has taken place, largely concentrated around Sakhalin Island, it is reasonable to infer that there must be considerable shipping resources present to support those operations, particularly at terminals in the Strait of Tartar (west of Sakhalin) and the southern point of Sakhalin. It can also be inferred that with new major production streams being tapped over about the last two decades, at the Sakhalin 1, 2, and 3 developments (see Section 2.3.14.6 of this review), there have been similarly large increases in industrial shipping near the island. These likely hotspots of vessel activity are confirmed by visualizations of AIS data from 2019 (Silber et al. 2021), showing year-round high activity near the two terminals, presumably a mix of tanker and icebreaker vessels; peak vessel activity occurred during the ice-free period on the northeastern coast in areas adjacent to the platforms (i.e., oil fields), presumably a mix of tanker, support, and seismic vessels. Southwestern Kamchatka Peninsula and the northeast Okhotsk coast (not including Shelikof Gulf) were characterized by more regular year-round vessel traffic though with a pulse in the winter, roughly corresponding spatially to the winter trawl fishery for pollock (Artukhin 2018; Silber et al. 2021). Although the 2010 Status Review cited efforts to monitor oil pollution and to develop methods for remote sensing of oil releases in the Sea of Okhotsk (Ivanov and Zatyagalova 2008), we found no evidence of subsequent monitoring or new mitigation efforts to reduce the risks of an accidental release.

2.3.13.3. Baltic Sea

The Baltic Sea experienced significant shipping growth in the years leading up to the 2010 Status Review, becoming a critical shipping hub that continues to comprise some of the busiest shipping corridors in the world. Some low thousands of vessels transit its waters daily, with about one-quarter oil tankers. Since the time of the 2010 Status Review, it appears some of the shipping growth projections (2010 to 2020) have not materialized, as reflected in the gross weight of goods and passengers at ports (across all bordering countries) showing essentially zero growth, with the exception of notable increases of goods handled in Poland (no data in Russian waters; HELCOM 2023e) and oil transportation through the Gulf of Finland (Brunila and Storgård 2014). Degraded ice conditions in Bothnia Bay and Gulf of Finland continue to be a concern for ringed seals during pupping, with ongoing icebreaking activity increasingly compounding climate-driven loss of sea ice (HELCOM 2023a). In its first assessment of continuous noise levels, HELCOM (2023f) estimated that undersea noise—based on the median total sound level and a threshold of 500 Hz (decidecade bands)—was not a behavioral or masking risk factor for marine mammals, though it was judged to be a risk factor for different fish species (at 125 Hz) across a majority of assessment units. Methods for monitoring and establishing similar thresholds for impulsive noise, with spatial and temporal components, are under development.

2.3.13.4. Lake Ladoga

As described in the 2010 Status Review, Lake Ladoga is part of an extensive inland waterway (Volga-Baltic) branching eastward from St. Petersburg, Russia, comprising a system of artificial channels, lakes, and rivers. The transit route takes cargo vessels along Ladoga's southern shoreline, though tourism ships and small craft regularly transit the lake on day trips from St. Petersburg to the Valaam archipelago and northern shoreline, raising concerns about environmental impacts from disturbance and pollution (Agafonova et al. 2007; Sipilä 2016). Ship traffic along the Volga-Baltic waterway (2008–2017; reflected by cargo volumes) has not shown any linear trends, climbing to a peak in 2012 (at 23M tonnes) then gradually declining and leveling off at its lowest level by 2015–2017 (at 16M tonnes; Pantina et al. 2019). The establishment in 2017 of Ladoga Skerries National Park (along the lake's northwest shoreline), followed a nearly 5-fold increase in tourism over the preceding two decades (approaching half a million visitors) to the northern Ladoga region (Stepanova 2019). Aside from potential oil spills from a maritime disaster, the main shipping or vessel-related threats to ringed seals are habitat degradation and disturbance via tourism and recreational fishing, which are known threats at nearby Lake Saimaa (Sipilä et al. 2002; Sipilä 2016). Though we found no reporting of vessel-based tourism on Lake Ladoga, the dramatic increase in visitation to the region and growing tourism infrastructure along the shoreline and in the archipelago (Stepanova 2019) suggest a high likelihood of increased human activity within ringed seal habitat in the lake.

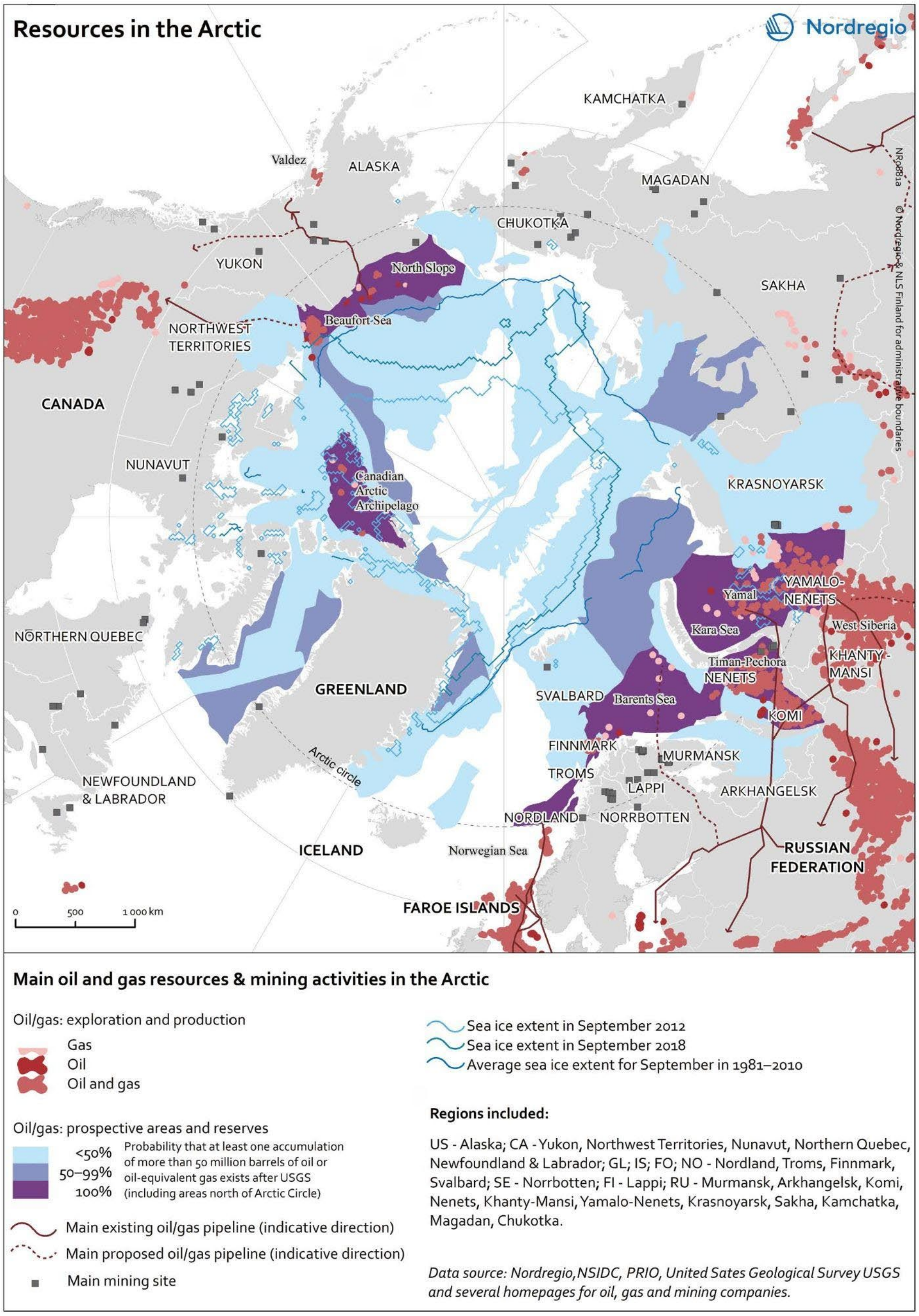
2.3.14. Oil and gas exploration, development, and production

2.3.14.1. Arctic overview

The 2010 Status Review provided a comprehensive description of oil and gas exploration, development, and production in relation to ringed seals. Since 2010, market fluctuations, legal challenges, and changes in global and U.S. energy policies have had varying regional effects on the oil industry and thus development and production outcomes as they relate to ringed seals.

The USGS (2008) estimate of undiscovered conventional oil and gas resources north of the Arctic Circle (412 billion barrels of oil equivalent, or 'Bboe') appears to still be the accepted industry upper bound for untapped reserves, though an analysis that factored in market and economic considerations suggests that the actual production could be much lower (178 Bboe) (Smith 2007; McGlade 2012). Current and future oil and gas reserves with the highest potential are in the Beaufort Sea, Canadian Archipelago, Barents Sea, and western Siberia (Figure 13, dark blue and purple areas) (Jungsberg et al. 2019). The proportion of global oil and gas production attributed to the Arctic, despite enhanced access to reserves due to reduced ice, has been forecast to remain essentially unchanged (22%) or decline as far out as 2050 (Lindholt and Glomsrød 2012; Ermida 2014; Jungsberg et al. 2019). An estimated 84% of these potential global reserves will be found offshore (Figure 13) (USGS 2008, Jungsberg et al. 2019).

As noted in the 2010 Status Review, climate change is expected to complicate Arctic land-based infrastructure for oil drilling. This in turn will incentivize marine-based oil exploration and production, thus allowing for potential capitalizing on reduced sea ice, enhanced access, and lower logistical costs.



Regions included:

US - Alaska; CA - Yukon, Northwest Territories, Nunavut, Northern Quebec, Newfoundland & Labrador; GL; IS; FO; NO - Nordland, Troms, Finnmark, Svalbard; SE - Norrbotten; FI - Lappi; RU - Murmansk, Arkhangelsk, Komi, Nenets, Khanty-Mansi, Yamalo-Nenets, Krasnoyarsk, Sakha, Kamchatka, Magadan, Chukotka.

Data source: Nordregio, NSIDC, PRIO, United Sates Geological Survey USGS and several homepages for oil, gas and mining companies.

Figure 13. (Reproduced with full caption from Jungsberg et al. 2019) Oil and gas resources, actual and prospective, in the Arctic.

2.3.14.2. United States (Alaska)

Most recently, U.S. crude oil production declined during the Covid-19 pandemic but exceeded pre-pandemic levels in 2023 when it reached record-high levels (U.S. Energy Administration 2023a). Under a scenario that assumes current laws and regulations through 2050, production is projected to gradually increase through 2030 and then remain at similar levels through 2050 (U.S. Energy Administration 2023a). The rate of increase this decade, however, hinges on the predicted cost per barrel (U.S. Energy Information Administration 2023a, 2023b), which is increasingly unstable due to current geopolitical uncertainties. Under a higher cost scenario, oil production would be expected to increase rapidly through 2030, plateauing at a much higher production level than under the reference scenario before declining after 2040 (U.S. Energy Information Administration 2023a). In 2022, Alaska drilling represented about 4% of U.S. crude oil production, with the U.S. overtaking Russia as the world's single largest producer at about 12M barrels per day in 2019 (U.S. Energy Information Administration 2023c; Gelles 2023). The U.S. is also leading the world in future expected extraction of oil and gas from projects planned as of 2023: extractions are projected to exceed 7 trillion barrels of oil equivalent (Tboe) over the proposed project durations, primarily due to increases in shale fracking (Bearak 2023). In this context, requests for permits for additional seismic survey activities and test drilling—both on-ice and in open water—in federal and state waters over the Alaska Outer Continental Shelf are expected to increase (NMFS 2016b). Still, it is unknown to what extent the current and future U.S. policies will favor offshore drilling in the Arctic versus oil fields in southern U.S. waters, such as Cook Inlet and Gulf of Mexico (Phillips 2022).

About 35% of the total U.S. potential Alaska offshore oil and gas resources (based on BOE) are contained in the Chukchi (27%) and Beaufort seas (8%) (Bureau of Ocean Energy Management; BOEM 2021), pointing to the importance of the U.S. Arctic for oil development. Despite the potential, the two lease sales (one each in the Chukchi and Beaufort) scheduled during the 2012–2017 leasing program were canceled by the Department of Interior due to market conditions and low interest (DOI 2015). The next BOEM lease sale program (2024–2029) is not likely to include the Chukchi and Beaufort Outer Continental Shelf planning areas due to presidential withdrawal of the areas for future leasing consideration without a specific expiration (BOEM 2023).[14] In July 2017, BOEM approved plans for Eni to conduct exploratory drilling in federal waters at Spy Island, north of the Nikaitchuq oil field (NN-01) in the Beaufort Sea. Drilling at an initial site was completed in April 2019 but, despite reaching an 8,000-foot

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[14] Presidential withdrawal of the Chukchi Sea Planning Area and the majority of the Beaufort Sea Planning Area was upheld by the Alaska District Court in 2019, and was reinstated by President Biden in 2021; the remaining portion of the Beaufort Sea Planning area was withdrawn by the President from oil or gas leasing in 2023 (BOEM 2023).

well depth, further exploration was suspended due to drilling complications; the lease was terminated in 2022 (Cashman 2022).

Production drilling in U.S. Arctic federal waters is currently limited to the Northstar facility in the Beaufort Sea, northwest of Prudhoe Bay (Figure 14). There are two production facilities in Alaska State waters on artificial islands in the Beaufort Sea, namely Endicott and Oooguruk. There are numerous coastal onshore drilling facilities split among three distinct units: Colville River, Kuparuk River, and Prudhoe Bay, with the latter consistently producing more than 50% of the oil recovered. Combined oil production across all units has been declining steadily since the late 1980s to currently about 25% of the peak (U.S. Energy Information Administration 2021).

In 2018, a new offshore oil field development project (Liberty)—estimated to hold 150 million barrels of recoverable oil—was approved on existing leases in the Beaufort Sea. After the start of construction, BOEM's approval of the project was vacated by the U.S. Court of Appeals for the Ninth Circuit in December 2020 (Rosen 2023). As of April 2023, the BP-owned Liberty project had been sold to Hilcorp Energy. The challenging offshore location, ice conditions, and underlying shale layer, as well as continued potential for litigation, have seemingly reduced the priority of this site for future development (Rosen 2023). New offshore drilling activities in the Beaufort Sea were scheduled to begin in 2022 at Nikaitchuq, Oogruk, and Pikka oil development areas, as per letters of authorization requested to allow for incidental disturbance of marine mammals (USFWS 2023). There are currently no U.S. offshore production facilities in the Chukchi Sea, following Royal Dutch Shell's test drilling at the Burger J site and indefinite suspension of oil exploration activities in the Chukchi Sea in 2015 (Eilperin and Mufson 2015).

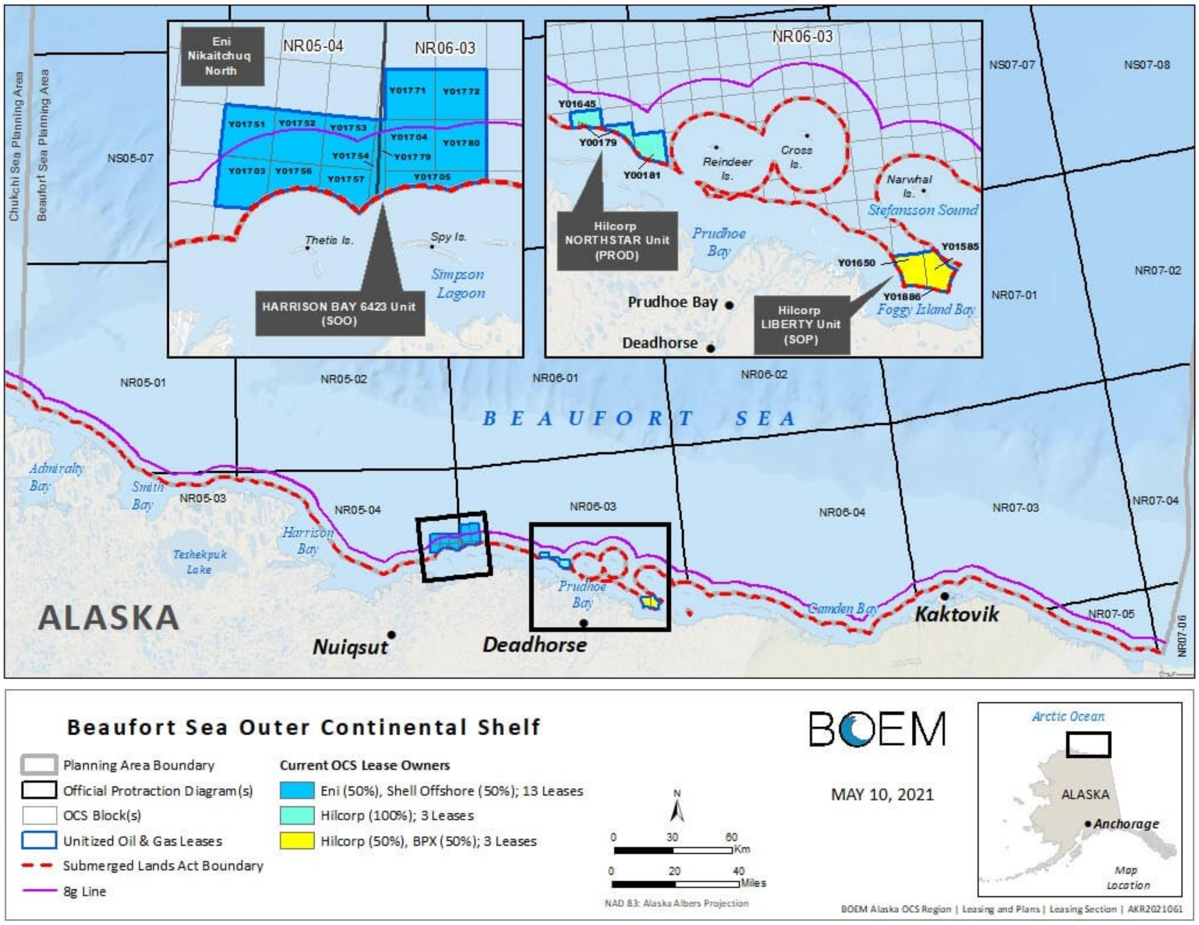


Figure 14. Current oil and gas production sites and lease areas in the Beaufort Sea (Source: https://www.boem.gov/sites/default/files/documents/environment/Active%20Leases%20Beaufort%20Outer%20Continental%20Shelf.pdf; accessed November 27, 2023).

In March 2023, the Bureau of Land Management (BLM) approved a new onshore oil drilling project (involving the Beaufort coastline) known as Willow (ConocoPhillips). The project allows for three drilling pads (50 wells each) on wetlands adjacent to Harrison Bay within the National Petroleum Reserve in Alaska (NPR-A), and is projected to produce 600 million barrels of oil over 30 years (BLM 2023a; Friedman 2023). The project's infrastructure will include ice and gravel roads, pipelines, an airstrip, and processing and housing facilities on leased federal lands in the northeastern portion of NPR-A. Multiple lawsuits have been filed over the Willow project but to date construction, which began in spring 2023, continues, with final construction anticipated by 2029. During the construction phase, regular, seasonal sealift barges will be used to transport materials north from Dutch Harbor, through the Bering Strait, to the existing Oliktok Dock (BLM 2023a). In September 2023, BLM proposed to update its regulations for the management and protection of NPR-A, which would enhance protections for the five existing

Special Areas (e.g., Kasegaluk Lagoon and Peard Bay) that encompass more than half of the remaining NPR-A, amounting to about 13 million acres (ma) (Figure 15) (BLM 2023b).

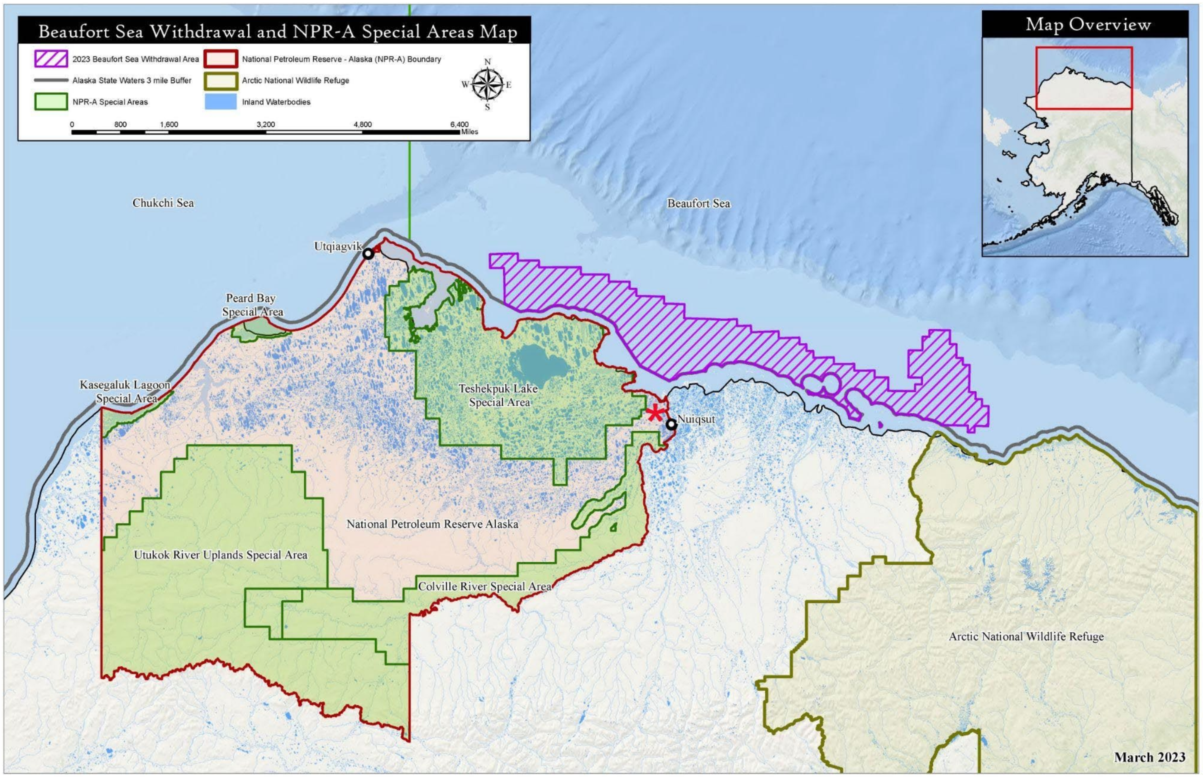


Figure 15. Map of special areas within the National Petroleum Reserve in Alaska (in green) for which enhanced protections were proposed in September 2023, and the March 2023 presidential withdrawal in the Beaufort Sea (in purple hatched; see legend) (Source: https://eplanning.blm.gov/projects/109410/200258043/20075031/250081213/Beaufort%20Sea%20Withdrawal_NPR-A%20Special%20Areas.pdf; assessed November 27, 2023).

