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# BOWHEAD WHALE (*Balaena mysticetus*): Western Arctic Stock

## STOCK DEFINITION AND GEOGRAPHIC RANGE

Western Arctic bowhead whales are distributed in seasonally ice-covered waters of the Arctic and near-Arctic, generally north of 60°N and south of 75°N in the western Arctic Basin (Braham 1984, Moore and Reeves 1993). For management purposes, four stocks of bowhead whales are recognized worldwide by the International Whaling Commission (IWC 2010). Small stocks, comprising only a few hundred individuals, occur in the Sea of Okhotsk and the offshore waters of Spitsbergen (Zeh et al. 1993, Shelden and Rugh 1995, Wiig et al. 2009, Shpak et al. 2014, Boertmann et al. 2015, Vacquié-Garcia et al. 2017). Bowhead whales occur in western Greenland (Hudson Bay and Foxe Basin) and eastern Canada (Baffin Bay and Davis Strait), and evidence suggests that these should be considered one stock based on genetics (Postma et al. 2006, Bachmann et al. 2010, Heide-Jørgensen et al. 2010, Wiig et al. 2010), aerial surveys (Cosens et al. 2006), and tagging data (Dueck et al. 2006; Heide-Jørgensen et al. 2006; IWC 2010, 2011). This stock, previously thought to include only a few hundred animals, may number over a thousand (Heide-Jørgensen et al. 2006, Wiig et al. 2011) and perhaps over 6,000 (IWC 2008, Doniol-Valcroze et al. 2015, Frasier et al. 2015). The only stock found within U.S. waters is the Western Arctic stock (Fig. 1), also known as the Bering-Chukchi-Beaufort Seas stock (Rugh et al. 2003) or Bering Sea stock (Burns et al. 1993). The IWC Scientific Committee concluded, in several reviews of the extensive genetic and satellite telemetry data, that the weight of evidence is most consistent with one bowhead whale stock that migrates throughout waters of northern and western Alaska and northeastern Russia (IWC 2008, 2018).

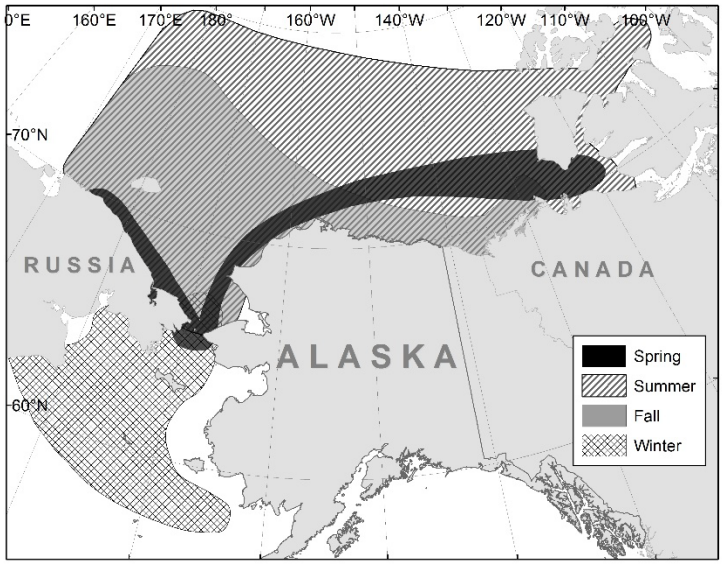


**Figure 1.** Annual range of the Western Arctic stock of bowhead whales by season from satellite tracking data, 2006-2017 (map based on Quakenbush et al. (2018): Fig. 2).