The 2017 Tax Act (Public Law 115-97) directs the BLM to hold at least two lease sales by December 2024 in the Coastal Plain area of the Arctic National Wildlife Refuge (ANWR). The first lease seal in the Coastal Plain of ANWR was held on January 6, 2021, resulting in the issuance of nine leases (two of which were later relinquished). Subsequently, a pause was placed on leasing activities in ANWR's Coastal Plain to allow the Department of Interior to complete a new analysis of the potential impacts of the leasing program. In September 2023, a draft supplemental EIS was issued for the Coastal Plain Oil and Gas Leasing Program, and the remaining seven leases from the 2021 sale were also canceled (DOI 2023).

The Bureau of Safety and Environmental Enforcement (BSEE) and BOEM issued a final rule in 2016 governing exploratory drilling conducted during the open-water season by drilling vessels and jack-up rigs in the U.S. Arctic Outer Continental Shelf, aimed to ensure that such activities are conducted in a safe and environmentally protective manner (30 CFR 250, 254, and 550). In 2020, BSEE proposed revisions to the final rule, which were withdrawn in 2021.

2.3.14.3. Canada

Oil exploration in recent decades has revealed some of Canada's largest reserves in the Mackenzie Delta and Beaufort Sea areas. However, an offshore drilling moratorium in 2016, followed by a refund of all drilling-right deposits to oil companies, has greatly reduced any prospects for increasing oil production in Arctic offshore areas of western Canada and the Canadian Archipelago (Kyle 2019; Bowling 2023).

2.3.14.4. Greenland

As described in the 2010 Status Review, by 2007 policies in Greenland were becoming more favorable to offshore oil exploration over the shelf regions. However, by 2021, with no actual oil reserves yet being mapped, the Greenland government suspended all offshore oil exploration indefinitely, citing concern about climate change (Associated Press 2021). There are currently no prospects for increasing global oil production in Greenland waters.

2.3.14.5. Norway and Svalbard

Oil and gas production continues to be Norway's single largest industry, despite reaching peak levels in 2001 (3.4 million barrels per day, 'bpd') and gradually declining by about a third to its current production (2 million bpd). Norway currently supplies 2–3% of global gas and oil consumption. It is estimated over the past 50 years Norway's continental shelf oil reserves have been depleted by half. However, with significant annual investment in exploration there have been significant discoveries in recent years, including the Sverdrup field in the North Sea which is expected to yield 2–3 billion barrels (U.S. International Trade Administration 2022). As of 2020, Norway had 87 oil fields under production with about two-thirds in the North Sea, and as many as 6 coming online in the last decade (PAME 2021b).

In early 2023, Norway announced plans to offer a record number of permitting blocks for oil exploration in the Barents and Norwegian seas, in areas within the annual sea ice zone and just south of the Svalbard archipelago (Adomaitis and Fouche 2023). Oil exploration around Svalbard is still in dispute with Russia claiming the shelf waters around the archipelago are protected by treaty, but under which Russia would claim equal rights if Norway initiated oil exploration (Staalesen 2021).

2.3.14.6. Russian Federation

Russia extracts petroleum offshore in its Arctic and Sea of Okhotsk regions. It is the third and second top producer of oil and gas worldwide, respectively, with 20% of its oil and 80% of its gas coming from domestic Arctic reserves (IEA 2022b, 2023). The vast majority (80%) of untapped Arctic oil and gas is still believed to occur over the Russian Shelf, of which more than three-quarters is estimated to be gas (Figure 16) (Kireeva 2019). With this potential, Russia had anticipated increasing Arctic oil and gas production to offset declines at older production sites and sustain positive trends into the future (IEA 2022b). However, the two invasions of Ukraine (2014 and 2022), and the resulting withdrawal of Western suppliers and investors, has turned those forecasts negative, with new estimates out to 2028 showing a 5–6% decline in production (IEA 2023). Still, between 2017 and 2019, Russia developed at least 10 projects at oil and gas fields across the Kara and Laptev seas and Gulf of Ob (PAME 2021b).

Production forecasts partly hinge on Rosneft's Vostok Oil megaproject actively under construction on Yenisei Bay and the Taymyr peninsula, bordering the Kara Sea, which will host Russia's single largest oil terminal with secondary aims to boost development of the Northern Sea Route (Figure 13). Upon its planned completion in 2030, the Vostok project—the largest in Russia since the 1970s—is projected to produce 700 million barrels per year. But present uncertainties in fossil fuel demand and global geopolitics, and in particular the array of sanctions placed on Russia since the Ukraine invasion, have raised doubt whether these production goals will ever be met (Ross 2023).

In 2014, the state-owned (majority) Gazprom began oil production at Russia's first commercial offshore oil development in the Arctic at the Prirazlomnoye oil field in the Pechora Sea, estimated to contain 600 million barrels of oil. Ice-breaking shuttle tankers transfer oil more than 600 km, depending on the sea ice, to storage tankers from the Arctic-class ice resistant rig which is located 35 miles offshore in waters that are ice-free only about a third of the year (Offshore Technology 2017). Production was delayed for two years due to concerns by scientists and environmental groups citing inadequate safety provisions, use of decommissioned equipment, and expired oil spill response plans, culminating in 2013 with the illegal seizure of a Greenpeace International vessel by the Russian Coast Guard (Alpert 2012; The Hague 2015). At present, production at Prirazlomnoye is reportedly well below initial estimates in both quality and quantity (Kireeva 2019).

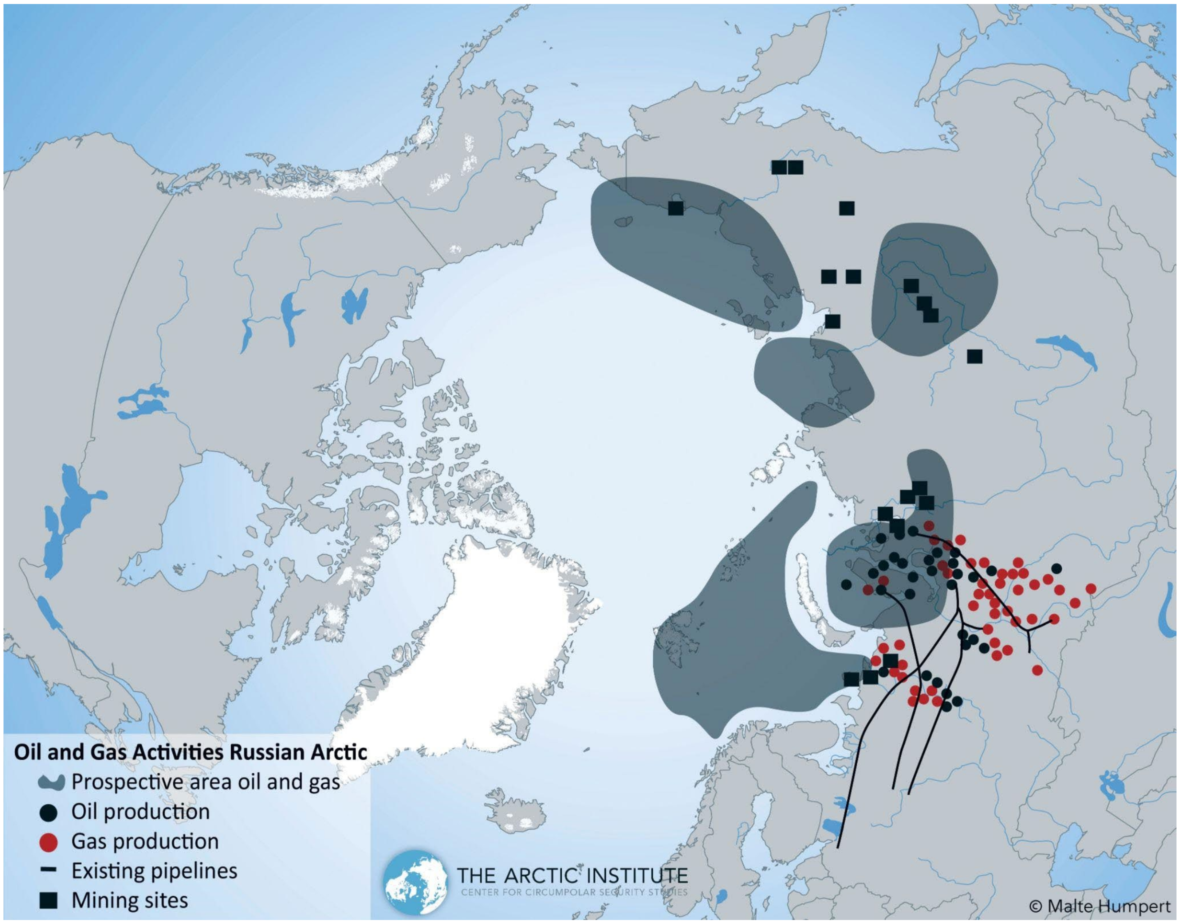
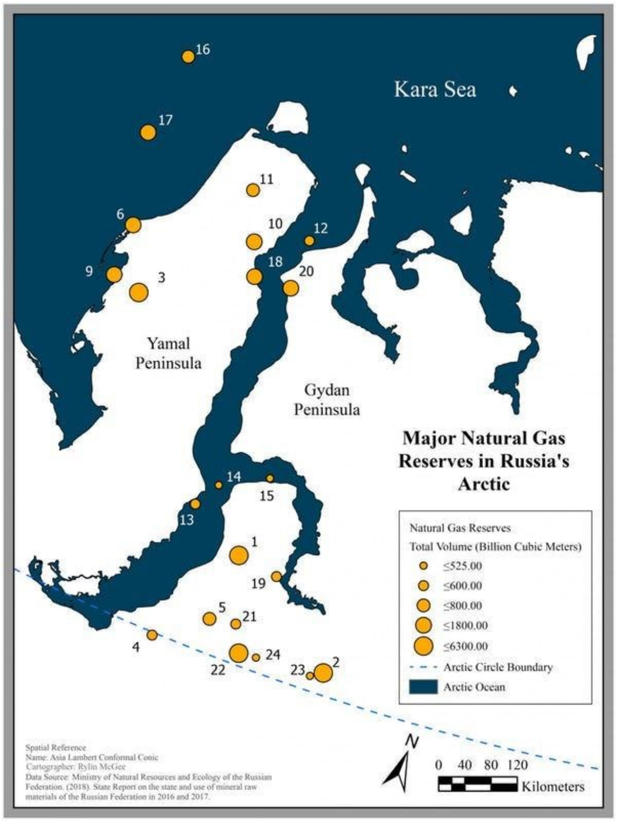


Figure 16. Locations of oil and gas development in the Russian Arctic (Source: Map by Malte Humpert, Arctic Institute, https://www.thearcticinstitute.org/arctic-maps/; accessed November 27, 2023).

Novatek's LNG megaproject on the Yamal Peninsula (Figure 17)—in partnership with France's Total and China's NPC—began producing in 2017, tapping an unprecedented reserve estimated to hold more than 15 trillion cubic meters of LNG, or 80% of Russia's natural gas and 15% of the global gas supply (Kireeva and Digges 2019). Moreover, the associated infrastructure is projected to build capacity throughout the region to support greater shipping traffic along the NSR with more than half of the LNG anticipated to be shipped to Asian markets, despite little infrastructure east to the Bering Strait (Conley and Melino 2017; Foy 2017; Kireeva and Digges 2019). Currently, icebreaker tankers deliver LNG from the project's docking facility year-round. Despite reaching full production capacity of nearly 1 million tons LNG per year in June 2021, technological breakdowns since then have reduced output (Global Energy Monitor 2021). With LNG deliveries using carriers on the NSR projected to increase, in conjunction with a warming

Arctic and declining sea ice, there is a concomitant concern that the entire project stands on permafrost which will also melt under climate change (Kireeva and Digges 2019).

Novatek has the leading stake in another large-scale LNG project, Arktik LNG-2, on the Gydan Peninsula (~100 km west of Yamal LNG; Figure 17). This project is expected to gradually launch during 2023–2026, with three liquefaction trains that will each have a capacity of 6.6 million tonnes per year (Soldatkin 2023). These launch estimates, however, were announced prior to the invasion of Ukraine and have not since been updated (U.S. Energy Information Administration 2023d). As with the Yamal LNG terminal, gas will be shipped via a fleet of LNG ice-class carriers from Utrenniy to transhipment facilities in Murmansk and Kamchatka; this is therefore another example of a planned project that relies on the increasingly open NSR as a sea route to Asia. The gas field has estimated reserves of almost 2 trillion cubic meters of gas, with untapped reserves of another 400 billion (Shadurskiy 2021).



Spatial Reference
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Cartographer: Rylin McGee
Data Source: Ministry of Natural Resources and Ecology of the Russian Federation. (2018). State Report on the state and use of mineral raw materials of the Russian Federation in 2016 and 2017.

Figure 17. Major natural gas fields on the Yamal and Gydan Peninsulas, two main centers of Russia’s Arctic hydrocarbon development (McGee 2020).

Another potential LNG project in the Shtokman field, 370 miles north of the Kola Peninsula in the Barents Sea, was thought to hold the largest known offshore gas reserve and be a strong prospect for development. However, the project was finally abandoned in 2019 due to spiraling costs related to the depth of the seabed, extreme sea ice conditions, and an unfavorable market (Staalesen 2019)**.**

Since seismic exploration began over the Sakhalin Shelf in the Sea of Okhotsk during the late 1970s, more than 100 deep wells have been drilled across multiple fields, estimated to have total reserves of oil and gas exceeding 1 billion tonnes (Fadeev et al. 2020). The Exxon/Rosneft Sakhalin 1 complex, starting at 50 km off the island's NE coast, was Russia's first offshore block to be developed, producing oil in three distinct fields (Chayvo, Odoptu, and Arkutun) which were brought into production, respectively, every 5 years between 2005 and 2015 (Fig. 16; NS Energy 2019). Reserves are estimated at 2.3 billion barrels of oil and 17 trillion cubic feet of gas, with annual production at approximately 11 million tonnes of oil and condensate, and 2.5 billion cubic meters of gas (NS Energy 2019). The 15-km well at the Chayvo field is considered to be the world's deepest. A pipeline across the Straits of Tartary, west of Sakhalin Island, transports the oil to an onshore processing facility, later bound for the tanker terminal at De Kastri or further pipeline transfers via the mainland to the west (Fig. 16; ArcticEcon 2011). Despite relatively low latitudes, operations on northern Sakhalin Island are currently impacted by harsh weather and sea ice for an average of 6 months a year (Nov–Apr; Fadeev et al. 2020). With ExxonMobil running operations, production at the complex peaked in 2019, and was estimated to have about one-third of recoverable reserves remaining and to continue to be economically viable until 2054 (Offshore Technology 2023a). However, following the 2022 invasion of Ukraine and subsequent western sanctions, Exxon issued a force majeure, reduced output to local requirements, and withdrew from the project. Moscow seized Exxon's one-third holdings in late 2022, and established a new Rosneft subsidiary to take over. As of early 2023, output was still at less than 150,000 barrels per day, about 65% of capacity (Verma 2023).

Launched in 2009, the Shell-Gazprom Sakhalin 2 comprises two fields (Pil'tun-Astokhsk and Lunskoye), three platforms, an onshore processing facility, the TransSakhalin pipeline, an LNG plant, and an oil export terminal (Figure 18) (ArcticEcon 2011). Production peaked in 2017 and by 2023 about half of the LNG had been recovered with field viability projected until 2055; remaining reserves are estimated at 1.2 billion barrels of oil and 500 billion cubic meters of LNG (NS Energy 2022a; Offshore Technology 2023b). In 2022, months after Russia's invasion of Ukraine, the Russian government announced the nationalization of the project, necessarily ordering the sale of Shell's interest to Russia's Novatek at a substantial mark down. In 2020, annual production was roughly 11.6 million tonnes of LNG (Ambrose 2023).

Southeast of the Lunskoye field lies Sakhalin 3, composed in part by Gazprom's Kirinskoye field which came online in 2014, is expected to peak in 2025, and will reach the end of recoverable LNG resources by 2074 (Figure 18) (Offshore Technology 2023c). Further south, and also part of Sakhalin 3, is Kirinskoye South field, discovered in 2010, and expected to begin commercial operations in 2025 (Offshore Technology 2023d). Initial reserves were estimated at 1.2 billion barrels of oil and 9 trillion cubic feet of LNG (U.S. EIA 2008).

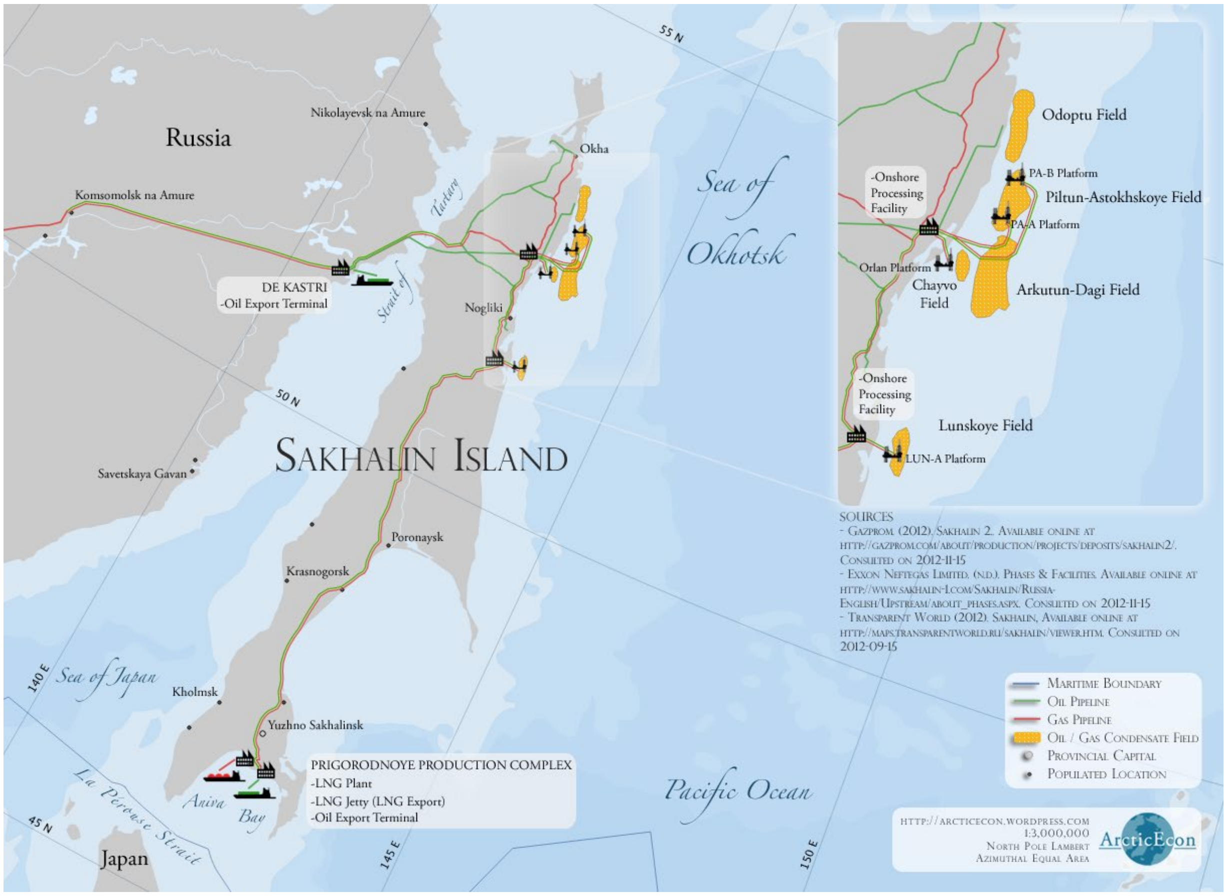

Figure 18. Map of oil fields and extraction facilities in the Sakhalin Island area in the Sea of Okhotsk (ArcticEcon 2011).

2.3.14.7. Baltic States

Hydrocarbon reserves in the central Baltic are estimated to hold 150 billion cubic meters of gas and 1.5 billion barrels of oil, though the majority is believed to be unconventional and difficult to extract (Brownfield et al. 2015; HELCOM 2023e). Oil extraction is currently taking place only in Polish and Russian waters. The first offshore oil rig, Baltic Beta, is located 80 km off the Polish coast in the B3 oil field and has been in production since the mid-1990s. Oil production peaked in 2003 and as of 2023 the rig is producing at less than 50% of the peak with about 25% of recoverable reserves remaining. Oil is shipped by tanker to a refinery in Gdansk, and associated gas is sent by pipeline to an onshore power generating plant (Offshore 2000; Offshore Technology 2023e).

The B8 oil field is located 70 km offshore in Polish waters. It was initially developed in 2014 and was projected to contain 3.5 million tonnes of crude oil. By 2016, it had its first offshore rig positioned and operational, capable of drilling in water depths of 120 m (Offshore Technology 2016, 2023f). This first rig was connected to the B3 oil field (Baltic Beta) via a 35-km undersea pipeline where the oil was then transferred to a Gdansk refinery by tanker. Subsequently, an additional drilling rig, LOTOS Petrobaltic, was converted to a production platform and placed on the B8 deposit in 2019 (Wyrzykowski 2019). In 2021, a newly completed 75-km undersea pipeline started transferring dense-phase gas to a separation station in order to supply a heat and power plant in Wladyslawowo (Wyrzykowski 2021). By 2023, an estimated third of the reserve had been recovered with peak production projected in 2026; about 85% extracted is crude oil, with the rest LNG; projected to be viable until 2056 (Offshore Technology 2023f).