The majority of the Western Arctic stock migrates annually from wintering areas in the northern Bering and southern Chukchi seas (December to April), through the Chukchi Sea and Beaufort Sea in the spring (April through May), to the eastern Beaufort Sea (Fig. 1) where they spend much of the late spring and summer (May through September). During late summer and autumn (September through December), this stock migrates back to the Chukchi Sea and then to the Bering Sea (Fig. 1) to overwinter (Braham et al. 1980; Moore and Reeves 1993; Quakenbush et al. 2010, 2018; Citta et al. 2015). During winter and spring, bowhead whales are closely associated with sea ice (Moore and Reeves 1993, Quakenbush et al. 2010, Citta et al. 2015, Druckenmiller et al. 2018). The bowhead whale spring migration follows fractures in the sea ice along the coast to Point Barrow, generally in the shear zone between the shorefast ice and the mobile pack ice, then continues offshore on a direct path to the Cape Bathurst polynya (Citta et al. 2015). In most years, during summer, a large proportion of the population is in the relatively ice-free waters of Amundsen Gulf in the eastern Beaufort Sea (Citta et al. 2015), an area where industrial activity related to petroleum exploration often occurs (e.g., Richardson et al. 1987, Davies 1997). Summer aerial surveys conducted in the western Beaufort Sea during July and August of 2012-2017 have had relatively high sighting rates of bowhead whales, including cows with calves and feeding animals (Clarke et al. 2018a, 2018b), suggesting interannual variability in bowhead whale summer distribution. Additionally, data from a satellite-tagging study conducted between 2006 and 2018 indicated that, although most tagged whales began to leave the Canadian Beaufort Sea in September, the timing of their westward migration across the Beaufort Sea was highly variable; furthermore, all tagged whales observed in summer and fall in Beaufort and Chukchi waters near Point Barrow were known to have returned from Canada (Quakenbush and Citta 2019). Timing of the onset of the westward migration across the Beaufort Sea is associated with oceanographic conditions in the eastern Beaufort Sea (Citta et al. 2018, Clarke et al. 2018b). During the autumn

migration, bowhead whales generally inhabit shelf waters across the Beaufort Sea (Citta et al. 2015). The autumn migration across the Chukchi Sea is more dispersed (Clarke et al. 2016). During winter in the Bering Sea, bowhead whales often use areas covered by nearly 100% sea ice, even when polynyas are available (Quakenbush et al. 2010, Citta et al. 2015).

This stock assessment report assesses the abundance and Alaska Native subsistence harvest of Western Arctic bowhead whales throughout the stock's entire geographic range. Human-caused mortality and serious injury, other than Alaska Native subsistence harvest, is estimated for the portion of the range within U.S. waters (i.e., the U.S. Exclusive Economic Zone) because relevant data are generally not available for the broader range of the stock. However, some pot gear entanglements and rope scars detected in U.S. waters may have been caused by Russian pot fisheries (Citta et al. 2014).

## POPULATION SIZE

All stocks of bowhead whales were severely depleted during intense commercial whaling, starting in the early 16th century near Labrador, Canada (Ross 1993), and spreading to the Bering Sea in the mid-19th century (Braham 1984, Bockstoce and Burns 1993, Bockstoce et al. 2007). Woodby and Botkin (1993) summarized previous efforts to estimate bowhead whale population size prior to the onset of commercial whaling. They reported a minimum worldwide population estimate of 50,000, with 10,400 to 23,000 in the Western Arctic stock (dropping to less than 3,000 at the end of commercial whaling). Brandon and Wade (2006) used Bayesian model averaging to estimate that the Western Arctic stock consisted of 10,960 bowhead whales (9,190 to 13,950; 5th and 95th percentiles, respectively) in 1848 at the start of commercial whaling.

**Table 1.** Summary of abundance estimates for the Western Arctic stock of bowhead whales. The historical estimates were made by back-projecting using a simple recruitment model. Historical estimates are from Woodby and Botkin (1993); 1978-2001 estimates are from George et al. (2004) and Zeh and Punt (2005). All other estimates were developed by corrected ice-based census counts. The 2019 estimate is reported in Givens et al. (2021a, 2021b).

| Year | Abundance range or estimate (CV) | Year | Abundance estimate (CV) |
|---|---|---|---|
| Historical | 10,400-23,000 | 1985 | 5,762 (0.253) |
| End of commercial whaling | 1,000-3,000 | 1986 | 8,917 (0.215) |
| 1978 | 4,765 (0.305) | 1987 | 5,298 (0.327) |
| 1980 | 3,885 (0.343) | 1988 | 6,928 (0.120) |
| 1981 | 4,467 (0.273) | 1993 | 8,167 (0.017) |
| 1982 | 7,395 (0.281) | 2001 | 10,545 (0.128) |
| 1983 | 6,573 (0.345) | 2011 | 16,820 (0.052) |
| | | 2019 | 14,025 (0.228) |