The Baltic Sea also has significant undersea pipeline infrastructure to move liquid fuel between shore-based terminals. Gazprom's Nordstream 1 undersea pipeline was completed in 2011, hence delivering 400 billion cubic meters of LNG from Russia to Europe as of 2021 (NS Energy 2022b). In 2018, construction was started on a second undersea (twin) pipeline, Nordstream 2, which was completed in 2021 and expected to carry gas by 2022. The gas would originate from an estimated 5 trillion cubic-meter gas reserve (Bovanenkovo) on the Yamal Peninsula (NS Energy 2022b). This 1,230-km pipeline has a similar design and route as the first Nordstream pipeline, originating at a gas compressor station southwest of St. Petersburg (Narva Bay) and passing through Russian, Finnish, Swedish, and Danish waters, before terminating on the northern German coast. In early 2022, despite the pipeline filled with LNG and ready for operations, final authorization by the German government was halted in February just days before Russian forces invaded Ukraine. In September 2022, underwater explosions ruptured 3 of the 4 pipelines, with evidence supporting an act of sabotage (Masih 2023). Despite the estimated 150–500 million cubic meters of gas released into the water column, the largest release of LNG ever recorded, authorities initially did not expect any long-term effects on marine life (Mathiesen and Weise 2022). However, scientists are now studying a number of possible long-term effects ranging from a disruptive nutrient influx from the dissolved methane to physical injuries to critically endangered Baltic porpoises (*Phocoena phocoena*) and spawning Baltic cod (*Gadus morhua callarias*). These impacts could add cumulative effects to an already stressed Baltic ecosystem suffering from heavy pollution, low oxygen levels, and overfishing (Farmbrough 2023).

First proposed in 2016, the first train of Gazprom's Baltic LNG at Ust-Luga port (Leningrad Oblast) in the Gulf of Finland is estimated to begin operations in 2023 (U.S. Energy Information Administration 2023d). The second train is estimated to start production in 2024. At full capacity, the two-train LNG export facility will produce 13 million tonnes of LNG, 4 million tonnes ethane, and more than 2.2 million tonnes of LPG per year (NS Energy 2023). The Gulf of Finland has at least 17 oil and gas terminals, distributed almost evenly across Finland, Estonia, and Russia, with more than 50% of the oil transportation (via tankers) in the Baltic passing through its waters (Brunila and Storgård 2014). From 2000 to 2012, hydrocarbon volumes passing through the Gulf of Finland increased 4-fold from 43 to 171 million tonnes, almost entirely due to increases in exports from the Russian ports at Primorsk, Vysotsk, St.Petersburg, and Ust-Luga (Brunila and Storgård 2014). Oil transportation across the Baltic as a whole increased about 3-fold over the same period. Brunila and Storgård (2014) forecast Baltic oil transportation across a range of scenarios that hinged largely on oil demand. Their models predicted Baltic oil transportation from 2012 to 2020 could remain level or increase up to ~20% depending on the demand scenario; projections out to 2030 ranged from largely level to potential declines. The high density of container ships, with areas of cross traffic, and security threats were cited as significant risk factors for a maritime disaster and major oil discharge (Brunila and Storgård 2014).

Also in the Russian sector is the largest oil field in the Baltic Sea, the Lukoil D-6 (Kravtsovskoye; Figure 19). This oil field is located 22 km offshore of Kaliningrad, with reserves estimated at 21 million tonnes of crude oil. Production was first achieved in 2004 and is projected to last until about 2040 (Offshore Technology 2004). The offshore, ice-resistant, stationary complex consists of two platforms linked by walkway, and is connected to the mainland by a 47-km undersea pipeline which transports a mixture of gas and oil. The separated oil is then pumped 31 km via an underground pipeline to an oil terminal in a coastal lagoon in Kaliningrad Bay, where 20K T tankers can load the oil (Kostianoy et al. 2013). The Kravtsovskoye oil field peaked in 2007, and now has about 25% of its recoverable reserves remaining as of 2023 (Offshore Technology 2023g). In 2019, Lukoil also completed construction at two offshore wells in the D-41 oil reserve (Figure 19), south of D-6 and close to shore. These are the longest wells to have been drilled in the Baltic Sea and are projected to produce 2 million tonnes (Offshore Technology 2019). Another shallow-water, fixed platform at the D33 oil field is currently under construction (Lukoil; Figure 19) with production expected in 2025 and reserves estimated at 21 million tonnes (Offshore Technology 2023h). Plans for another nearby offshore oil field, D-29, awarded to Lukoil (Figure 19), have not yet been announced.

It appears Latvia is the only other Baltic nation with tested offshore oil reserves, in particular the E6-1 block, but test drilling has so far not been conclusive to justify full-scale production at any sites (Katona 2017).

Figure 19. Locations of oil fields in the southern Baltic Sea (Source: WM Upstream Russia: https://twitter.com/wm_russia/status/1131601550441422848; accessed: November 6, 2023).

2.3.15. Offshore wind energy development and production

2.3.15.1. The Arctic

There are currently no commercial offshore wind farms above the Arctic circle, largely due to unknown risks associated with the relatively new technology and interactions with extreme weather and oceanic conditions (e.g., shifting sea ice, blade icing; Salo and Syri 2014). There are six areas proposed for wind development off of Norway in the Norwegian and Barents seas, with one area awaiting permitting (TGS New Energy Solutions 2023a).

2.3.15.2. Baltic States

Offshore wind energy production in the North Sea has been growing exponentially since the early 1990s, especially since 2002, with a total capacity of about 30 GW; coastal wind farms have been developed in Denmark (2,308 MW), Sweden (192 MW), UK (13,918 MW), Finland (71 MW), Norway (66 MW), Netherlands (2,829 MW), Belgium (2,261 MW), Germany (8,055 MW), and France (482 MW) (Cruciani 2018; WindEurope 2023).

Producing about 84% of the world's wind energy, these developments—located in the southern North Sea, Skagerrak Strait and Kattegat Bay, and in the Baltic Sea (mostly southern)—are predominantly bottom-fixed substructures (Figure 20). Only three floating wind farms are currently online, one off Sweden and two off Norway (in the Skagerrak Strait), which partly power the Snorre and Gullfaks oil and gas fields. Early planning for offshore wind is underway in Iceland, the Faroe Islands, Greenland and Åland (Nordic Energy Research 2023).

Currently, there are 8 wind farms online in the southern Baltic Sea, most operated by Denmark, producing about 2,450 MW. There are currently 24 areas either approved for wind farm construction or awaiting approval; two are under construction. There are more than 100 distinct farms in the early planning phase. In the northern Baltic, there are two offshore wind farms online in Finnish waters (Ajos and Tahkoluoto; 68 MW combined), in the Gulf of Bothnia (TGS New Energy Solutions 2023b).

As a component of the European Union's climate neutrality target, projections out to 2050 have North Sea wind production at 212 GW and the Baltic Sea at 83 GW, which would represent an order of magnitude increase in combined energy production and more than 30X for the Baltic Sea alone (WindEurope 2023; Nordic Energy Research 2023). However, shorter-term European Union goals of producing 42.5% of energy from renewables by 2030 may be unrealistic due to unexpected high costs (partly resulting from the Ukraine War), supply-chain constraints, and the low cost of electricity impacting bids for new construction (Chestney 2023). Required surface areas, grid connections, and anchor arrangements will occupy a significant amount of pelagic and seabed space, and thus are likely to compound existing space-use competition with other industries and environmental impacts (Nordic Energy Research 2022, 2023).

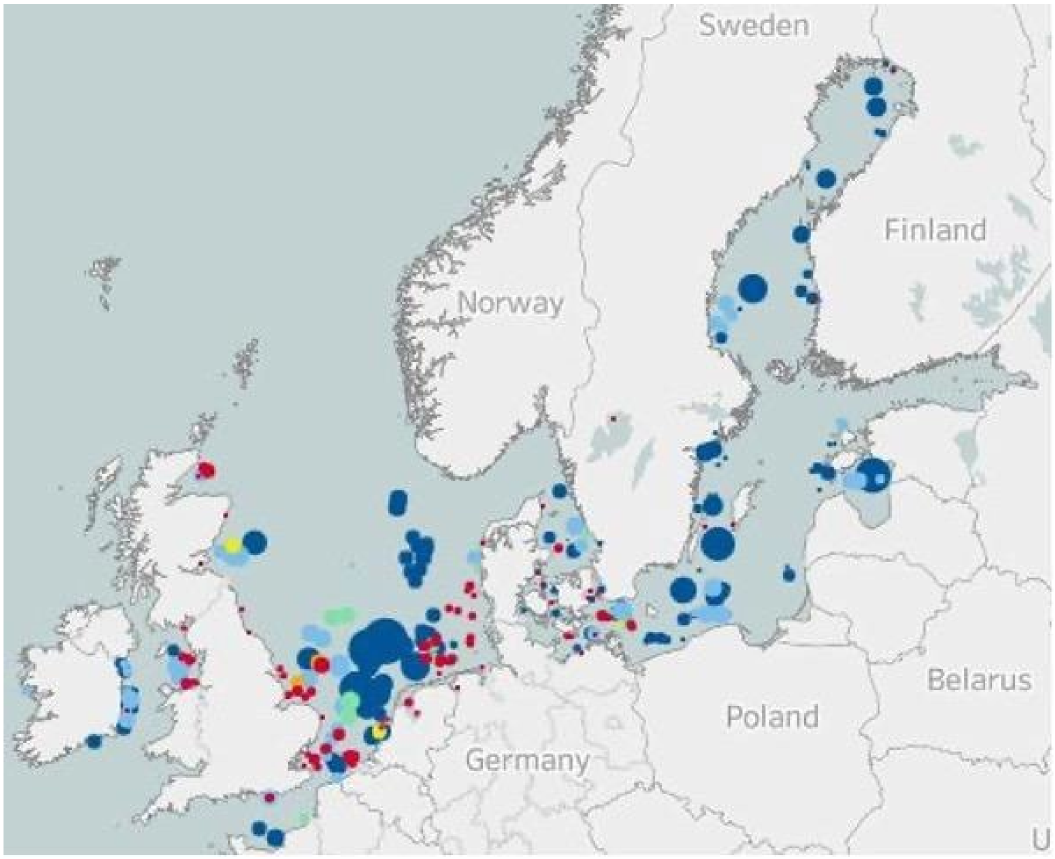

Figure 20. Status of offshore, bottom-fixed wind farm projects in the Baltic Sea and other northern European countries (Source: WindEurope, European Offshore Wind Farms Map Public, https://windeurope.org/intelligence-platform/product/european-offshore-windfarms-map-public/; accessed July 10, 2022).

2.4. FIVE-FACTOR ANALYSIS (THREATS, CONSERVATION MEASURES, REGULATORY MECHANISMS)

The ESA defines an "endangered species" as a species that is in danger of extinction throughout all or a significant portion of its range, and a "threatened species" as a species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range. The ESA requires that NMFS determine whether any species is a threatened species or endangered species based on any one or a combination of the following five factors (i.e., categories of threats) specified in section (4)(a)(1) of the ESA: The present or threatened destruction, modification, or curtailment of its habitat or range; overutilization for commercial, recreational, scientific, or educational purposes; disease or predation; the inadequacy of existing regulatory mechanisms to address identified threats; or other natural or manmade factors affecting its continued existence.

This section summarizes our analysis of the best scientific and commercial data available regarding each of the five ESA section 4(a)(1) factors as they relate to the status of the Arctic, Okhotsk, Baltic, and Ladoga ringed seal, including any relevant new information regarding the magnitude and imminence of previously identified threats or emerging threats to each subspecies. As part of the analysis we also consider whether there is new information regarding implementation of regulatory mechanisms or conservation measures that affect the magnitude or imminence of these threats.

The context, or reference level for this 5-factor analysis is the threats assessment conducted in preparation for the listing decisions. Four of the five ESA section 4(a)(1) factors were evaluated by the BRT as part of the 2010 Status Review and the summary threat scores are presented in Table 2. The fifth factor, inadequacy of existing regulatory mechanisms, was evaluated by the NMFS Alaska Region, and the results were communicated in the final listing rule.

Table 2. Threats assessment scores considered in the listing decisions for four subspecies of ringed seals (Kelly et al. 2010). BRT members judged the significance of four of the ESA section 4(a)(1) factors to the persistence of the population within the foreseeable future. Each factor was scored by the BRT—in consideration of the threats' severity, geographic scope, and likelihood of occurrence—as follows: 1 = low or zero significance, 2 = moderate significance, 3 = high significance, and 4 = very high significance. The averages and ranges (in parentheses) of these scores are presented. The significance of the remaining factor, inadequacy of existing regulatory mechanisms, was assessed separately by the NMFS Alaska Region in the listing rule.

ESA Section 4(a)(1) Factor	Arctic Ringed Seal Overall Factor Score (Range)	Okhotsk Ringed Seal Overall Factor Score (Range)	Baltic Ringed Seal Overall Factor Score (Range)	Ladoga Ringed Seal Overall Factor Score (Range)
Destruction, modification, or curtailment of habitat or range	3.2 (2-4)	3.5 (3-4)	3.5 (3-4)	3.5 (3-4)
Overutilization	1.1 (1-2)	1.2 (1-2)	1.1 (1-2)	1.0 (1-1)
Disease, parasites, and predation	2.5 (1-4)	2.5 (1-4)	2.6 (1-4)	2.5 (1-4)

ESA Section 4(a)(1) Factor	Arctic Ringed Seal Overall Factor Score (Range)	Okhotsk Ringed Seal Overall Factor Score (Range)	Baltic Ringed Seal Overall Factor Score (Range)	Ladoga Ringed Seal Overall Factor Score (Range)
Other natural or man-made factors	1.6 (1-2)	2.1 (1-3)	2.0 (1-3)	2.0 (1-3)

In conducting this 5-year review, we did not convene a panel to formally score expert judgment about the current significance of the five ESA section 4(a)(1) factors. Rather, our conclusions reflect the considered judgment by the reviewer(s) responsible for reviewing and summarizing the new information relevant to each factor. We express the conclusions in part, by simple qualitative comparison to the terms used by the BRT in the 2010 Status Review: *low or zero*, *moderate*, *high*, and *very high*.

2.4.1. Present or threatened destruction, modification, or curtailment of its habitat or range

Climate-driven changes to ringed seals' physical environment were the primary concerns when NMFS listed the four subspecies of ringed seals. Climate-driven physical changes are among the factors that can also influence ringed seals' biological habitat (i.e., ecosystem effects). In this section, we review and analyze how new information since the seals were listed relates to the magnitude and imminence of threats from both physical and biological habitat destruction or modification. Rather than reiterating all of the new information that has become available, we provide hyperlinks to previous areas of the document where information used in our threat analysis is presented in greater detail.

Arctic Ringed Seal

In the 2010 Status Review, the BRT judged the overall significance of threats to the Arctic ringed seal from the present or threatened destruction, modification, or curtailment of its habitat to be *high*. The individual habitat threats with the highest scores were "decrease in ice habitat suitable for whelping and nursing" and "increased hypothermia due to insufficient depth and/or duration of snow cover". The BRT concluded that, "Persistence of ringed seals will depend on the amount and phenology of ice and snow cover, habitat features forecasted to change heterogeneously over the next century" (Kelly et al. 2010). In the listing rule, NMFS found that, "The main concern about the conservation status of ringed seals stems from the likelihood that their sea ice habitat has been modified by the warming climate and, more so, that the scientific consensus projections are for continued and perhaps accelerated warming in the foreseeable future." New observations since the time of listing have confirmed those projected trends, and the updated scientific consensus projections continue to portend a major loss of Arctic ringed seal physical habitat through the remainder of this century.

Warming in the Arctic, which is happening two to four times faster than the global average, has continued to drive reductions in sea ice extent. Observations since the time of listing indicate that the amplification may be stronger than previously thought, and it is not yet clear how much of the recent strengthening of the amplification is forced by human activities versus natural climate variability. In either case, it is consistent with the concern in the listing rule that warming was projected to continue and perhaps accelerate.

Arctic sea ice continues to follow the trend projected at the time of listing, in which the high Arctic seas have exhibited relatively little decline in ice extent during March–May, the critical months for ringed seal whelping, nursing, and molting. The peripheral seas, however, such as the Bering, Okhotsk, Barents, and Greenland regions, have lost substantial portions of their sea ice extent in March–May (Stroeve and Notz 2018) (Table 1). Landfast ice, which is prime habitat in many parts of the Arctic ringed seal's range, has declined at a faster rate than overall sea ice. There is a well-documented association between the decline in sea ice extent and a decline in the seasonal duration of sea ice coverage, due to later freeze-up and earlier melting of the sea ice.

Later freeze-up and earlier melting of the sea ice are important factors in the development and persistence of the seasonal snow cover that Arctic ringed seals depend on throughout the vast majority of their breeding range. Much of the snow cover on seasonal sea ice falls during autumn and early winter. When the sea ice is delayed in forming, the snow falls into the water, rather than accumulating on the ice surface, causing reduced snow depth during the critical period for ringed seal whelping and nursing in lairs. Perhaps the most significant new information about Arctic ringed seal habitat is the clear documentation of declines in snow depth on sea ice. A strong need within the geophysical research community to monitor snow cover as a factor in estimating sea ice volume led to advances that significantly improved capabilities for Arctic-wide surveillance of snow depth. Several studies have now confirmed that snow depth—the primary factor of concern in the 2010 Status Review—was at the time of listing already in a multi-decadal decline on seasonal sea ice, which is the primary platform for ringed seal whelping, nursing, and molting.

The demographic risks that stem from the threat of declining snow depth on Arctic sea ice are the same risks cited at the time of listing: insufficient thickness and seasonal persistence of snow on sea ice poses risks to ringed seal pup survival. Although predation by polar bears on adult ringed seals may also increase when snow cover is insufficient for adequate lairs, the pups are the most vulnerable age class. Their smaller size and relatively poor defenses make them susceptible to predation by not only polar bears but other predators as well, such as birds and foxes. Inadequate lairs that collapse or become flooded by rain or snowmelt pose risks of hypothermia for pups because their natal coats insulate poorly when wet. Thus, increasingly frequent years with poor accumulation of autumn and early winter snow depth, followed by warm winter and spring conditions, are expected to reduce the survival of pups and make breeding habitat unsuitable throughout much of the Arctic ringed seal's range before the end of the century. More frequent years of poor recruitment in these areas will in time impact the numbers of breeding adults and lead to population declines. The demographic impacts are expected to occur earliest and to be strongest in the peripheral Arctic waters such as the Bering, East Greenland, and Barents seas, where projections considered in the final listing rule show the most substantial reductions in snow depth on sea ice by mid-century. But they will eventually manifest in core parts of the range such as the Chukchi and Beaufort seas as the considerable decline in Arctic on-ice now depths evident at mid-century continues through the century.

The 2010 Status Review did not predict that impacts on Arctic ringed seals from habitat loss would be evident by the time of this review, approximately a decade after listing. The loss of habitat and accrual of demographic impacts were expected to unfold gradually in terms of observations over a human lifetime, but extremely rapidly on the evolutionary time scale that has shaped ringed seals' specialized adaptations to Arctic life. Nonetheless, more evidence collected since the listing indicates that pup survival or related biological parameters are responding to interannual Arctic change in sea ice and/or on-ice snow conditions farthest from ringed seals' core Arctic habitat. In western Hudson Bay, an index of pup production and survival was lowest following winters of shorter snow cover duration and higher spatial variability in remotely-sensed spring snow depth. In the Bering Sea, a similar index of pup production and survival was lower, but only in a few recent years strongly influenced by a North Pacific marine heatwave. In Svalbard, however, where large areas have not had regular seasonal sea ice since 2006, an interdecadal synthesis of several vital rates indices found no clear pattern consistent with climate-related hypotheses. The lack of an effect may be due to the recent samples having been collected from a much smaller area where suitable ice persists—in other words, the recent samples no longer represent the full population whose habitat disappeared. No evidence is available yet to distinguish between that and an alternative hypothesis that ringed seals in the region have somehow adapted to the new regime.

The ability to project future climatic threats to ringed seals has improved since the time of listing, due to greater understanding of the relevant geophysical processes. One example is the recent narrowing of the range for the equilibrium climate sensitivity, the amount of climate warming that results from a doubling of the atmospheric CO_2 concentration. Another example is the near linear relation between Arctic sea ice loss and cumulative CO_2 emissions that is apparent in all months of the year. These results, based on observations, strengthen confidence in future projections by providing additional means of evaluating the skill of climate models at reproducing past climatic patterns.

A second factor lending greater confidence to projections of future climatic threats stems from advances in capabilities to model the natural processes that determine the climate. The current (CMIP6) models have been improved over their predecessors by increased resolution, more accurate representation of natural processes, and tuning of models for greater correspondence between model outputs and observations. The spread among CMIP6 models for Arctic summer ice extent is slightly smaller than in CMIP5. The CMIP6 models are better at capturing the satellite-observed Arctic sea ice loss, though they continue to estimate too much sea ice for a given level of global warming. This should be recognized as a component of conservation risk for ringed seals; ESA management decisions based on any specific projection of future sea ice habitat availability should account for the fact that current model projections may be over-optimistic for Arctic sea ice. Overall, CMIP6 and CMIP5 model results remain similar to those used at the time of listing, with a slightly narrowed range of uncertainty in outputs that pertain to ringed seal habitat.

As was the case at the time of listing, the climate warming and related changes over the next few decades to around mid-century are already ‘locked in’ by previous GHG emissions, in large part due to the long persistence time of fossil fuel-derived CO_2. Uncertainty in prediction on that time scale is primarily due to natural internal processes within the climate system. For predictions into the latter half of this century, the uncertainty is increasingly dominated by ‘scenario uncertainty’, due to the challenges of projecting geopolitical and socioeconomic conditions decades into the future. However, in the context of assessing risks to ringed seals, all of the illustrative scenarios in the IPCC’s Shared Socioeconomic Pathways are expected to drive substantial Arctic warming and loss of sea ice within this century.

Improved understanding of the climate response to GHG emissions has made it possible to more confidently discern which IPCC scenarios are currently plausible climate futures. Despite some progress in slowing the growth of global GHG emissions, emissions have not yet begun to decline to anywhere near the extent that would be necessary to meet the targets of the Paris Agreement and limit 21st-century warming to well below 2 °C while aiming at 1.5 °C. In this review, we consider the low and very low IPCC scenarios, SSP1-1.9 and SSP1-2.6 to be currently not credible because their budgets for remaining CO_2 emissions that would keep warming under the targets will almost certainly be exceeded within the next few years to two decades. The progress in implementing some emission reduction commitments under the Paris Agreement, however, has contributed to recognition that the highest warming scenario, SSP5-8.5, is likely avoidable.

The remaining, current IPCC illustrative scenarios, SSP2-4.5, SSP6-6.0, and SSP3-7.0, cover a range of 21st-century warming very similar to the scenarios used for the analyses in the 2010 Status Review and the listing rule. Within the range of the remaining IPCC illustrative scenarios, NMFS has considered consensus outlooks from broad coalitions of experts—including the

International Energy Agency, the United Nations Environment Program, and the National Intelligence Council—in selecting SSP3-7.0 as the assumed (i.e., ‘default’) scenario for ESA assessments and decisions at this time. The GHG emissions pathway of SSP3-7.0 is about midway between the A2 and the A1B scenarios used in the 2010 Status Review and the listing rule. Therefore, the new information accrued since the listing has not appreciably changed the magnitude and imminence of global warming expected during the remainder of this century.

Climate-driven threats to biological habitat are more difficult to predict than threats to physical habitat. While the Arctic oceans, atmosphere, and cryosphere have largely followed the paths predicted by the international climate science community over the past several decades, there has been less consensus about, and less ability to comprehensively monitor, the state of Arctic ecosystems. A few themes, however, have emerged that are relevant to threats to ringed seals.

Reduced sea ice extent and increased open-water duration has allowed more light to reach phytoplankton in Arctic seas, one of several factors responsible for a large increase in primary production. This also marks a shift in the source of the production, from sympagic under-ice algae toward phytoplankton as the dominant producers. Primary production is predicted to increase further as the Arctic continues to warm, but there is uncertainty about whether and when nutrient limitation might curtail this trend. The types and sizes of algal cells can dictate the species that are successful as grazers and higher consumers, structuring the energy pathways and efficiencies of transfer to ringed seals. Therefore, the amount of primary production may be less important to ringed seals than the trophic pathways to their prey but it is not currently possible to predict whether ringed seals will benefit from increased Arctic primary productivity.

There is now a well-documented trend of borealization in which formerly sub-Arctic species have expanded or shifted north, and true Arctic species have contracted in range. The trend has been observed across trophic levels from the plankton to top predators. Incursion of sub-Arctic prey and predator species into the Arctic poses risks of disrupting ringed seal demography from both the bottom up (prey) and the top down (predators). Of particular concern is a decline in abundance and range of Arctic cod, a primary prey for Arctic ringed seals throughout much of their range. Arctic cod are energy-dense, high quality prey, and they facilitate a relatively efficient transfer of energy to higher trophic species. Borealization is closely interrelated to a suite of observed shifts in food web dynamics. Because some warming-driven shifts in food webs stem from widely-applicable ecological rules—reduced body size of ectotherms, range shifts toward higher latitudes, and shifts of seasonal life cycle events—it may become more feasible to predict future food web dynamics. An extensive, multi-authored review of climate impacts on Arctic cod predicted an overall decrease in suitable habitat, and associated decline in Arctic cod biomass through mid-century, particularly in areas characterized by advection of warmer Atlantic and Pacific waters. Another study, focused on the future of Pacific Arctic biodiversity, suggested that the expansion of larger generalist predatory fish to the Arctic shelves could reduce the biomass of typically smaller and less fecund Arctic species which, presumably, would include Arctic cod.

Ocean acidification in the Arctic is happening three to four times faster than in the other ocean basins. Increased atmospheric CO_2 uptake is the main driver of ocean acidification; however, other processes that are prevalent in the Arctic also contribute (e.g., freshening from ice melt and terrestrial river runoff), and it is likely that the combination of processes have amplified ocean acidification in the Arctic. Although ocean acidification does not appear to directly affect ringed seals, it does affect ringed seals' prey, and several studies have documented negative effects on their prey due to ocean acidification. Models indicate that future ocean pH levels in the Arctic will continue to decrease through this century. It is difficult to predict how ocean acidification will affect ringed seals, but food web dynamics in the Arctic will be impacted, which will have unknown and potentially adverse consequences for ringed seals.

In summary, the threats to Arctic ringed seals from present or threatened destruction or modification of its habitat or range are of similar magnitude (severity and scope) to those identified and judged by the BRT in the 2010 Status Review to be of *high* significance. The primary threats continue to be the amount and phenology (timing) of ice and snow cover, habitat features essential to successful reproduction and rearing of young. There is substantially more information available about the nature of the threats to both the physical and the biological components of the seal's habitat. The additional information lends greater confidence to the conclusions of the 2010 Status Review and to the rationale for providing protection to Arctic ringed seals under the ESA. The habitat threats, nearly all of which stem from human-caused climate change and are anticipated to become acute later in this century, are naturally somewhat more imminent than they were at the time of listing, simply by virtue of the decade that has elapsed.

Okhotsk Ringed Seal

In the 2010 Status Review, the BRT judged the overall significance of threats to Okhotsk ringed seals from the present or threatened destruction, modification, or curtailment of its habitat or range to be midway between *high* and *very high*. The individual habitat-related threats with the highest scores were "decrease in ice habitat suitable for whelping and nursing" and "increased hypothermia due to insufficient depth and/or duration of snow cover". These scores reflected in part that model projections suggested snow cover was already inadequate for birth lairs, and available information indicated many Okhotsk ringed seals apparently depended on sheltering in the lee of ice hummocks on pack ice. Since the 2010 Status Review, additional research has determined that landfast sea ice extent and duration, sea ice production, and sea ice volume have all shown declining trends in the Sea of Okhotsk in recent years. Although there is still considerable variability in sea ice cover from year to year, given the ongoing decline of sea ice, the significance of the sea-ice habitat related threats to Okhotsk ringed seals is at least equal to the significance determined in 2010, and potentially more severe since sea ice declines appear to be continuing.

Baltic Ringed Seal

In the 2010 Status Review, the BRT scored the overall significance of threats to Baltic ringed seals from the present or threatened destruction, modification, or curtailment of its habitat to be midway between *high* and *very high*. The individual habitat-related threats with the highest scores were “decrease in ice habitat suitable for whelping and nursing” and “increased hypothermia due to insufficient depth and/or duration of snow cover”.

For our review of new information on the Baltic ringed seal’s habitat or ecosystem conditions, we relied on two comprehensive reports compiled by leading regional experts that summarized and assessed recent research on the effects of climate change on the Baltic Sea region (HELCOM and Baltic Earth 2021; Meier et al. 2022). Regarding observed changes to the physical components most directly related to the ringed seal’s habitat or ecosystem, the studies reported that Baltic air and sea surface temperatures and heavy precipitation events have increased while sea ice and snow cover have declined. The decreases in sea ice and snow cover have accelerated in recent years. These trends are expected to continue with future climate warming.

In Bothnian Bay, the birth rate of adult female ringed seals improved in recent decades following a period of low reproductive health due to environmental contaminants. The population growth rate, however, does not appear to be increasing at a similar rate, and may be hampered by poor ice conditions during the nursing period. Earlier ice breakup and lower ice coverage have also impacted ringed seal behavior and distribution during aerial surveys, which has led to extremely variable abundance estimates and made trend analysis infeasible. New survey and/or analytical methods are needed to account for these changes.

In the southern subpopulations, new survey methods have been under development due to a lack of ice in most years. These subpopulations are quite small yet appear to be relatively stable. There is considerable concern for these subpopulations, however, partly because the sea ice and snow cover declines have been greater in this region compared to Bothnian Bay. In recent years with particularly early ice breakup, there have been reports of ringed seals giving birth and nursing their pups on land, and land haul-outs have become increasingly important during the molting period as ice has become increasingly rare. No estimates of productivity or mortality rates are available for this region.

This new information indicates that the Baltic ringed seal’s sea ice habitat has been reduced in quality, extent, and duration, and that these reductions are expected to continue. The habitat threats, nearly all of which stem from human-caused climate change and are anticipated to become acute later in this century, are naturally somewhat more imminent than they were at the time of listing, simply by virtue of the decade that has elapsed.

Ladoga Ringed Seal

In the 2010 Status Review, the BRT scored the overall significance of the threats to Ladoga ringed seals from the present or threatened destruction, modification, or curtailment of its habitat to be midway between *high* and *very high*. The individual habitat-related threats with the highest scores were “decrease in ice habitat suitable for whelping and nursing” and “increased hypothermia due to insufficient depth and/or duration of snow cover”.

We found very little new information that specifically addressed changes in the physical components of the Ladoga ringed seal’s habitat. The new information we did find indicated that the lake ice is forming later in the fall and melting earlier in the spring, resulting in a shorter ice season, and winters with intermittent ice (i.e., less than 100% coverage) are becoming more frequent. These trends are expected to continue with future climate warming.

Although this new information is limited and not directly comparable to the observations and projections cited in the 2010 Status Review, it indicates that the Ladoga ringed seal’s lake ice habitat has been reduced in both seasonal duration and coverage, and these reductions are expected to continue. The habitat threats, nearly all of which stem from human-caused climate change and are anticipated to become acute in the coming decades, are naturally somewhat more imminent than they were at the time of listing, simply by virtue of the decade that has elapsed.

2.4.2. Overutilization for commercial, recreational, scientific, or educational purposes

In the 2010 Status Review, the BRT judged the threats from overutilization to each of the ringed seal subspecies to be of *low or zero* significance, and NMFS concluded in the listing rule that, “there is no evidence that overutilization of ringed seals is occurring at present.” Our review of new information indicates that this is still an accurate assessment because: 1) The total numbers of ringed seals used for scientific or educational purposes are small and are not expected to increase significantly in the future; 2) While new information about harvest levels is limited for Arctic and Okhotsk ringed seals, there is no evidence of increased harvest or over-harvest of these subspecies. In Greenland, where the largest subsistence harvests take place, and in Alaska, there is evidence of declining harvests; 3) Reported harvest of Baltic ringed seals has increased in recent years and is thought to be one of the main pressures affecting the abundance and growth rate of Baltic ringed seal populations (HELCOM 2023c), but we found no information indicating that over-harvest of Baltic ringed seals is occurring at present; and 4) Hunting of Ladoga ringed seals remains prohibited. As noted in the listing rule, "Accurate information on both harvest levels and the species' population size and trends will be needed in order to assess the impacts of hunting as well as to respond appropriately to potential future climate-induced changes in populations."

2.4.3. Disease, parasites, or predation

Arctic Ringed Seal

Diseases and parasites—In the 2010 Status Review, the BRT judged the significance of the threat to Arctic ringed seal populations from disease and parasites to be *low*. Since the 2010 Status Review, ringed seals have tested positive for protozoan, bacteria, and virus species that have previously been found, and the prevalence rates for all species were low (Simon et al. 2011; Nymo et al. 2018; Reiling et al. 2019; VanWormer et al. 2019). Studies that screened apparently healthy Arctic ringed seals for disease surveillance programs found a novel parasite, *Sarcocystis pinnipedi*, and a novel gammaherpesvirus in ringed seals; however, the prevalences were low, and the infected seals did not show signs of disease. Neither novel disease appeared to cause morbidity or mortality in ringed seals (Haman et al. 2015; Bellehumeur et al. 2016).

Since 2010, only a couple new species of helminth parasites have been found in Arctic ringed seals (Soltysiak et al. 2013; Karpiej et al. 2014; Walden et al. 2020), and all other species found in Arctic ringed seals since 2010 (Seymour et al. 2014a; Walden et al. 2020) were documented in Arctic ringed seals previously (Kelly et al. 2010). Although numbers of helminths are increasing in fishes across the world, none of the recent studies found high rates of infection or evidence of mortality in Arctic ringed seals due to helminths.

The potential expansion of harmful algal bloom (HAB) toxins farther north into Arctic ringed seal habitat due to warming climate trends and increasing water temperatures poses a risk for ringed seals. Ringed seals were positive for domoic acid and saxitoxin in a study of HAB toxins in marine mammals in Alaska, but the effects that increasing HAB toxins will have on ringed seal populations are still unknown (Lefebvre et al. 2016).

Since the 2010 status review, ringed seals in Alaska have been part of two Unusual Mortality Events (UMEs) declared by NOAA Fisheries. During the first UME (2011-2016), high numbers of sick and dead seals were found throughout the Arctic and Bering Strait regions of Alaska. In the second UME (2018-2022), large numbers of dead seals were stranding in the Bering and Chukchi Seas. Extensive testing was conducted for each UME, and no known cause has been identified for either UME, although testing is ongoing for the 2018-2022 UME. Although neither UME appears to have caused declines in ringed seals in Alaska, the occurrence of two UMEs in a short time period, with unknown causes, indicates that conditions in the Arctic are changing in complicated and unidentified ways, which poses new threats to ringed seals that are difficult to assess.

Predation—In the 2010 Status Review, the BRT judged the threat to Arctic ringed seal populations from predation to be *moderate*, primarily because predation was expected to increase due to changes in sea ice and snow cover. Since 2010, however, studies have found that polar bear predation on ringed seals may be reduced in some regions or that interannual variability in predation has a negligible effect on the ringed seal population. In years of low pup productivity, polar bears switched to select older seals for prey rather than pups, which are preferred in typical years (Pilfold et al. 2012; Reimer et al. 2019a). Increased predation on older seals does not appear to negatively affect ringed seal population growth, and with declining polar bear numbers in some regions, the impact of polar bear predation on ringed seals could be reduced (Bromaghin et al. 2015; Reimer et al. 2019a). In some areas of the Arctic, polar bears consume fewer ringed seals during years of lighter sea ice conditions and/or warmer climate indices (Pilfold et al. 2015; McKinney et al. 2017; Florko et al. 2021b; Rode et al. 2021); however, the opposite pattern has been found for other regions or polar bear sex and age classes (Sciullo et al. 2017; Florko et al. 2021b), so changes in predation in response to climate change may not be uniform. Another study examined polar bear and ringed seal movements to evaluate changes in spatial overlap before and after a sudden decline in sea ice, and they determined that there was a significant decrease in spatial overlap between the species after sea ice declined (Hamilton et al. 2017a). A decrease in spatial overlap between these species indicates that their predator-prey relationship would also weaken, which suggests that declining sea ice could lead to reduced polar bear predation on ringed seals (Hamilton et al. 2017a; Yurkowski et al. 2020).

Threats to ringed seal populations due to other predators are also uncertain. Stable isotope analysis of Pacific walrus tissues have indicated that walrus consume more higher trophic-level prey than observed from stomach content analysis, suggesting that walrus may change to forage on pinnipeds and seabirds during stressful times when their usual benthic invertebrate prey might not be available (Seymour et al. 2014b); however, direct evidence of increased walrus predation on ringed seals has not been observed.

Over the past decade (2010 to present) passive acoustic monitoring and sighting data have provided evidence that killer whale numbers are increasing in the Arctic, and they are moving farther north in both the eastern Canadian Arctic and Pacific Arctic (Higdon and Ferguson 2009; Ferguson et al. 2010; Stafford et al. 2022a, 2022b). Despite the fact that killer whale numbers have increased in Hudson Bay, Canada, and are observed there every year, some models have predicted that predation would not greatly affect the population growth of ringed seals in the area (Ferguson et al. 2010, 2012). However, a recent study that used quantitative fatty acid analysis to estimate diet composition determined that the diets of a quarter of the whales sampled in the eastern Canadian Arctic were dominated by ringed seals (Remili et al. 2023).

Since the 2010 Status Review, new information has not indicated that threats to Arctic ringed seal populations due to disease or parasites have increased substantially, and the threat from polar bear predation may be reduced in some regions. In contrast, the steadily growing presence of killer whales in the Arctic as sea ice has declined, and the recent evidence that ringed seals dominate the diets of some killer whales in the eastern Canadian Arctic, indicate that killer whale predation on ringed seals in the Arctic may be increasing and has the potential to affect ringed seal populations. Because declining risk from some predators could be offset by increasing risk from others, we conclude that there has been no substantial change in the overall predation risk since the listing.

Okhotsk Ringed Seal

Our review did not identify any new information about disease, parasites, or predation of Okhotsk ringed seals that became available since the time of listing. However, the effects of a warming climate in the Sea of Okhotsk are likely to be similar to changes that have been observed in Arctic waters due to warming temperatures and declining sea ice. For Arctic ringed seals, it was determined that threats due to disease, parasites, or predation had not increased since the 2010 Status Review or have the potential to become problematic in the near future, and it is likely that the severity of these threats will be comparable for Okhotsk ringed seals.

Baltic Ringed Seal

The significance of disease, parasites, and predation threats to Baltic ringed seals was judged to be between *moderate* and *high* in the 2010 Status Review. Since then, we found only one study on disease in Baltic ringed seals that was subsequently published. This study found the first evidence of exposure to *Brucella* spp. in Baltic ringed seals with a low prevalence of seropositive seals (Sonne et al. 2018). Evidence of exposure and infection of *Brucella* spp. in Arctic ringed seals has been reported, but reproductive failure in seals exposed to *Brucella* spp. has not been documented (Kelly et al. 2010). The new finding of exposure to *Brucella* spp. in Baltic ringed seals suggests that the population should be monitored for this in the future. One cestode helminth species was found in a small sample of Baltic ringed seals, and it was a species that has been detected in seals before (Nyman et al. 2021). The threat to the Baltic ringed seal population from disease, parasites, or predation does not appear to have changed substantially since the listing.

Ladoga Ringed Seal

Since the 2010 Status Review, one Ladoga ringed seal was examined for helminths, and DNA sequencing was used to identify the species. Only one cestode species was identified in the seal, and it was a species that had not been previously reported in seals. The threat to the Ladoga ringed seal population from disease, parasites, or predation likely has not changed from the significance in the 2010 Status Review, which was between *moderate* and *high*; however, the potential for disease epidemics may increase with a warming climate, and Ladoga ringed seals are at high risk under epidemic scenarios because of their small population size and limited range (Trukhanova 2013). The lack of current information and the potential for a serious risk situation due to disease outbreaks makes it difficult to assess the threat to Ladoga ringed seals from disease, parasites, and predation, but the overall threat does not seem to have changed since the 2010 Status Review.

2.4.4. Inadequacy of existing regulatory mechanisms

In all, there is no new information since listing that suggests existing regulatory mechanisms affect the magnitude or imminence of previously identified threats. The principal threats to all four ringed seal subspecies continue to stem from declines in sea or lake ice and the depth and seasonal persistence of snow cover on ice within the foreseeable future. NMFS concluded in the listing rule that, “Current mechanisms do not effectively regulate GHG emissions, which are contributing to global climate change and associated modifications to ringed seal habitat.” NMFS explained in the listing rule that because, “The projections we used to assess risks from GHG emissions were based on the assumption that no new regulation will take place (the underlying IPCC emissions scenarios were all ‘nonmitigated’ scenarios) . . . the inadequacy of mechanisms to regulate GHG emissions is already included in our risk assessment, and contributes to the risks posed to ringed seals by these emissions.”

Our review of information concerning changes in regulatory mechanisms aimed at limiting GHG emissions indicates that there has been some progress in addressing anthropogenic GHG emissions since the listings. However, there are still no mechanisms in place that would effectively reduce emissions to the extent necessary to address the primary threat to each of the ringed seal subspecies from reductions in their sea ice habitat within the foreseeable future. The inadequacy of regulations governing GHG emissions was considered above as part of our analysis of threats from present or threatened destruction, modification, or curtailment of the subspecies’ habitat or range.

Inadequacy of existing regulatory mechanisms to regulate bycatch of Ladoga ringed seals was found in the listing rule to be “contributing to the severity of the threat posed by fisheries interactions with that subspecies, and compounds the effects of threats induced by climate change.” Our review indicates that concerns persist about bycatch of Ladoga ringed seals in fishing gear, and we identified no new regulatory mechanisms that address this threat.

2.4.5. Other natural or manmade factors affecting its continued existence

2.4.5.1. Contaminants

Arctic Ringed Seal

Most of the contaminants that have been measured in Arctic ringed seal populations since the 2010 Status Review in 2010 have declined (see Section 2.3.11 of this review). Total mercury (Hg) concentrations have shown slow declines over the past 45 years (Houde et al. 2020). Arctic ringed seals had some of the lowest Hg concentrations of five groups of phocids that were examined in one study (Aubail et al. 2011); however, changes such as a shorter ice season and a decrease in ice cover may increase the risk of Hg exposure in ringed seals in the Arctic (Pinzone et al. 2019).

Similarly, most persistent organic pollutants (POPs) that were measured in Arctic ringed seals showed a significant general decline, which suggests that regulations to ban and limit their production have led to long-term reduction of POPs in Arctic ringed seals (Vorkamp et al. 2011, 2012; Houde et al. 2017, 2019). The transfer of POPs from mother to fetus in Arctic ringed seals was also found to be very low (Brown et al. 2016). However, Riget et al. (2013) found that years with more sea ice correlated with lower PCB levels in Arctic ringed seals, which is concerning and important to consider with the warming conditions in the Arctic.

Perfluorinated contaminants (PFCs) in Arctic ringed seals showed similar trends as the POPs. Most of the PFC concentrations that were measured decreased or stayed level (Riget et al. 2013; Law 2014; Routti et al. 2016). One type of PFC did show a slow increase in ringed seals in recent years, which suggests that some of these compounds are still present in the Arctic and may be increasing (Rotander et al. 2012).

Overall, contaminants measured in Arctic ringed seals since the 2010 Status Review have remained level or decreased, thus, the immediate threat from contaminants is likely to be *low*. Several studies indicated that changes associated with the warming climate (e.g., shorter ice season, less sea ice) may lead to increased risks to ringed seals from contaminants, so it is important to continue to monitor them in Arctic ringed seal populations.

Okhotsk Ringed Seal

Our review did not identify any new information about contaminants in Okhotsk ringed seals that became available since the time of listing. In the Arctic, contaminants in ringed seals overall have declined in the past decades. Declines in contaminant levels in ringed seals are closely related to policies that have banned or restricted the use of many contaminants, so it is difficult to assess if changes in contaminant levels in Okhotsk ringed seals would be comparable to Arctic ringed seals.

Baltic Ringed Seal

Although a study of Baltic ringed seals found that higher levels of persistent organic pollutants (POPs) were related to levels of thyroid hormones that were high enough to disrupt endocrine functions (Routti et al. 2010), overall contaminant levels in Baltic ringed seals have declined over the past decades (Bjurlid et al. 2018). Thus, the threat to Baltic ringed seals from contaminants is likely to be *low*.

Ladoga Ringed Seal

A review with an analysis of pollutant levels in lakes in northwest Russia, including Lake Ladoga, indicated that pollutants in the lake have varied widely over the last century. The highest levels of contamination in the lakes occurred in the 1970s, but pollutants have decreased since 1990 due to less industrial production and more emission controls, suggesting that the lakes may be recovering to a more productive ecosystem (Moiseenko and Sharov 2019). Hair samples of Ladoga ringed seals, collected in 2020–2021, were analyzed for concentrations of trace elements. Overall, the levels of trace elements were relatively low, and several of the elements were significantly lower than in the 1990s (Trukhanova et al. 2022). Although there is little information about contaminants in Ladoga ringed seals, the threat to the population from contaminants is probably *low*.

2.4.5.2. Fishery interactions and bycatch

Arctic Ringed Seal

In the United States, incidental take of Arctic ringed seals by commercial fisheries has been low from the 1990s through 2018 (most recent estimates), with an average of 5 seals per year and a maximum of 14 seals per year. Information about incidental takes of ringed seals in other areas of the Arctic is limited, and observer coverage in most fisheries is low. Since the 2010 Status Review, incidental takes of ringed seals have been reported from Icelandic waters, and estimates ranged from 0 to 53 seals per year. Although the numbers of Arctic ringed seals taken in commercial fisheries have been low and are not likely to affect abundance, information about interactions with fisheries in most areas is limited. Additionally, the potential for increased commercial fishing in the Arctic due to warmer waters, less sea ice, and changing fish species suggests that fishery bycatch could negatively affect Arctic ringed seals in the future. In spite of this, the Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean, which prevents commercial fishing operations in the high seas portion of the Central Arctic Ocean, went into effect in 2021 and will remain in force for 16 years (Balton 2021). This is a hopeful step toward avoiding increased fisheries interactions in areas of the high Arctic, at least for the duration of the agreement. The significance of the threats to Arctic ringed seals from bycatch is likely to be *low*.

Okhotsk Ringed Seal

Since the 2010 Status Review, there has been no new information about incidental take of Okhotsk ringed seals in commercial fisheries. Intensive commercial fishing occurs in the Sea of Okhotsk, thus some level of bycatch is probable, but the magnitude is unknown. It is difficult, therefore, to assess the effects that fishery interactions will have on the Okhotsk ringed seal population.

Baltic Ringed Seal

Data about bycatch of Baltic ringed seals in commercial fisheries is limited, but recent numbers of ringed seals taken in a fyke net fishery from 2008 to 2013 were fairly low. Additionally, after nets and equipment in that fishery were modified to mitigate ringed seal takes, survival of ringed seals caught in the nets increased from zero to 70%. The lack of information about bycatch of Baltic seals makes it difficult to predict how fisheries will affect the population. Even so, recent take numbers were low, and ringed seals that interacted with the fishery had much greater survival after nets were modified, which suggests that fishery interactions are not likely to substantially affect Baltic ringed seal abundance.

Ladoga Ringed Seal

In Lake Ladoga, commercial fishery interactions have been a significant source of mortality for Ladoga ringed seals since the early 1900s. Although recent fisher surveys (2007–2019) indicated that bycatch of ringed seals has declined substantially, there have been no regular bycatch monitoring efforts with any of the fisheries since 2012. Actual numbers of incidental takes and the location of commercial fisheries in the lake are both uncertain, and bycatch estimates may be biased low due to under-reporting. Therefore, fisheries bycatch is likely to persist as a significant threat for the Ladoga ringed seal.

2.4.5.3. Shipping and transportation

Arctic Ringed Seal

As detailed in the 2010 Status Review, the most significant acute threat to ringed seals from shipping is an accidental oil discharge due to a maritime disaster, in part attributed to the extreme challenges of mounting a cleanup response in the Arctic (as addressed in this review, Section 2.4.5.4). More recent assessments substantiate oil spills as the most significant environmental threat from shipping (AMAP/CAFF/SDWG 2013). Though there have been major advances in the last decade with regard to modeling the behavior of oil spills under more explicit treatment of Arctic conditions, and improvements in recommended mitigation measures, we found little evidence of significant improvements to spill response infrastructure along coastlines adjacent to the NSR and NWP—beyond early planning—that would currently enable a timely and predictable cleanup effort of an oil spill across the vast majority of Arctic vessel routes. In Alaska, despite much needed progress in response planning in recent years, in particular planning responses for Arctic marine mammals in the event of oil discharges of varying magnitudes, there is an ongoing recognition that the human resources and infrastructure in Arctic coastal communities needed to base a response are largely still lacking (Wright et al. 2017). As addressed in the 2010 Status Review, and reviewed here (Section 2.4.5.4), studies of longer-term impacts from a major discharge or chronic (even legal) oil releases and contamination from ships are still needed, though in a recent opportunistic study of oiled seals (with available controls), lasting injuries were demonstrated (Stimmelmayr et al. 2018). There is more discussion of oil spill threats related to oil and gas development in Section 2.4.5.4 of this review.

As discussed in this review (Section 2.4.5.4), and previously in the 2010 Status Review, noise from anthropogenic sources can have significant effects on sound-orienting pinnipeds, including masking of communication, displacement, and, in some cases, permanent damage to auditory systems (Reichmuth et al. 2019). There is a growing awareness that more chronic anthropogenic noise in the Arctic may have disproportionate effects on marine mammals due to relatively low ambient sound levels, resulting in noise detection over long distances, with implications for habitat exclusion and masking (Halliday et al. 2020). Studies of ambient noise in the Arctic report seismic airguns and vessel traffic (particularly icebreakers) as the most common anthropogenic sources (Halliday et al. 2020), with the latter largely accounting for the steep gradient in background noise from lower (noisier) to higher (quieter) latitudes. Most acoustic studies on marine mammals have focused on acute responses with few examining effects of chronic noise exposure, or any cumulative and/or interactive response in conjunction with multiple noise or physical stressors. Although projected (and now realized) increases in vessel traffic in the Arctic have and will continue to alter the soundscape under which Arctic species have evolved, we found no conclusive information bearing on whether these changes have or will mask ringed seal communication, cause displacement, affect energetic budgets, or have any other effects related to sound that would likely impact population demographics over the long-term. Only recently have technological advances allowed for simultaneous recording of sound exposure and response in small pinnipeds, so that the biological significance of noise can be better understood (Mikkelsen et al. 2019).

With increased AIS tracking of vessels (and data availability), and greater awareness of movement patterns across the Arctic, there have been recent efforts to quantify the overlap of vessels and ringed seals during both the spring pupping season, in ice-covered waters, and during the open-water season (Wilson et al. 2017, 2019; Hauser et al. 2018). Vessel-based observations of Caspian seals during approaches of ice-breakers provide the most comprehensive and relevant comparison to potential threats similarly faced by ringed seals near shipping channels during the sensitive pupping period (Wilson et al. 2017). These threats include fragmented habitats (e.g., destroyed lairs, altered ice near birth sites), mother-pup separation (some permanent), and ship-seal collisions (direct mortality; Wilson et al. 2017). Despite some hundreds to thousands of mother-pup pairs estimated to be exposed to these threats along a single icebreaker route in the Caspian, the demographic consequences of direct mortality, degraded pupping habitat, and additional energetic costs of repeated disturbance are not known at this time (Wilson et al. 2017, 2019). By comparison, the much larger Arctic icebreakers can negotiate thicker ice at higher speeds with implications for collision avoidance and possible maneuvering (Wilson et al. 2017). Areas in the Arctic projected to have the highest overlap between industrial vessel traffic and ringed seals, during the pupping season, are in the vicinity of major shipping ports: Gulfs of Bothnia and Finland in the Baltic Sea, the White Sea, and Tartar Straits in the Sea of Okhotsk; and in regions overlapping hydrocarbon exploration and production: Gulf of Ob in the Kara Sea and East Sakhalin Island in the Sea of Okhotsk. Conversely, Hauser et al. (2018) identified many of these same areas as not having high vulnerability to shipping for ringed seals during the open-water season, but rather identified other areas as most vulnerable: Laptev Sea (adjacent to the NSR), Bering Strait, and areas along the NWP in Canadian Arctic, thus highlighting the importance of addressing seasonal differences in vessel impacts. Despite these studies showing areas of high vulnerability of ringed seals to threats by vessels, we found no detailed assessments of ringed seal behavior in the presence of vessels beyond icebreakers.

We found convincing evidence that the substantial increases in Arctic shipping forecast in the 2004 Arctic Marine Shipping Assessment (2-3 fold increases by 2020; Arctic Council 2009), and reported in the 2010 Status Review, have been realized and in most cases been exceeded. As expected, destination shipping demands have increased in response to building infrastructure to support new production streams in resource extraction, in particular new offshore drilling projects in the Kara Sea and land-based LNG terminals on the Yamal and Gydan peninsulas, each supported by icebreakers and ice-class tankers.

Greater presence of ships in the Arctic—both in terms of distance-traveled and time— can be attributed to a combination of economic and climate variables, with increased seasonal access (e.g., reduced sea ice) and ship (e.g., natural resource) demands as regulating forces. Though refined climate and industry analyses have put up more reliable temporal and spatial scenarios suggesting how greater access to trans-Arctic routes will materialize, geopolitical tensions have had the opposite effect of adding uncertainty to future resource extraction, market demand, and thus Arctic shipping needs. There is also much uncertainty about the global transition to renewable energy, which will impact future Arctic shipping. Still, despite uncertain future investment and profitability in Arctic shipping, and a high degree of volatility in navigating trans-Arctic routes with declining but variable seasonal ice, Arctic shipping is likely to continue its upward trajectory. New oil and gas megaprojects along the Beaufort (Willow) and Kara (Vostok) shelf areas stand to boost shipping traffic during construction to about 2030, after which traffic along the NSR (particularly icebreaker convoys) will likely increase dramatically as Russian exports to Asia ramp up from what will then be Russia's and the Arctic's largest oil terminal.

In 2010, trans-Arctic shipping was essentially non-existent, and shipping along the NSR and NWP was more experimental than profitable. Traffic along those routes, but especially along the NSR, has since risen dramatically, though is still predominantly destination-based. Trans-Arctic shipping is evolving more slowly while still facing uncertain profitability and risks due to still variable ice conditions in navigationally challenging areas over the continental shelf that are incompletely mapped, as illustrated by the recent icebreaker rescue of more than a dozen ships beset in the Laptev Sea after an early freeze up. With new oil and gas developments along the Kara Sea, and construction beginning on another—and shipping corridors to both likely overlapping ringed seal habitat—this region is projected to be an area of increased threats to ringed seals. The Willow project along the Beaufort Sea coastline, and new proposals to expand the U.S. Alaska Marine Highway into the Arctic, will also likely increase shipping traffic through ringed seal habitat in the Bering Sea, Bering Straits, and Beaufort Sea. So, as was the case at the time Arctic ringed seals were listed, persistent and evolving threats to ringed seals from shipping will be regionally intensive, with the overall physical and acoustic footprint of ships in the Arctic projected to continue increasing.

Since 2010, a greater than two-fold increase in shipping across the NWP and NSR, still inadequate resources and infrastructure to respond to a major oil discharge along the vast majority of vessel routes, new analyses showing close overlap between shipping "hot spots" and ringed seals during both the ice breeding and open-water seasons, and new hydrocarbon megaprojects developing along Russian (Kara Sea) and U.S. (Beaufort Sea) coastlines with significant vessel support for construction, suggests the threats from shipping to Arctic ringed seals has increased, though within the range of trajectories projected in the 2010 Status Review.

Okhotsk Ringed Seal

See the section above on Arctic ringed seals for more broadly applicable threats that relate to Okhotsk ringed seals. As in the 2010 Status Review, there is still very limited information on current shipping levels and trends, and even less on future projections for the Sea of Okhotsk. Still, significant expansion of oil production on Sakhalin Island since 2010 points to an increase in disturbance threats to ringed seals from industrial shipping, particularly icebreakers and ice-class tankers. The Strait of Tartar (west of Sakhalin) and East Sakhalin were identified as ringed seal breeding areas that overlap closely with high levels of vessel traffic during the spring (Wilson et al. 2019). As documented for Caspian seals (Wilson et al. 2017), direct interactions between mother-pup pairs and icebreaking vessels can cause mortality and for others a likely energetic cost, which can accrue for individuals over the nursing period when a haul out area is confined by land or ice extent, and regular vessel traffic causes repeated disturbance and increasingly degraded habitat.

Since 2010, despite limited direct information on changes in shipping, the continued and extensive expansion of industrial activity around Sakhalin Island in conjunction with oil and gas development, and the equally extensive increase in shipping activity that would be expected to maintain and transport these new production streams, in conjunction with new analyses showing close overlap between shipping "hot spots" and known breeding areas for ringed seals, suggests the threat from shipping to Okhotsk ringed seals has increased, though within the range of trajectories projected in the 2010 Status Review.

Baltic Ringed Seal

See the section above on Arctic ringed seals for more broadly applicable threats that relate to Baltic seals. As described in the 2010 Status Review, the Baltic Sea saw significant growth of shipping in the preceding decades, especially oil transportation, to currently host some of the highest densities of ships in the world with up to 15% of the world's cargo plying its waters. Despite little apparent growth in cargo shipping more recently, threats to ringed seals remain relatively high from disturbance, particularly from icebreakers in the Gulfs of Finland and Bothnia during the spring pupping period, and from accidental and illegal oil discharges from ships in the southern Baltic and the Gulf of Finland. Though icebreakers are still opening shipping channels throughout the seasonal ice period, and we found no current monitoring of icebreaker impacts to ringed seals, we expect at least modest threats from acoustic and physical disturbance and habitat destruction to persist, as reported in the 2010 Status Review. As noted in the section above on Arctic ringed seals, Wilson et al. (2019) highlighted the breeding areas of ringed seals in the Gulfs of Bothnia and Finland as having some of the highest vessel counts and thus highest threats from shipping across all breeding areas identified in the Arctic and sub-Arctic. It is also notable that vessels pushing through ice habitat in the Gulfs of Bothnia and Finland were some of the largest vessels (median > 99 m) and were the fastest (median > 10.6 knots), compared to the other areas studied (Wilson et al. 2019).

The numerous oil and gas terminals in the Gulf of Finland draw tankers that compose at least half of the oil transportation in the entire Baltic. Starting in about 2000, with oil tankers increasing in capacity and frequency, there was a 4-fold increase in Baltic oil volumes over a 12-year period (3-fold in ship numbers). Though growth is projected to level off through 2030, at present there are up to 500 tankers in the Baltic on a given day. Of most recent concern are the geopolitical circumstances causing large numbers of so-called "ghost tankers"—with novice crew, aging ships, and often without AIS—to transit Russian oil terminals in the Gulf of Finland due to a cap on oil prices from global sanctions. With two LNG pipeline ruptures in the last two years from apparent sabotage, the unknown environmental impacts and maritime security in the Baltic have also become growing concerns. Despite the relatively high level of spill-response preparedness, the comparatively small area of the Baltic Sea, with low turnover and seasonal presence of sea ice, points to the threats to ringed seals from a maritime disaster being potentially significant if not catastrophic.

Since 2010, the significant development of oil and LNG terminals in Gulf of Finland, and increased tanker traffic throughout the Baltic Sea, with new concerns about vessel and crew fitness due to international sanctions on Russia, in conjunction with new analyses showing overlap between shipping “hot spots” and known breeding areas for ringed seals in the Gulfs of Bothnia and Finland–both with high vessel counts (and largest and fastest-moving ships) compared to breeding areas across the Arctic–suggests the threat from shipping to Baltic ringed seals has increased, though within the range of trajectories projected in the 2010 Status Review; greater uncertainty is anticipated in the future.

Ladoga Ringed Seal

See the section above on Arctic ringed seals for more broadly applicable threats that relate to Ladoga seals. As reviewed in the 2010 Status Review, Lake Ladoga has experienced previous oil spills from shipping so with recent data suggesting no obvious trends in barge traffic along the adjoining waterway, we expect discharges from larger vessels to be a persistent though still a low-frequency threat to Ladoga ringed seals and their habitat. Dramatic increases in lake tourism over the last two decades, however, points to increasing smaller boat traffic (private and commercial), which was reported in the 2010 Status Review as a source of disturbance to seals hauled out on the lake’s offshore islands, sometimes causing mass disturbance events. This elevated threat to Ladoga ringed seals from small vessel disturbance stands to increase further, a trend not anticipated in the 2010 Status Review. Moreover, these threats may be compounded by increasing diversity of smaller craft (varying types and speeds), which may lead to a higher frequency of collisions and discharges. Ringed seals in nearby Lake Saimaa, which is experiencing similar growth of tourism, flushed in response to small boats as far out as 500 m (median: 150 m), a reaction deemed more tolerant than Arctic ringed seals possibly due to habituation and/or lack of predators (Niemi et al. 2013). The recently established Ladoga Skerries National Park will likely sustain and possibly increase tourism to the area, but it remains unclear whether there are any new protections for ringed seals that haul out within the Park (Osipov 2023).

Since 2010, cargo traffic has not shown any obvious trends, though an unexpected and significant boost in lake tourism stands to increase small boat traffic and in turn the frequency of disturbance to ringed seals, particularly when hauled on islets and lake ice during sensitive periods of whelping and pupping. To the extent that increasing visitation continues to promote new shoreline infrastructure, and year-round residency, we project overall human presence on lake waters to be a growing threat, particularly if climate-induced loss of lake ice enhances year-round human access. Though we found no empirical data on increases in anthropogenic threats on the lake, similar patterns and concerns at nearby Lake Saimaa suggest that the threat to Ladoga ringed seals from vessel-based tourism has a high potential to be significant now or in the near future, particularly with continued, rapid development around the lake.

2.4.5.4. Oil and gas exploration, development, and production

Arctic Ringed Seal

As described in the 2010 Status Review, exploration, development, and production of oil resources involve numerous and potentially habitat-altering activities, such as seismic surveys, exploratory and production drilling, extensive construction of infrastructure, and vessel and aircraft operations. These activities, and the associated noise, physical disturbance, pollution, and particularly a possible large oil spill or blowout, each represent a unique potential threat to ringed seals. Despite known mechanisms of impact for these threats, and varied evaluations of information needs to move toward development based on mitigation strategies for species conservation, there are still multiple knowledge gaps in 1) population size and trends, habitat requirements, and physiological parameters of Arctic marine mammals (particularly for ringed seals), and 2) detecting and defining impacts, particularly cumulative impacts for which there is a critical need for standardized and universally accepted methodologies (Holland-Bartels and Pierce 2011; LeVine et al. 2014).

The subsections below detail particular threats from oil and gas development (i.e., oil spills, noise and disturbance, and seismic) that are relevant to each of the ringed seal subspecies. Discussion of how these threats pertain to Arctic ringed seals (entitled: *Status of Arctic development activities*) follows the last threat subsection, which is then followed by a discussion of each subspecies relative to the same threats.

Oil spills—The explosion in 2010 at the Deepwater Horizon mobile drilling unit in the Gulf of Mexico marked the beginning of multiple new initiatives for better understanding the anthropogenic effects on marine life, including the effects on marine mammals following a large release of oil into marine habitats (Marine Mammal Commission 2014). As pointed out in the 2010 Status Review, however, the Arctic presents unique and extreme challenges (compared to temperate waters) for mitigating the risk of an oil release, responding to an accident in freezing conditions, the remoteness and lack of infrastructure, and for containing a spill in potentially ice-covered waters. Most recently, NOAA (2017) published new recommendations, entitled: *Arctic Marine Mammal Disaster Response Guidelines*, which provide a detailed template from which to mount an oil spill response in the Arctic with a focus on reducing marine mammal impacts, including best practices covering pinnipeds. The National Research Council (2014) and PEW Environmental Group (2010) published more general guidelines for preparing for an oil spill in the Arctic, emphasizing knowledge gaps related to seasonal distributions of species and subsistence use, coastal mapping from which to stage a response, applicability of various countermeasures and sufficient testing in harsh Arctic conditions, and needs related to infrastructure and international cooperation essential in the event of significant oil spill.

Limited information has been published recently regarding actual or predicted effects of oil on pinnipeds, and especially ringed seals. Ringed seals were described as "moderately" to "extremely" sensitive to the impacts related to a large oil spill, especially if it were to occur during the breeding season and/or if the oil persisted overwinter to impact next years' breeding and/or whelping (AMAP/CAFF/SDWG 2013; NMFS 2016b). In relation to oil spills, numerous breeding and feeding habitats of ringed seals throughout the Arctic were described as "fragile and critical": the Barents Sea, the Pechora Sea, fjords of Svalbard Island, the Kara Sea, fast ice areas of the W. Yamal, adjacent to polynas in the E. Siberian Sea, Cape Bathurst Polynya (Amundsen Gulf), the Canadian Archipelago, Baffin Bay, and Davis Straits. Despite the sensitive nature of ringed seal habitat, the species itself was not viewed as particularly vulnerable (i.e., moderately sensitive) due to its scattered distribution in fast ice (AMAP/CAFF/SDWG 2013).

A recent review of the effects of oil on marine mammals summarized many of the same findings as the 2010 Status Review, highlighting the uncertainty of studying post-exposure animals without adequate controls to interpret possible changes in behavior or abundance and distribution, even following a major event like the Exxon Valdez oil spill (Helm et al. 2015). Since limited experimental exposures on seals, and field studies following the Exxon Valdez spill—both over 30 years ago—there have been no known findings on oil toxicity in phocids until recently. Following an oil spill of unknown origins in the Bering Strait region, three seals (2 spotted, 1 ringed), 50–75% oiled, were harvested and compared to unoiled seals (Stimmelmayr et al. 2018). The authors found hepatic, adrenal, pulmonary, and cardiac lesions in the oiled seals; each had relatively low levels of PAH metabolites though still elevated compared to non-oiled harvested animals (n = 91). Despite the low sample size, this unprecedented comparison with unoiled seals (having none to very few of the same lesions) provides compelling evidence of lasting injuries to phocids due to oil exposure (Stimmelmayr et al. 2018).

Oil spill response analysis has been a tool used since the 1970s to assess the risks to the environment posed by outer continental shelf oil and gas development (Damour et al. 2014). Since the 2010 Deepwater Horizon blowout, oil spill risk analysis has provided the most detailed (to date) assessments of oil spill risks to ringed seals in Alaska, particularly in relation to the State's recent and largest offshore lease sale in history: Chukchi Lease Sale 193, some 29M acres starting 60 miles offshore between Point Barrow and Cape Lisburne (BOEM 2015). The Chukchi Lease Sale 193 drew record bids on a record number of blocks (Minerals Management Service 2008); Shell had the largest bid and filed an exploration plan in 2009 (Rosen 2016). Following the British Petroleum Deepwater Horizon oil spill, Shell, in pursuing the Chukchi Lease, faced a number of legal challenges, permitting issues, court-mandated environmental studies, U.S. Coast Guard safety deficiencies and violations aboard support and rig vessels, culminating in 2012 with the grounding of its test drilling rig, Kulluk, near Kodiak Island (Rosen 2016). Shell ultimately received final approval in mid-2015 to drill two wells at the Burger J and V sites. However, in September 2015, Shell abruptly abandoned its Alaska offshore oil plans for the "foreseeable future" citing disappointing results at the Burger J well, overall high costs, and unpredictable regulatory challenges (Eilperin and Mufson 2015; Rosen 2016). Though the majority of environmental risks from Chukchi Lease Sale 193 have been precluded, to now, the focus on modeling Arctic oil spills, scenario building, risk assessments to wildlife (including ringed seals) provided new insights into the potential impacts of a large-scale, multi-decadal, offshore drilling development in the challenging seasonal ice zone of the Chukchi Sea that comprises habitat for numerous marine mammals (BOEM 2015; NMFS 2015).

Application of oil spill risk analysis, which in part uses historical spill data, had to be adapted to the Arctic because there have been no sizable oil spills in offshore, seasonal ice areas, thus requiring an approach using a "fault tree" of interacting, ice-related variables and an extended time frame that allows for the possibility of oil overwintering in sea ice before cleanup is completed or even attempted (Damour et al. 2014; BOEM 2015; NMFS 2015). These adaptive and complex efforts at forecasting acute effects (for a 77-year scenario) across a range of oil spill magnitudes, sources, seasons, and clean-up and sea conditions, are informative for assessing event-based risk over an extended period, and in this case estimating 100s to 1,000s of seals being impacted by oil releases during a project-lifetime. However, given substantial knowledge gaps regarding species biology and seasonal distributions, these predictive models shed little light on potential population-level effects from chronic exposure, lasting habitat degradation, and/or long-term species displacement due to behavioral responses. In particular, it is unknown how these effects would scale up under the small but not impossible chance of catastrophic release like Deepwater Horizon event; but in a more remote area, with less infrastructure, possibly with sea ice, and with impacts lasting for decades.

In a hypothetical 77-year scenario, where production at a site in the Chukchi Lease Sale 193 expands to 8 platforms, 500 wells, with a lifetime production of over 4B barrels of oil, BOEM (2015) estimated a 75% chance of a single large oil spill (> 1,000 barrels), an estimate arbitrarily increased to two spills over 75 years given a number of uncertainties. Further acknowledging the difficulty in forecasting rare events and using assumptions in the absence of Arctic data, BOEM (2015) estimated the chance of a Deepwater-Horizon-type event (e.g., loss of well control) in the Chukchi Sea, releasing more than 2.2M barrels, at less than 0.1% per well. In the scenario of a high-pressure blowout, if the rig were intact, intervention by drilling a relief well would take an estimated 39 days; if a second drilling rig were required, not prepositioned, oil would be flowing from the well for at least 74 days (BOEM 2015), assuming weather and sea ice did not further delay efforts. NMFS (2015), in its Biological Opinion, recognized the multitude of factors, and untested interactions, that would define the outcome of a major release of oil during the seasonal ice period and/or during extreme cold, and the similar uncertainty regarding the availability and effectiveness of blowout relief and cleanup efforts. Moreover, as is the case with previous oil risk assessments in the Arctic that had limited relevant data on the movement and fate of oil in ice-covered waters, risks have been described mostly relative to singular processes, in qualitative terms, and with a limited treatment of uncertainty (Nevalainen et al. 2017; Helle et al. 2020). Only in the last several years have there been efforts to comprehensively model oil trajectories in ice-covered waters while accounting for the interdependence of a large array of processes (Afenyo et al. 2016; French-McCay et al. 2018; Wilson et al. 2018).

Oil spill threats specific to shipping are discussed in Section 2.4.5.3 in this review.

Noise and physical disturbance—The 2010 Status Review defined the mechanisms of noise impacts and physical disturbances from oil development and production activities, pointing to generally mild or no effects on ringed seals, though citing relatively few studies. There were no findings pertaining to effects of long-term noise exposure. Similarly, a recent environmental impact statement related to oil exploration and development in the U.S. Arctic Ocean pointed to significant gaps in knowledge pertaining to links between noise and biologically meaningful impacts to marine mammals, such as survival and reproduction (NMFS 2016b). In particular, the environmental impact statement underlined the potential for chronic noise exposure to mask important ecological cues and conspecific communication, and discussed the concept of “activity caps” in relation to managing the acoustic space of marine mammals in habitats adjacent to production facilities. The authors concluded that much additional work was needed to better understand cumulative effects and estimate a “sound cap” in advance of any project. A novel modeling method was tested (with an emphasis on cetaceans) to develop a new metric (i.e., “lost communication space”) under several oil development scenarios and locations, concluding there was still not enough evidence to support absolute noise thresholds to avoid communication masking in any marine mammal (NMFS 2016b). Moore et al. (2012), in addressing noise effects on Arctic marine mammals, stressed the need to consider a species’ acoustic habitat as the sum of all sound sources across multiple scales, rather than the traditional approach of considering single-source acoustic impacts in isolation of each other. Most recently, Reichmuth et al. (2019) documented the first case of a permanent threshold shift (PTS) in a phocid seal (*Phoca vitulina*) from a known underwater sound exposure, composed of mid-frequency tones similar to the intense, high duty-cycle military sonars, with the authors concluding these to be “dangerous to the auditory systems of seals”.

A recent review of baseline global soundscapes detailed the (still) overall quietness of the Arctic relative to lower latitudes, and showed across diverse natural and anthropogenic sources that disparate levels of shipping (i.e., higher in non-polar regions) created the steepest gradient of ambient sound sources (Halliday et al. 2020), a gradient projected to diminish with melting sea ice and greater ship access in the Arctic. Moreover, due to the dampening characteristics of sea ice (i.e., most quiet under the ice), the authors concluded that ambient sound from natural sources in the Arctic will also increase with melting ice as ocean-atmosphere interactions (e.g., wind and storms) intensify (Halliday et al. 2020). Overall, Halliday et al. (2020) reinforced the paucity of underwater noise studies on Arctic species, and in particular on ringed seals, and pointed out a needed shift from studies describing acute responses to noise to those of poorly known cumulative exposures especially from varied sources and in conjunction with other stressors. Noise and physical disturbance threats specific to shipping are discussed in Section 2.4.5.3 of this review.

Seismic surveys—There are few recent findings relating to impacts on phocids by seismic surveys. In a recent environmental impact statement, NMFS (2016b) cited long-standing knowledge gaps and challenges in determining sound level thresholds that correspond to injurious effects. New technologies, such as airgun silencers, bubble curtains, and more focused arrays, are actively being developed to attenuate noise from seismic surveys and reduce impacts to wildlife (NMFS 2016b). Reichmuth et al. (2016) reported that ringed and spotted seals in a laboratory study (n = 2 of each) tolerated single-shot, low frequency (100 MHz) seismic pulses with little behavioral reaction and no significant TTS, though the authors warned against generalizing these findings to actual conditions under seismic disturbance in the Arctic where wild seals might be exposed to chronic noise over weeks to months.

Status of Arctic development activities—As noted in the 2010 Status Review, at the time there were numerous and varied prospects for growth of offshore oil and gas development in the Arctic Ocean. In the U.S. Arctic, the North Slope (Alaska) oil fields had long since peaked in the late 1980s, at about 2M barrels per day, declining to current production now at less than 500K barrels per day (U.S. Energy Information Administration 2023e). But interest in offshore lease sales and proposed expansions of existing oil field developments suggested an overall movement toward increased growth in offshore production, at a minimum to replace maturing fields. The 2010 Deepwater Horizon catastrophe marked a significant change in the regulatory environment for offshore development, and a reassessment of such scenarios thought to be highly unlikely. It sparked new efforts to enhance oil spill response planning and technologies, and increased an awareness—particularly in contrast to the relatively pristine, remote Arctic—that even when all known safeguards are in place, in waters 50 miles from extensive infrastructure, at temperate-weather middle latitudes, a blown well can take 3 months to cap and release 3M barrels of oil across 43,000 square miles, of which only 25% may be recovered (Deepwater Horizon Natural Resource Damage Assessment Trustees 2016).

In the Russian Arctic, at the time of the 2010 Status Review, oil exploration and wide-ranging prospects for exploitable reserves also pointed to expanding production to replace maturing oil and gas wells in the coming decades. Similarly, Deepwater Horizon spill brought increased scrutiny by environmental groups, but it was the invasion and annexation of Crimia (2014) and the second invasion of Ukraine (2022) that marked significant change, bringing successive waves of sanctions against varied Russian interests, especially restrictions on U.S. (and allied) investment and technological collaboration with Russia's national oil entities. These events changed positive projections into predominantly negative ones for Russian oil and gas production, potentially for decades. These events also underline intrinsic instabilities in world geopolitics, their influence on resource extraction and investment potential, and in turn the difficulty in forecasting changing risks to marine wildlife under varied scenarios. Despite a warming Arctic, the still high costs of offshore drilling in conjunction with increasingly volatile oil and gas markets, and increasing foreign technology required for offshore extraction, points to future investments for Russian developments (some already under construction) being less likely. Still, Russia has recently launched new Arctic oil and gas megaprojects in the Kara and Pechora seas in the seasonal ice zone (requiring ice-breakers), that stand to increase risks of oil spills and/or environmental contamination to ringed seals. Russia's interest in expanding Asian markets, particularly for LNG exports, stands to further increase tanker and cargo traffic along the NSR and with it risks of oil spills from maritime accidents. In the context of environmental threats, it is unknown how new risks associated with recent, planned, or prospective projects, and increased shipping, may counter the declining production and eventual decommissioning of rigs at maturing oil and gas fields.

Similarly, Norway has maturing oil fields and has been compensating declining production with numerous new wells in the southern Barents, Norwegian, and North seas, with others under construction. Despite new production streams, and additional prospects on the continental shelf, the overall trend in Norwegian oil production has been negative since the early 2000s. In contrast, over the last decade, Canada and Greenland have suspended all oil exploration, despite previous favorable policies and, for Canada, prospects of substantial reserves—both countries citing uncertain market conditions, concern about climate change, and lack of support from local communities. No hydrocarbon exploration has been completed in Icelandic waters.

Since 2010, with oil production generally declining across the largest Arctic nations—amidst a mixed backdrop of unprecedented new megaprojects (particularly LNG) but also numerous abandoned prospects, new moratoriums, and financial and geopolitical hurdles—the threat from oil and gas development to ringed seals is not obviously different from the time of listing, though there is now more uncertainty about the future.

Okhotsk Ringed Seal

Offshore oil and gas operations near Sakhalin Island advanced significantly during 2005–2015, with three phases (Sakhalin 1, 2, and 3) of platforms, pipelines, and processing facilities, and other infrastructure being completed. Over 1,000 miles of subsea and onshore pipelines now transfer liquids west to the mainland, across an ocean channel, and to an oil terminal at the southern tip of the island, where reduced sea ice permits access of ice-class tankers and LNG carriers for most of the year. At its completion, the Sakhalin Island complex comprised the largest hybrid oil-LNG project in the world. Due to rapid growth of oil development on Sakhalin, previous oil spills, detections of local contamination and oil-resistant bacteria, and inadequate oil-response infrastructure and regulations, oil spills and releases were identified as a central threats to coastal waters and marine and aquatic species (UNEP 2006).

Moreover, the extensive Sakhalin oil production complex was impacted significantly by Russia's most recent invasion of Ukraine, which led to the withdrawal of ExxonMobil and Shell (from Sakhalin 1 and 2, respectively, including their proprietary technology) and caused sanctions aimed at preventing support, maintenance, and insurance of the production facilities and ice-class tankers. These logistical constraints have in turn impacted production and export capacity, and may have compromised safeguards and monitoring to reduce environmental threats. By late 2022, the environmental non-governmental organization that negotiated the first safety measures with oil companies and conducted the only regular monitoring around Sakhalin was declared a foreign agent by the Russian government and forced to close (Skorobogatov 2020; Morozova 2022).

Since 2010, with the rapid growth of offshore oil production around Sakhalin Island (and commensurate tanker traffic), the withdrawal of the U.S. companies responsible for day-to-day operations, less international coordination and technology sharing, and reduced environmental monitoring, there is evidence that the threat from oil and gas development to ringed seals in the Sea of Okhotsk has increased within the range of trajectories projected in the 2010 Status Review, though there is now more uncertainty about the future.

Baltic Ringed Seal

Since the 2010 Status Review, the number of offshore rigs in the Baltic has more than doubled to at least 8. There has also been construction on extensive infrastructure, undersea pipelines, and the Baltic's first LNG plant (with two trains) on the Gulf of Finland, which is nearing completion. The undersea Nordstream pipelines 1 and 2—each 1,200 km long—were laid since 2011, with the latter twin pipeline being destroyed in 2022 by sabotage and releasing unprecedented quantities of LNG with still unknown environmental impacts. In October 2023, the undersea Baltic-connector pipeline running between Finland and Estonia across the Gulf of Finland, just completed in 2020, was also severely damaged by an external force and is under investigation (Armstrong and Sri-Pathma 2023). There has also been extensive new terminal infrastructure in the Gulf of Finland—mostly in Russia—to accommodate recent dramatic increases in oil and LNG exports via tanker ships. Since the Russian invasion of Ukraine in early 2022, followed by a price cap imposed on Russian oil (via sanctions to retain vessel insurance by western countries), there has been a shift from modern tanker ships with experienced crews to decades-old ships and crew with no local knowledge of the navigation challenges of the crowded, shallow, and narrow ice-covered waters of the Gulf, as well as the rest of the Baltic. This has raised concerns, some already realized, that a breakdown, collision, and/or grounding of an uninsured ship could bring an environmental catastrophe to the Baltic Sea (Birnbaum 2023).

In contrast, the quantity and frequency of visible oil spills in the Baltic from accidental and illegal discharges has declined substantially over the last two decades, which has been attributed to tight restrictions and intense monitoring by a network of maritime agencies (Krek et al. 2021; HELCOM 2023g). Using satellite and aerial imagery to identify surface oil, Krek et al. (2021) estimated that at least two-thirds of spills were discharged from ships, though in situ sampling was unable to attribute the large background levels of hydrocarbons in their study area to the relatively small but numerous surface spills coming from ships. The authors highlighted the significant contribution of “major accidents”—some going unreported—and identified other potential pollution sources including river runoff, currents from the west, or undersea oil seeps associated with drilling platforms. This inconsistency combined with widely varying estimates of the amount of surface oil, and declining aerial monitoring in recent years, points to large uncertainty about current and future sources, trends, and distribution of hydrocarbon pollutants in the Baltic Sea (Krek et al. 2021; HELCOM 2023g).

Since 2010, with the significant growth of offshore oil production, commensurate growth in the shipping of liquid hydrocarbons throughout the Baltic (particularly in areas overlapping spring ringed seal breeding habitat), extensive undersea pipelines increasingly at risk due to security issues, and inconclusive and declining environmental monitoring for oil discharges, there is evidence that the threat to ringed seals from oil and gas development in the Baltic Sea has increased within the range of trajectories expected in the 2010 Status Review.

Ladoga Ringed Seal

There are no oil or gas exploration or development projects in Lake Ladoga. See Section 2.4.5.3 (Shipping and Transportation) for a discussion of threats related to an oil discharge from a maritime accident.

2.4.5.5. Offshore wind energy development and production

Baltic Ringed Seal

As offshore wind farms are increasingly developed to meet renewable energy targets, particularly in Europe, studies have primarily focused on understanding impacts to cetaceans and volant species with relatively little known about effects on pinnipeds, and even less on ringed seals. Potential effects from offshore wind farms fall into three main categories: 1) direct impacts during the construction phase, such as piling noise causing injury or displacement; 2) long-term habitat alteration that may either be negative or positive; and 3) disturbance from operational turbines or support vessels (Thompson et al. 2013). Based on (then) current noise exposure criteria for marine mammals (Southall et al. 2007), and modeled sound propagation, Hastie et al. (2015) predicted that half of their tagged harbor seals in the North Sea (n = 24) ventured close enough to pile driving activities at a wind farm to have experienced permanent auditory damage (PTS). The authors highlighted the range of contexts where a loss of auditory sensitivity would likely impact individual fitness (e.g., breeding vocalizations, foraging, predator detection), but also pointed out uncertainties and in turn the rapidly evolving field of predictive sound exposure, including how sound travels in shallow water and the effects of pulsed sound on pinnipeds at greater distances (e.g., Southall et al. 2019). Despite the high sound exposure, these same tagged harbor seals exhibited avoidance (up to 25 km; relative to historical tagging data) during pile driving; the displacement was short-lived (about 2 hours) and was not observed after construction and the wind farm was operational (Russell et al. 2016). There was also no evidence of population consequences, with numbers of seals at nearby haulouts continuing to increase (10–13% per annum) throughout the wind farm construction (Russell et al. 2016). A similar study at a wind farm in Denmark, also comparing new and historical tagging data on harbor and grey seals, found no statistical tendency for seals to alter residence time, movement patterns, or proximity in relation to the wind farm or individual towers; local population trends also showed no pattern attributable to the wind farm (McConnell et al. 2012). Tougaard and Henriksen (2009) concluded that sound propagated underwater from an operational wind farm was unlikely at any distance to reach dangerous levels for harbor seals nor cause any masking of acoustic communication. Another tagging study in the North Sea found that a small proportion of harbor and grey seals, though often repeatedly, exhibited movement characteristic of foraging that targeted wind farm towers and undersea pipelines, raising questions about whether these novel structures promote foraging success (i.e., increased productivity) or represent so-called ecological traps (concentrate prey; Russell et al. 2014). With unprecedented development of marine renewables, there is still much uncertainty about the net ecological footprints of these structures and how effects vary across marine species.

We found no similar studies on ringed seals in relation to wind farm construction or operation in the Baltic Sea or elsewhere. Though the above studies provide a useful context for pinnipeds, we exercise caution generalizing results to ringed seals as many impacts to marine mammals are unique to a species' life history and physiology.

Since 2010, there has been significant growth in offshore wind generation, but it is still on a small scale in the Baltic Sea. Though we found no direct evidence pointing to significant threats to ringed seals from wind farms or towers, there are studies of other phocid species that suggest a potential for auditory injury from pile driving during construction—though the injury mechanisms have so far only been modeled under a number of assumptions, and not yet been used to assess potential impacts to ringed seals. At present, the significance of threats to ringed seals from wind farm development and operation is believed to be low.

2.5. SYNTHESIS

As a preface to concluding its extinction risk assessment in the 2010 Status Review, the BRT wrote,

> Warming—driven by GHG emissions—is accelerated in the Arctic by positive feedbacks including reduced albedo. Recent reductions in the areal extent of sea ice and the seasonal duration of snow on sea ice have contributed strongly to the reduction in albedo, meaning more heat is retained by the ocean and earth's surface. Current atmospheric levels of GHGs are sufficient to continue warming the climate and diminishing ice and snow cover throughout the century. The changes to the ice and snow habitats of ringed seals are forecasted to be rapid relative to generation time, challenging the species' ability to respond adaptively.
>
> Ringed seal populations will be impacted indirectly through changes in biological community composition as consequences of ocean and lake warming and acidification. Direct effects will result from diminishing ice and snow cover. The BRT considered 17–18 threats to each subspecies of ringed seals and assessed how those threats are likely to manifest demographically (presently and in the foreseeable future) as risks to abundance, productivity, spatial structure, and diversity.

In this synthesis section, based on updated information, we take a similar approach of assessing both the threats to ringed seals and how those threats are likely to manifest demographically.[15] For each of the four subspecies we reviewed, we first provide the 2010 Status Review conclusions as context. We then briefly summarize relevant new information about the

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[15] The 2010 Status Review considered the demographic risks and status of the species under the categories of abundance, productivity, spatial structure, and diversity. The template provided for this review had sections with headers for (paraphrasing in some cases) abundance and trends; demographic features or trends; genetics, genetic variation; or trends in genetic variation; and spatial distribution or trends in spatial distribution. We tried to use terms consistent with the latter descriptors, to maintain consistency with the template and other 5-year reviews.

threats, organized by the ESA’s five section 4(a)(1) factors. Finally, we summarize the demographic implications of the new threats information, including consideration of any relevant new information about the subspecies’ biology.

2.5.1. Arctic Ringed Seal

The 2010 Status review concluded,

> The BRT judged the greatest threat to the Arctic ringed seal to be increased hypothermia due to decreasing depth and duration of snow cover. The threat considered the second highest to this subspecies was increased predation, also associated with diminishing snow cover. The BRT considered current risks to be low for all four demographic attributes [abundance, vital rates, genetics, and spatial distribution], but they rated risks higher in the foreseeable future for all attributes. Overall, risks to productivity and spatial structure were rated high in the foreseeable future. Persistence of the Arctic subspecies likely will be challenged as decreases in ice and, especially, snow cover lead to increased juvenile mortality from hypothermia and predation. Spatial structure likely will be disrupted by rapid loss of habitat patches, and the subspecies likely will disappear from a substantial portion of its range.

2.5.1.1. Habitat threats

The main threats facing Arctic ringed seals continue to stem from diminished snow cover on sea ice. New information confirms that snow depth and seasonal persistence are declining as was predicted at the time of listing, and that further declines can reasonably be expected through the foreseeable future (which we take to be the end of the century for most climate-driven habitat threats to ringed seals, consistent with the 2010 Status Review and the listing rule). The range of future warming scenarios that we consider currently plausible in this review remains roughly the same as at the time of listing, but there are now grounds for greater confidence about the relationship between a given amount of GHG emissions, the resulting warming, and the loss of sea ice area that can be expected. Our review identified no new information that would alter NMFS’s conclusions on threats to the Arctic ringed seal from expected future declines in sea ice and the depth and season persistence of snow cover, and the demographic implications of the threats. Threats from climate-driven shifts in other habitat components, particularly biological components such as prey, were identified in the 2010 Status Review. Like the main physical threats, the magnitude and imminence of those threats has not changed appreciably but the new information provides greater insight into the natural processes involved. The biological habitat threats remain difficult to project into the future due to the complexity of ecosystem relationships.

2.5.1.2. Overutilization threats

The total numbers of Arctic ringed seals used for scientific or educational purposes remain small and are not expected to increase significantly in the future. While new information about harvest levels is limited for Arctic ringed seals, there is no evidence of increased harvest or over-harvest of this subspecies, and there is some evidence of declining trends in Greenland, where the largest subsistence harvests take place, and in Alaska. The overall significance of the threats to Arctic ringed seals from overutilization were judged in the 2010 Status Review to be *low or zero*, and new information about these activities, albeit limited, does not indicate that the significance of these threats has changed substantially.

2.5.1.3. Disease, parasites, or predation threats

No significant disease or parasite outbreaks were documented since the time of listing. Two unusual mortality events (UMEs) have affected Arctic ringed seals in Alaska, the first in 2011–2016, and the second in 2018–2022. Neither has been conclusively associated with a pathogen or parasite or is known to have caused major declines in ringed seals in Alaska. The second UME occurred near the end of a marine heatwave in the North Pacific that disrupted the Bering and Chukchi seas' ecosystems, raising the possibility that the UME was at least partly related to the anomalously warm conditions. In the 2010 Status Review, the significance of the threat to Arctic ringed seals from infection or disease as *low*, and the data currently available do not suggest that the magnitude or imminence of this threat has changed appreciably.

New information indicates that polar bear predation may be reduced in some regions. In contrast, there is evidence that killer whale presence is increasing in the Arctic. A recent study in the eastern Canadian Arctic found that ringed seals dominated the diets of some killer whales, indicating that killer whale predation on ringed seals in the Arctic may be increasing. Because declining risk from some predators could be offset by increasing risk from others, we conclude that there has been no substantial change for Arctic ringed seals in predation risk since the listing, which was judged in the 2010 Status Review to be midway between *moderate* and *high*.

2.5.1.4. Inadequate regulatory mechanism threats

NMFS concluded in the listing rule that, "Current mechanisms do not effectively regulate GHG emissions, which are contributing to global climate change and associated modifications to ringed seal habitat." Our review of information concerning changes in regulatory mechanisms that aim to limit GHG emissions indicates that there has been some progress addressing anthropogenic GHG emissions since the listings. There are still no known mechanisms in place that effectively address the primary (climate-driven) threat to Arctic ringed seals from reductions in their sea ice habitat within the foreseeable future. The projections used to assess climate-driven threats under our assumed scenario of SSP3-7.0 do not include additional climate mitigation. The lack of new climate regulatory mechanisms under this scenario does not contribute an additional threat to Arctic ringed seals beyond what we have included in our assessment of the threats from present or threatened destruction, modification, or curtailment of the subspecies' habitat or range.

2.5.1.5. Other natural or man-made threats

As was done in the 2010 Status Review, we considered under this category threats that stem from contaminants; fishery interactions and bycatch; shipping; and oil and gas activities. In addition, we evaluated new information relevant to threats from offshore wind energy development. The overall significance of threats in this category to Arctic ringed seals was scored as *moderate* in the 2010 Status Review. A large volume of new information about activities with potential for these largely man-made threats provides increased clarity about the status of these activities and the extent of overlap with Arctic ringed seals and their habitat. However, we found no new information indicating that these threats have changed significantly in magnitude or imminence relative to the range of trajectories anticipated in the 2010 Status Review.

2.5.1.6. Summary

Arctic ringed seals remain abundant but poorly monitored for population size throughout much of their range. There are no reliable trend estimates for any significant portion of the subspecies' range. In some areas, Indigenous seal hunters inform resource management and research agencies about ringed seal relative abundance and condition, and collaborate on sample-based studies, which helps to corroborate that the populations remain abundant and continue to occupy their range. One area of concern is around Svalbard in the Atlantic Arctic, where the seasonal sea ice essentially ceased to form in 2006. It is not clear from available information whether the population there is currently sustaining itself.

In Svalbard, Hudson Bay, the western Canadian Arctic, and Alaska there are hints that ringed seal demographic features such as condition or vital rates are responding to signals of climate trends or very anomalous conditions in a particular year (Alaska). Most of the studies, however, occurred during years with substantial natural variability such that some years had vital rates or condition indices that were lower in years with extensive sea ice or other indicators of cold conditions. Together, the results suggest that Arctic ringed seals may still be mostly within their range of tolerance for climatic variability, wherein some years are colder than optimal and others warmer than optimal.

New information about genetics continues to support prior findings that genetic diversity is high and that there seems to be relatively little population structure. A very recent study revealed the existence of a previously undocumented small subpopulation or ecotype in the fjord-dominated west coast of Greenland.

Risk from issues of spatial distribution remain low for Arctic ringed seals at present because they continue to occupy all or nearly all of their extensive range.

As was the case at the time of listing, future demographic risks associated with abundance, demographic features, genetics, and spatial distribution are expected to be higher than at present due to expected loss of large portions of present-day suitable habitat for whelping and rearing pups within the foreseeable future. In this 5-year review of the status of the Arctic ringed seal, NMFS considered the best scientific and commercial data available, and found that overall, the available information does not indicate a significant change in threats or the demographic implications of threats since the time of listing. Therefore, no change is warranted in the classification of the Arctic ringed seal as threatened.

2.5.2. Okhotsk Ringed Seal

The 2010 Status review concluded,

> The greatest threat to Okhotsk ringed seals was judged by the BRT to be increased hypothermia due to decreasing depth and duration of snow cover. The threat judged second highest for the Okhotsk ringed seal was a decrease in sea-ice habitat suitable for whelping and nursing, reflecting forecasts that April ice will be limited to the northernmost Sea of Okhotsk and that snow cover already appears to be inadequate for birth lairs throughout the range. The BRT judged the current risks to persistence to be low for ringed seals in the Sea of Okhotsk but judged risks in the foreseeable future to be moderate (diversity) or high (abundance, productivity, and spatial structure). By the end of the century, reduced extent of sea ice and inadequate snow accumulation will challenge the persistence of ringed seals throughout their range in the Sea of Okhotsk.

2.5.2.1. Habitat threats

The overall significance of habitat related threats to Okhotsk ringed seals was judged to be midway between *moderate* and *high* in the 2010 Status Review. Sea ice has continued to decline, and new research has shown that landfast sea ice extent and duration is also declining in the Sea of Okhotsk. No new information about snow depth on sea ice in the Sea of Okhotsk was available for our review. Because winter snow depth on sea ice tends to decline with the seasonal duration of sea ice persistence—as our review found for the Arctic—it is reasonable to assume that snow depth on Sea of Okhotsk ice has declined since the listing and will continue to do so. There was insufficient information about trends in sea ice and snow depth to assess whether declines in ice extent and snow depth differ in magnitude or imminence from those projected in the 2010 Status Review, but that review suggested that snow depth may have already been inadequate at the time of listing; these threats almost certainly remain serious for Okhotsk ringed seals.

2.5.2.2. Overutilization threats

Our review of new information indicates that the significance of threats from overutilization of Okhotsk ringed seals remain low because: 1) The total numbers of Okhotsk ringed seals used for scientific or educational purposes are small and are not expected to increase significantly in the future; and 2) While new information about harvest levels is limited for Okhotsk ringed seals, there is no evidence of increased harvest or over-harvest of this subspecies.

2.5.2.3. Disease, parasites, or predation threats

This review did not identify any new information about disease, parasites, or predation for Okhotsk ringed seals that became available since the 2010 Status Review. The overall significance of these threats was judged by the BRT to be between *moderate* and *high* in the 2010 Status Review, and with no new information, nothing changes the previous assessment of these threats.

2.5.2.4. Inadequate regulatory mechanism threats

NMFS concluded in the listing rule that, “Current mechanisms do not effectively regulate GHG emissions, which are contributing to global climate change and associated modifications to ringed seal habitat.” Our review of information concerning changes in regulatory mechanisms that aim to limit GHG emissions indicates that there has been some progress addressing anthropogenic GHG emissions since the listings. There are still no known mechanisms in place that effectively address the primary (climate-driven) threat to Okhotsk ringed seals from reductions in their sea ice habitat within the foreseeable future. The projections used to assess climate-driven threats under our assumed scenario of SSP3-7.0 do not include additional climate mitigation. The lack of new climate regulatory mechanisms under this scenario does not contribute an additional threat to Okhotsk ringed seals beyond what we have included in our assessment of the threats from present or threatened destruction, modification, or curtailment of the subspecies’ habitat or range.

2.5.2.5. Other natural or man-made threats

The overall significance of the threats to Okhotsk ringed seals in this category were judged to be *moderate* in the 2010 Status Review. We found no new information about contaminants or incidental take from commercial fisheries for Okhotsk ringed seals since the 2010 Status Review.

Similarly, there was virtually no information available about changes in shipping operations in the Sea of Okhotsk, but increased industrial activity and oil and gas development, as anticipated in the 2010 Status Review, suggests a commensurate increase in shipping. New AIS monitoring has increased confidence regarding suspected overlap in vessel traffic with ringed seal habitat, following new hydrocarbon drilling and terminal infrastructure, pointing to new areas where threats from shipping are likely. Despite the paucity of information, and any regular monitoring to help discern the status and growth of industrial activities in the Sea of Okhotsk, the expansion of anthropogenic threats was largely anticipated in the 2010 Status Review. Though there is increased clarity regarding the status and evolution of these activities, and especially an increase of spatial concordance with Okhotsk ringed seals and their habitat, we found no new information indicating that these threats have changed significantly in magnitude or imminence relative to the range of trajectories projected in the 2010 Status Review.

2.5.2.6. Summary

Information about the abundance of the Okhotsk seal population is extremely limited. The most recent population estimate for Okhotsk ringed seals (120,000 seals), obtained from an aerial survey of the Sea of Okhotsk in 2013, was much lower than the estimate from aerial surveys conducted during 1968–1990 (676,000 seals), published in the 2010 Status Review. These estimates indicate the possibility of a large decrease in ringed seal numbers, but both population estimates are highly uncertain, so the current population trend in the Sea of Okhotsk is still unknown. Population estimates derived from CPUE from harvest data showed fluctuating numbers during the 1970s–1990s, but these estimates were highly uncertain and likely reflect problems with harvest management rather than population dynamics. Thus, these estimates do not provide reliable data about population trends of Okhotsk ringed seals either.

As was the case at the time of listing, our review found no information about demographic features or vital rates of Okhotsk ringed seals.

Our review found no new information about genetics or diversity of Okhotsk ringed seals, areas that were also information-deficient at the time of listing. If the most recent abundance estimate of about 120,000 individuals in 2013 is reliable, it would be unlikely that there is substantial current risk due to a substantial change or loss of variation in life-history traits, population demography, morphology, behavior, or genetic characteristics, consistent with the BRT’s assessment in the 2010 Status Review.

As was the case at the time of listing, our review found no information about spatial structure and the associated risks to Okhotsk ringed seals. It remains the case that Okhotsk ringed seals are strictly limited in their pathway for adaptation to warming by shifting to more northerly breeding habitat; this sea is not contiguous with the Arctic Ocean. If and when seasonal sea ice ceases to form and persist through the ringed seal’s whelping, nursing, mating, and molting period, Okhotsk ringed seals would be constrained to try those critical functions on shore, where predation and hypothermia of pups will limit recruitment, likely to below sustainable levels.

In summary, current information indicates that it is likely but not certain that Okhotsk ringed seals remain abundant. Their future prospects are dim unless warming can be halted while sufficient sea ice still forms annually in the region. Future demographic risks associated with abundance, vital rates, genetics, and spatial distribution are expected to be higher than at present, mainly due to reductions in sea ice habitat suitable for whelping, nursing, and molting. In this 5-year review of the status of the Okhotsk ringed seal, NMFS considered the best scientific and commercial data available, and found that overall, the available information does not indicate a significant change in threats or the demographic implications of threats since the time of listing. Therefore, no change is warranted in the classification of the Okhotsk ringed seal as threatened. Prior to the next 5-year review, a quantitative analysis of sea ice trends and spatial distribution would be helpful for supporting a more certain risk assessment.

2.5.3. Baltic Ringed Seal

The 2010 Status Review concluded,

> The BRT judged decreased sea-ice habitat suitable for whelping and nursing, and increased hypothermia due to insufficient depth or duration of snow cover, to be the greatest threats to the persistence of the Baltic ringed seal. The threats were judged currently to pose low to moderate risks for each of the four demographic attributes. In the foreseeable future, however, the BRT judged the risks to be moderate (diversity) to high (abundance, productivity, and spatial structure). Forecasts of substantial reductions in sea-ice extent by mid-century, coupled with deteriorating snow conditions, represent drastic habitat modifications expected to decrease survival of ringed seal pups throughout the Baltic Sea.

2.5.3.1. Habitat threats

The greatest threats facing Baltic ringed seals continue to stem from losses to their sea-ice habitat, which continues to be diminished in quality, extent, and duration. New information confirms that sea ice has declined at an accelerated rate in recent decades and it is likely that snow depth has, as well; both are expected to continue declining for the foreseeable future. Poor ice conditions during spring have forced some ringed seals in the southern subpopulations to give birth and nurse pups on land in recent years, exposing them to higher risks from predation and hypothermia, and may be hampering the population growth rate in Bothnian Bay. Unlike some Arctic populations, Baltic ringed seals do not have the option of shifting their distribution northward to follow the receding ice field. Other changes have been observed in fish stocks and food webs of the Baltic ecosystem, but their potential impacts on ringed seals, now or in the future, remain uncertain. This new information supports the previous habitat threat assessment, and suggests that the magnitude or imminence of these threats has not substantially changed since the subspecies' listing.

2.5.3.2. Overutilization threats

Our review of new information indicates that the reported harvest of Baltic ringed seals has increased in recent years and is thought to be one of the main pressures affecting the abundance and growth rate of Baltic ringed seal populations, but we found no information indicating that over-harvest of Baltic ringed seals is occurring at present. The total numbers of Baltic ringed seals used for scientific or educational purposes are small and are not expected to significantly increase in the future.

2.5.3.3. Disease, parasites, or predation threats

Limited new information about disease, parasites, or predation for Baltic ringed seals has been published since the 2010 Status Review. The first evidence of exposure to *Brucella* spp. was documented, but prevalence was low. The significance of this combined threat was scored between *moderate* and *high* in the 2010 Status Review, primarily based on predation risk, and the information available since 2010 is not sufficient to change the significance of this threat for Baltic ringed seals.

2.5.3.4. Inadequate regulatory mechanism threats

NMFS concluded in the listing rule that, "Current mechanisms do not effectively regulate GHG emissions, which are contributing to global climate change and associated modifications to ringed seal habitat." Our review of information concerning changes in regulatory mechanisms that aim to limit GHG emissions indicates that there has been some progress addressing anthropogenic GHG emissions since the listings. There are still no known mechanisms in place that effectively address the primary (climate-driven) threat to Baltic ringed seals from reductions in their sea ice habitat within the foreseeable future. The projections used to assess climate-driven threats under our assumed scenario of SSP3-7.0 do not include additional climate mitigation. Therefore, the lack of new climate regulatory mechanisms under this scenario does not contribute an additional threat to Baltic ringed seals beyond what we have included in our assessment of the threats from present or threatened destruction, modification, or curtailment of the subspecies' habitat or range.

2.5.3.5. Other natural or man-made threats

Overall contaminant levels in Baltic ringed seals have declined over the past decades, and recent numbers of ringed seals taken in a fishery were fairly low, although data about bycatch in commercial fisheries is limited. In contrast, since 2010, oil and gas development (and associated shipping) in the Baltic Sea has grown considerably, though with little change in cargo shipping. New AIS monitoring has increased confidence regarding suspected overlap in vessel traffic with ringed seal pupping habitat, following extensive growth of terminal infrastructure in the Gulf of Finland, revealing that breeding ringed seals here experience the most frequent (and fastest traveling) ice-breaking vessels in comparison to other hotspots in the Arctic with high overlap between ships and ringed seals. The three-fold increase in tanker traffic observed in the Gulf of Finland (and in turn the rest of the Baltic) points to higher threats than projected in the 2010 Status Review related to oil and gas development. In the 2010 Status Review, the combined threats from oil and gas development and shipping were judged to be *moderate*; increased threats from shipping of oil and gas, observed since the 2010 Status Review, are believed to represent an elevated risk to seals from disturbance, habitat destruction, and accidental and intentional oil discharges from vessels. Still, the overall risk of man-made threats is believed to remain unchanged (i.e., moderate), relative to the overall range of trajectories projected in the 2010 Status Review.

2.5.3.6. Summary

There is considerable uncertainty around abundance estimates for Baltic ringed seals, making it difficult to assess changes in population size. No biologically plausible trends have been detected in the northern management unit, Bothnian Bay, and the population there is estimated to be below the growth rate threshold HELCOM defined for recovery. In the southern management unit, no trends have been detected in the western Estonia/Gulf of Riga populations, the Archipelago Sea, and the Gulf of Finland. HELCOM considers growth rates in the southern management unit to be “alarmingly” below their recovery threshold.

Findings on Baltic ringed seal vital rates since the 2010 Status Review have shown mixed trends, with some metrics improving and others declining. Birth rates have increased, but estimates of growth rate have not kept pace, suggesting that poor sea ice conditions and harvest may be limiting population growth. Population forecasts predict that reduced sea ice area will limit growth for all subpopulations in the Baltic Sea. Body condition trends have not been temporally consistent for juveniles and adult males, but the body condition of adult females has declined.

Genetic diversity within Baltic ringed seals appears to be high, possibly due to historic population size or genetic exchange with the Arctic subspecies. We found no evidence that demographic risks associated with genetic diversity have changed since the time of listing.

Ringed seal habitat in the Baltic Sea has become increasingly restricted and fragmented, limiting the breeding and molting distributions of all subpopulations. In years when sea ice is especially limited, seals have been seen pupping and molting on land. Ringed seal movement and foraging areas do not appear to have changed; however, the evident loss of breeding and molting distribution is concerning because these processes are a vulnerable period for ringed seal life history.

As was the case at the time of listing, future demographic risks associated with abundance, vital rates, genetics, and spatial distribution for Baltic Seals are expected to be higher than at present, primarily due expected to loss of pupping and molting habitat within the foreseeable future. Restrictions in spatial distribution during the critical breeding and molting periods have already been documented and are expected to continue with further declines in sea ice availability. In this 5-year review of the status of the Baltic ringed seal, NMFS considered the best scientific and commercial data available, and found that, overall, the available information does not indicate a significant change in threats or the demographic implications of threats since the time of listing. Therefore, no change is warranted in the classification of the Baltic ringed seal as threatened.

2.5.4. Ladoga Ringed Seal

The 2010 Status review concluded,

> Decreased ice habitat suitable for whelping and nursing, and increased hypothermia due to insufficient depth or duration of snow cover, were judged by the BRT to be the greatest threats to the persistence of the Ladoga ringed seals. The present risk to population persistence was judged to be moderate in terms of abundance, productivity, spatial structure, and diversity. The concern about spatial structure reflected the fact that the subspecies is landlocked and cannot respond to habitat loss by dispersing to new habitat. Risks in the foreseeable future were judged to be moderate (diversity) or high to very high (abundance, productivity, and spatial structure). Drastic reductions in snow cover forecasted for the region can be expected to result in increased pup mortality throughout Lake Ladoga.

2.5.4.1. Habitat threats

The greatest threats facing Ladoga ringed seals continue to stem from losses to their lake-ice habitat, which has been diminished in seasonal duration and coverage. New information confirms that lake ice is forming later in the fall and melting earlier in the spring, resulting in a shorter ice season, and winters with intermittent ice coverage are becoming more frequent. These trends are expected to continue for the foreseeable future. Unlike some Arctic populations, Ladoga ringed seals do not have the option of shifting their distribution northward to follow the receding ice field. Changes to the trophic state of Lake Ladoga have been observed in recent decades, but these are not known or expected to directly impact ringed seals. This new information supports the previous habitat threat assessment, and suggests that the magnitude or imminence of these threats have not substantially changed since the subspecies' listing.

2.5.4.2. Overutilization threats

Hunting of Ladoga ringed seals remains prohibited, and total numbers of Ladoga ringed seals used for scientific or educational purposes are small and are not expected to increase significantly in the future.

2.5.4.3. Disease, parasites, or predation threats

New data about disease, parasites, or predation for Ladoga ringed seals since the 2010 Status Review are extremely limited. Only one seal was examined for helminths, and one cestode species was documented. The threat to Ladoga ringed seals probably has not changed since the 2010 Status Review, which was judged to be between *moderate* and *high*, though it is difficult to assess with a lack of new information. However, the potential for disease epidemics may increase with a warming climate, and Ladoga seals could face serious consequences in the event of an epidemic because of their small population size and limited range.

2.5.4.4. Inadequate regulatory mechanism threats

NMFS concluded in the listing rule that, "Current mechanisms do not effectively regulate GHG emissions, which are contributing to global climate change and associated modifications to ringed seal habitat." Our review of information concerning changes in regulatory mechanisms that aim to limit GHG emissions indicates that there has been some progress addressing anthropogenic GHG emissions since the listings. There are still no known mechanisms in place that effectively address the primary (climate-driven) threat to Ladoga ringed seals from reductions in their lake ice habitat within the foreseeable future. The projections used to assess climate-driven threats under our assumed scenario of SSP3-7.0 do not include additional climate mitigation. Therefore, the lack of new climate regulatory mechanisms under this scenario does not contribute an additional threat to Ladoga ringed seals beyond what we have included in our assessment of the threats from present or threatened destruction, modification, or curtailment of the subspecies' habitat or range.

Our review indicates that concerns persist since the listing about bycatch of Ladoga ringed seals in fishing gear, and we identified no new regulatory mechanisms that address this threat.

2.5.4.5. Other natural or man-made threats

There are no oil and gas development projects in Lake Ladoga. Overall contamination levels in Lake Ladoga have declined in the past decades, and recent samples from Ladoga ringed seals had lower levels of trace elements compared to samples analyzed in the 1990s. Information about fisheries bycatch and shipping in Lake Ladoga since the 2010 Status Review is limited with some uncertainty. Substantial growth in tourism over the past 20 years, similar to Lake Saimaa, has resulted in intense development along the lake shore and likely significant increases in small watercraft around the lake—which was highlighted as a concern in the 2010 Status Review following reports of mass disturbance at island haulouts. While overall human presence around the lake has seen unprecedented growth, and disturbance has a high potential to impact seals during pupping—particularly in conjunction with climate-induced loss of ice habitat—behavior of seals in relation to boats and the frequency of disturbance has, to our knowledge, not yet been documented. The threat significance in the 2010 Status Review was *moderate*, and new information about these activities does not indicate that these threats have changed substantially.

2.5.4.6. Summary

An April 2012 survey of Lake Ladoga produced an estimate of 5,068 (95% CI: 4,026-7,086) ringed seals basking on the ice, and a total population of roughly 6,000-9,000 ringed seals in the lake. Compared to 2001 survey estimates, this indicated an annual growth rate of 7.5%, which was considered somewhat unrealistic considering the concurrent high fisheries bycatch rates. Even so, local experts believe the population may be recovering from previous steep declines that were caused by unregulated harvest. Although the larger population estimate is encouraging, the inability to confidently reconcile the recent estimate with purported trends in the late 20th century suggests that the new information should not alter the judgment expressed by the BRT in the 2010 Status Review that risks associated with abundance in Ladoga ringed seals are moderate at present but high in the foreseeable future.

No new information was found on demographic features or trends in the Ladoga seal population.

Two new studies confirmed that genetic diversity of Ladoga ringed seals is nearly as high as that in Baltic ringed seals. This adds confidence to, but does not significantly change the demographic risks associated with diversity, which were judged by the BRT in the 2010 Status Review to be moderate for the present and in the foreseeable future.

A covariate analysis of survey data from April 2012 found that water depth, proximity to shore, ice type, and presence of fisheries were among the most important factors influencing ringed seal density and distribution in Lake Ladoga. Local experts concluded that disturbance from human activities, especially ice fishing, has become a major factor influencing seal distribution in Lake Ladoga and has likely shifted the core pupping area from the shorefast ice to the central part of the lake. This purported shift could plausibly increase the demographic risks associated with the population's spatial structure or productivity; however, no such impacts have been documented thus far.

There remains a high likelihood that the severity of impacts of deteriorating snow and ice conditions will increase for this ringed seal subspecies. Because Ladoga ringed seals are landlocked, the seals will be unable to respond to habitat deterioration and loss by dispersing to new habitat. Bycatch and disturbance from human activities are significant conservation concerns for Ladoga ringed seals that could exacerbate the effects due to climate change and habitat loss. As was the case at the time of listing, future demographic risks associated with abundance, vital rates, and spatial distribution are expected to be much higher than at present, and future demographic risks associated with genetics are expected to be higher than at present, due to expected loss of large portions of present-day suitable habitat for whelping and rearing pups. In this 5-year review of the status of the Ladoga ringed seal, NMFS considered the best scientific and commercial data available, and found that overall, the available information does not indicate a significant change in threats or the demographic implications of threats since the time of listing. Therefore, no change is warranted in the classification of the Ladoga ringed seal as endangered.

3. RESULTS

3.1. RECOMMENDED CLASSIFICATION

____ **Downlist to Threatened**

____ **Uplist to Endangered**

____ **Delist** *(Indicate reasons for delisting per 50 CFR 424.11):*

  ____ *The species is extinct*

  ____ *The species does not meet the definition of an endangered or a threatened species*

  ____ *The listed entity does not meet the statutory definition of a species*

_X_ **No change is needed** (Arctic, Okhotsk, Baltic, and Ladoga subspecies of ringed seals)

3.2. NEW RECOVERY PRIORITY NUMBER

For the Arctic subspecies of ringed seal, NMFS will continue to apply the existing recovery priority number of 9C. Recovery priority number is not applicable for the Okhotsk, Baltic, or Ladoga subspecies of ringed seals, which occur entirely outside U.S. jurisdiction.

4. RECOMMENDATIONS FOR FUTURE ACTIONS

Arctic Ringed Seal

Population monitoring—Arctic ringed seals have not been adequately monitored for population trends in any significant portion of their range. Several studies have examined suites of indices for vital rates but have not had the means to directly measure those rates or to detect overall demographic impacts such as changes in abundance or loss of significant portions of breeding range. Changes in the stage structure of harvested seals may signal population declines, but this approach is sensitive to any trend in age-selectivity of the harvest. While monitoring indices of vital rates or other demographic parameters provides insight about mechanisms of response to environmental variability and climatic trends, sampling considerations are often complex, as are interpretations of the results. The need remains for complementary, direct means of monitoring abundance and distribution of breeding populations, such as count-based surveys. For Arctic ringed seals in U.S. waters, a baseline for trend detection has been established using aerial surveys completed between 2012 and 2021. Follow-on surveys should be completed at intervals of approximately 5 years to create a time series for trend estimation.

Population structure—With the application of advanced genetic tools for understanding evolutionary histories and rates of dispersal among populations, new analyses of traditional biological data such as morphometrics, and greater recognition of IK to help guide investigations of diversity, it is likely that significant genetic and demographic structure will eventually be found within the enormous range of the Arctic ringed seal. The evidence is just beginning to emerge and is yet insufficient to prompt a formal review for the existence of DPSs within the Arctic ringed seal subspecies, but the topic should be among the high priorities for research in support of ringed seal management and conservation.

Okhotsk Ringed Seal

Reducing uncertainty about extinction risk—Current information indicates that it is likely but not certain that Okhotsk ringed seals remain abundant. Under present conditions for funding of seal monitoring in the Russian Federation, the prospects are poor for acquiring updated information about the status of Okhotsk ringed seals in the next 5–10 years. Prior to the next 5-year review, a quantitative analysis of sea ice trends and spatial distribution would be helpful for supporting a more certain risk assessment.

Baltic Ringed Seal

Population structure—More work is needed for a fully consistent understanding of the biodiversity within and among the closely-situated Baltic, Saimaa, and Ladoga subspecies. We consider it premature to judge whether recent findings alter the genetic diversity-associated demographic risk to Baltic ringed seals, but it will be important to carefully consider any new genetic information that may become available prior to the next 5-year review.

Ladoga Ringed Seal

Population monitoring**—**Under present conditions for funding of seal monitoring in the Russian Federation, the prospects may be poor for acquiring updated information about the status of Ladoga ringed seals in the near future. Surveying the Ladoga ringed seal population is much less expensive and complex than surveying Okhotsk ringed seals, and has been accomplished in the past with funding from outside the Russian Federation; the prospects for similar collaborations appear dim for the near future, given current international relations strained by the Russian invasion of Ukraine in 2022. It will be important to carefully consider any new abundance or trend information about Ladoga ringed seal population status that may become available prior to the next 5-year review.

5. GLOSSARY/LIST OF ACRONYMS

AIS: Automatic Identification System: a technological system that allows suitably equipped vessels to broadcast their unique identification and movements

AMSA: Arctic Marine Shipping Assessment: comprehensive assessment of Arctic marine shipping released by the Arctic Council in 2009

ANWR: Arctic National Wildlife Refuge: A national wildlife refuge located in northeastern Alaska; the largest in the National Wildlife Refuge system

AR4 WG1: Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, titled *Climate Change 2007: The Physical Science Basis* (IPCC 2007)

AR5 WG1: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, titled *Climate Change 2013: The Physical Science Basis* (IPCC 2013a)

AR6 WG1: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, titled *Climate Change 2021: The Physical Science Basis* (IPCC 2021)

AR6 WG2: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, titled *Climate Change 2022: Impacts, Adaptation and Vulnerability* (IPCC 2022a)

BFN: Biologists for Nature Conservation: a non-profit public organization based in Saint Petersburg, Russia

BOEM: Bureau of Ocean Energy Management: U.S. federal agency responsible for development of energy and mineral resources on the Outer Continental Shelf of the United States in an environmentally and economically responsible way

BRT: Biological Review Team: authors of the *Status Review of the Ringed Seal (Phoca hispida)* (Kelly et al. 2010)

BSAP: Baltic Sea Action Plan: program of measures and actions adopted be HELCOM for achieving good environmental status of the Baltic Sea

BSEE: Bureau of Safety and Environmental Enforcement: U.S. federal agency charged with improving safety and environmental protection related to the offshore energy industry on the Outer Continental Shelf

BLM: Bureau of Land Management: a U.S. federal agency that manages public lands and resources for a variety of uses while ensuring while ensuring natural, cultural, and historical resources are maintained

CPUE: Catch Per Unit Effort: measure often used as a proxy for relative abundance of a target species

CMIP3: Coupled Model Intercomparison Project (Phase 3): an international climate modeling project that provides climate model projections with the aim of better understanding changes in the climate; the data outputs for Phase 3 of the project were archived in support of the IPCC's Fourth Assessment Report

CMIP5: Coupled Model Intercomparison Project (Phase 5): an international climate modeling project that provides climate model projections with the aim of better understanding changes in the climate; the data outputs for Phase 5 of the project were archived in support of the IPCC's Fifth Assessment Report

CMIP6: Coupled Model Intercomparison Project (Phase 6): an international climate modeling project that provides climate model projections with the aim of better understanding changes in the climate; the data output for Phase 6 of the project were archived in support of the IPCC's Sixth Assessment Report

COSEWIC: The Committee on the Status of Endangered Wildlife in Canada: advisory panel established under Canada's Species at Risk Act that is responsible for assessing the conservation status of wildlife species that may be at risk of extinction in Canada

DArTseq: Diversity Arrays Technology Sequencing Technology: a genetic marker technique used for genetic analysis and genotyping, without the need for DNA sequencing

DDT: Dichloro-Diphenyl-Trichloroethane: synthetic insecticide developed in the 1940s

Destination shipping: shipping to or from ports in the Arctic, or stopping in the Arctic, mainly in support of economic activities (i.e., cargo loading, fishing, or other resource extraction)

DOI: Department of the Interior: U.S. federal executive department with technical bureaus that include among others, the Bureau of Land Management, Bureau of Ocean Energy

Management, Bureau of Safety and Environmental Enforcement, U.S. Geological Survey, and U.S. Fish and Wildlife Service

DPS: Distinct Population Segment: under the Endangered Species Act, a vertebrate population or group of populations that is discrete from other populations of the species and is significant in relation to the entire species; the Endangered Species Act provides for listing species, subspecies, or distinct population segments of vertebrate species

EIS: Environmental Impact Statement: a document required by the U.S. National Environmental Policy Act for proposed federal actions that have the potential for significant environmental impacts to ensure that all such impacts, alternatives to the proposal that might reduce impacts, and mitigations measures are fully considered

ESA: Endangered Species Act: U.S. federal law enacted in 1973, designed to conserve and protect fish, wildlife, and plants that are listed as threatened or endangered under the Act

ESM: Earth System Models: complex climate models that incorporate representation of biogeochemical processes, such as the carbon cycle

ECS: Equilibrium Climate Sensitivity: the change in the surface temperature after reaching equilibrium, following a doubling of the atmospheric carbon dioxide (CO_2) concentration from the pre-industrial period

FR: Federal Register: official daily publication of the U.S. federal government for rules, proposed rules, and notices, as well as executive orders and other presidential documents

GHG: Greenhouse Gas: gases in the earth's atmosphere that trap heat, such as carbon dioxide, methane, nitrous oxide, and fluorinated gases

GWL: Global Warming Level: IPCC defined as a "global surface temperature increase in the year 2100, relative to the mean of the preindustrial years 1850–1900" (AR6 WG1 TS.1.3.2)

HAB: Harmful Algal Bloom: NOAA defined as when "simple plants that live in the sea and freshwater — grow out of control and that produce toxic or harmful effects on people, fish, shellfish, marine mammals and birds"[16]

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[16] NOAA, "What is a harmful algal bloom," accessed November 2023, https://www.noaa.gov/what-is-harmful-algal-bloom.

HBI: Highly Branched Isoprenoid Diatom Lipids: type of lipids found in diatoms, certain of which have been used as biomarkers of sea ice algae versus phytoplankton carbon sources in several marine mammal species

HELCOM: Baltic Marine Environment Protection Commission, or Helsinki Commission: intergovernmental organization that is the governing body of the Helsinki Convention

IEA: International Energy Agency: international energy forum that provides global energy analysis, data, and policy recommendations

IK: Indigenous Knowledge: defined by United Nations Educational, Scientific and Cultural Organization (UNESCO) as "understandings, skills, and philosophies developed by local communities with long histories and experiences of interaction with their natural surroundings"[17]

IPCC: Intergovernmental Panel on Climate Change: United Nations body for assessing the science related to climate change

LIA: Last Ice Area: The Arctic Circle polar region's thickest and oldest ice sheet

Listing Decision (and "Listing Determination" and "the listing rule"): determination made in accordance with section 4 of the Endangered Species Act and implementing regulations that a species is threatened or endangered; the "listing rule" or "final rule" refers to the official listing determination published in the Federal Register.

LNG: Liquefied Natural Gas: natural gas that has been reduced to a liquid state through cooling, for ease of transport

MARPOL: International Convention for the Prevention of Pollution from Ships: primary international convention addressing prevention of marine pollution by ships

MHW: Marine Heatwave: a period of unusually high ocean temperatures. IPCC defined a marine heatwave as "an exceedance of 99th-percentile 11-day de-seasonalized sea surface temperatures" (AR6 WG1 Annex VII Glossary)

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[17] UNESCO, "Local and indigenous knowledge system (LINKS"), accessed November 2023, https://en.unesco.org/links.

NDC: Nationally Determined Contributions: United Nations described as a national "climate action plan to cut emissions and adapt to climate impacts"; required for each party to the Paris Agreement[18]

NEP: Northeast Passage: shipping route between the Atlantic and Pacific oceans, along the Arctic coasts of Norway and Russia

NIC: National Intelligence Council: organization within the U.S. Office of the Director of National Intelligence that is responsible for leading analysis across the intelligence community to inform policy deliberations; produces the "Global Trends" report every four years

NMFS: National Marine Fisheries Service: subdivision of NOAA responsible for the stewardship and management of the United States' ocean resources and their habitat

NOAA: National Oceanic and Atmospheric Administration: U.S. federal agency responsible for predicting and understanding changes in climate, weather, oceans, and coastlines of the United States

NPR-A: National Petroleum Reserve in Alaska: a 23-million-acre unit of Federal land on the North Slope managed by the U.S. Bureau of Land Management

NSR: Northern Sea Route: shipping route between the Kara Strait and Pacific Ocean, along the Arctic coast of Russia; a subsection of the Northeast Passage

NWP: Northwest Passage: shipping route between the Atlantic and Pacific oceans, along the Arctic coasts of Alaska and Canada

OA: Ocean Acidification: reduction in the pH of the ocean over an extended period of time, caused mainly by uptake of CO_2 from the atmosphere

OC: Organochlorine (pollutants): chlorinated compounds (e.g., pesticide chemicals)

PAME: Protection of the Arctic Marine Environment: a working group of the Arctic Council which addresses "marine policy measures in response to environmental change from both land and sea-based activities"

PBDE: Polybrominated Diphenyl Ethers: class of chemicals used in the manufacturing process to decrease chances for products to catch on fire

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[18] United Nations, "All about the NDCs," accessed November 2023, https://www.un.org/en/climatechange/all-about-ndcs.

PCB: Polychlorinated Biphenyls: U.S. Environmental Protection Agency defined as "domestically manufactured from 1929 until manufacturing was banned in 1979. [PCBs] have a range of toxicity and vary in consistency from thin, light-colored liquids to yellow or black waxy solids"[19]

PCR: Polymerase Chain Reaction: defined by the National Human Genome Research Institute as "a laboratory technique for rapidly producing (amplifying) millions to billions of copies of a specific segment of DNA, which can then be studied in greater detail"

PDV: Phocine Distemper Virus: "Phocine morbillivirus" that impacts the breathing and nervous system of seals

PFC: Perfluorinated Contaminants, or Polyfluorinated Substances (PFAS): Centers for Disease Control and Prevention defined as a "group of chemicals used to make fluoropolymer coatings and products that resist heat, oil, stains, grease, and water." These elements can impact growth and development, and bioaccumulate in the marine environment.

PFCA: Perfluorinated Carboxylic Acids: used to synthesize peptides and can very easily bioaccumulate in the marine environment

PFOS: Perfluorooctane Sulfonate: synthetic fluorosurfactant used to manufacture stain repellents; recently added to "Annex B of the Stockholm Convention on Persistent Organic Pollutants" as a global pollutant

POP: Persistent Organic Pollutant: manufactured chemicals and byproducts used in industry which have a long lasting impact to human health and the environment

RCP: Representative Concentration Pathway: trajectory (time series) of emissions and concentrations of greenhouse gases, aerosols, and chemically active gases, as well as land use/land cover, that leads to a specific year 2100 radiative forcing

SRES: Special Report on Emissions Scenarios: report published by the IPCC which described greenhouse gas emission scenarios, a selection of which were used in the IPCC's Third and Fourth Assessment Reports

SSP: Shared Socioeconomic Pathways: five different storylines that describe major global developments that together would lead in the future to different challenges for mitigation

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[19] U.S. Environmental Protection Agency, "Learn about polychlorinated biphenyls," Accessed November 2024, https://www.epa.gov/pcbs/learn-about-polychlorinated-biphenyls#:~:text=PCBs%20belong%20to%20a%20broad,yellow%20or%20black%20waxy%20solids.

and adaptation to climate change; designed to function in combination with the representative concentration pathways

SST: Sea Surface Temperature

Status Review (and "2010 Status Review"): a compilation of the best scientific and commercial data available concerning a species' current status, threats, and extinction risk. The "2010 Status Review" completed by Kelly et al. (2010) evaluated the biology, ecology, population status, threats, and extinction risk of five ringed seal subspecies as of 2010.

TSR: Trans-polar Sea Route: shipping route between the Atlantic and Pacific oceans via a direct path over the North Pole

UKCCC: United Kingdom Climate Change Committee: independent committee responsible for advising the UK government on reducing greenhouse gas emissions to meet emissions targets and adapt to the impacts of climate change

UME: Unusual Mortality Event: defined under the Marine Mammal Protection Act as a "stranding event that is unexpected, involves a significant die-off of any marine mammal population, and demands immediate response"

UNEP: United Nations Environment Programme: United Nations entity that is focused on addressing environmental challenges within the United Nations system

UNFCCC: United Nations Framework Convention on Climate Change: United Nations Convention with 198 members which is the parent treaty of the Paris Agreement and the Kyoto Protocol

USGS: United States Geological Survey: U.S. federal agency that conducts scientific research to understand the environment, natural resources, and related public safety issues

USFWS (and FWS): United States Fish and Wildlife Service: U.S. federal agency whose primary responsibility is the conservation and management of fish, wildlife, plants, and their habitats

WMGHG: Well-mixed greenhouse gas: IPCC defined as a "greenhouse gas (GHG) that has an atmospheric lifetime long enough (greater than several years) to be homogenously mixed in the troposphere . . ." (AR6 WG1 Annex VII Glossary); includes carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, and a variety of halogenated species

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NATIONAL MARINE FISHERIES SERVICE
5-YEAR REVIEW of

Arctic Ringed Seal (*Pusa hispida hispida*), Okhotsk Ringed Seal (*Pusa hispida ochotensis)*, Baltic Ringed Seal (*Pusa hispida botnica*), and Ladoga Ringed Real (*Pusa hispida ladogensis*)

Current Classification: Threatened (Arctic ringed seal, Okhotsk ringed seal, and Baltic ringed seal) and Endangered (Ladoga ringed seal)

Recommendation resulting from the 5-Year Review:

☐ Downlist to Threatened
☐ Uplist to Endangered
☐ Delist
☒ No change is needed

Review Conducted By (Name and Office):

Jon Kurland, Tammy Olson, Kathleen Leonard, and Barbara Mahoney (AKR); and Peter Boveng, Shawn Dahle, John Jansen, Jessica Lindsay, and Heather Ziel, with literature review, bibliographic, and editing assistance by Skyla Walcott (AFSC)

REGIONAL OFFICE APPROVAL:

Lead Regional Administrator, NOAA Fisheries

Approve____ Date: 2/14/24

Cooperating Regional Administrator, NOAA Fisheries

☐ Concur ☐ Do Not Concur ☒ N/A

Signature____ Date: _______

HEADQUARTERS APPROVAL:

Assistant Administrator, NOAA Fisheries

☒ Concur ☐ Do Not Concur

Signature RAUCH.SAMUEL.DEAN.1365850948 Digitally signed by RAUCH.SAMUEL.DEAN.1365850948 Date: 2024.02.28 16:06:05 -05'00' Date: _______