The Aboriginal Whaling Scheme (IWC 2018) requires that abundance estimates be updated at least every 10 years as input into the Strike Limit Algorithm (SLA) that the IWC approved for estimating a safe strike limit for aboriginal subsistence hunting. Ice-based visual and acoustic counts have been conducted since 1978 (Krogman et al. 1989; Table 1). These counts have been corrected for whales missed due to distance offshore since the mid-1980s, using acoustic methods described in Clark et al. (1994). Correction factors were estimated for whales missed during a watch (due to visibility, number of observers, and offshore distance) and when no watch was in effect (through interpolations from sampled periods) (Zeh et al. 1993, Givens et al. 2016). The spring ice-based estimates of abundance have not been corrected for a small portion of the population that may not migrate past Point Barrow during the period when counts are made. According to Melnikov and Zeh (2007), 470 bowhead whales (95% CI: 332-665) likely migrated to Chukotka instead of Barrow in spring 2000 and 2001. More recent satellite tagging data also indicate that only a small proportion (~4%) of the population migrates to Chukotka (Quakenbush and Citta 2019).

Bowhead whales were identified from aerial photographs taken in 1985 and 1986, and again in 2003 and 2004, and the results were used in a sight-resight analysis (Table 2). These population estimates and their associated error are comparable to the estimates obtained from the combined ice-based visual and acoustic counts (Raftery and Zeh 1998, Schweder et al. 2009, Koski et al. 2010). An aerial photographic survey was conducted near Point Barrow concurrently with the ice-based spring census in 2011, which, in addition to an abundance estimate based on sight-resight data, also provided a revised survival estimate for the population (Givens et al. 2018) (Table 2). However, because the 2011 ice-based estimate had a lower coefficient of variation (CV), the IWC Scientific Committee considered this estimate the most appropriate for management and use in the SLA (IWC 2018).

**Table 2.** Summary of abundance estimates for the Western Arctic stock of bowhead whales from aerial sight-resight surveys. Estimates are reported in da Silva et al. 2000, 2007 (1986 estimate), Koski et al. 2010 (2004 estimate), and Givens et al. 2018 (2011 estimate). LB = lower bound of 95% confidence

| Year | Abundance range or estimate (CV) | Survival estimate (LB) |
|---|---|---|
| 1986 | 4,719 - 7,331 | 0.985 (0.958) |
| 2004 | 12,631 (0.2442) | |
| 2011 | 27,133 (0.217) | 0.996 (0.976) |

In 2019, a spring ice-based visual survey and a summer aerial line-transect survey were conducted to provide independent estimates of abundance. For the 2019 ice-based survey, Givens et al. (2021a) produced an initial estimate of abundance of 12,505 whales (CV = 0.228) but acknowledged that the estimate was likely biased low due to numerous factors, including closed leads that inhibited survey effort early in the migration; unprecedented wide leads later in the migration that resulted in an unusual migration route that was sometimes too distant from observers to detect whales; an unusually short observation platform compared to previous surveys; and hunters' heavy use of powered skiffs near the observation platform, which likely disturbed the whales during the survey. Givens et al. (2021b) developed a correction factor to account for the disturbance to the migration from powered skiffs, resulting in the best estimate of abundance from the 2019 ice-based survey of 14,025 whales (CV = 0.228). The 2019 abundance estimate from the aerial line-transect surveys is presently in review.

**Minimum Population Estimate**

The minimum population estimate ($N_{MIN}$) for the Western Arctic stock is calculated from Equation 1 from the potential biological removal (PBR) guidelines (NMFS 2023a): $N_{MIN} = N/\exp(0.842\times[\ln(1+[CV(N)]^2)]^{½})$. Using the 2019 population estimate (N) from the ice-based survey of 14,025 and its associated CV(N) of 0.228 (Table 1), $N_{MIN}$ for this stock of bowhead whales is 11,603 whales.

**Current Population Trend**

Based on concurrent passive acoustic and ice-based visual surveys, Givens et al. (2016) reported that the Western Arctic stock of bowhead whales increased at a rate of 3.7% (95% CI = 2.9-4.6%) from 1978 to 2011, during which time abundance tripled from approximately 5,000 to approximately 16,820 whales (Givens et al. 2016) (Fig. 2). Although the ice-based abundance estimate from 2019 (Givens et al. 2021a, 2021b) is lower than that from 2011, Givens et al. (2021a) do not interpret this to be a true decline in population abundance due to the abnormal ice conditions and migration route that were not accounted for in the abundance estimate and likely resulted in an underestimate of abundance. Schweder et al. (2009) estimated the yearly growth rate to be 3.2% (95% CI = 0.5-4.8%) between 1984 and 2003 using a sight-resight analysis of aerial photographs.

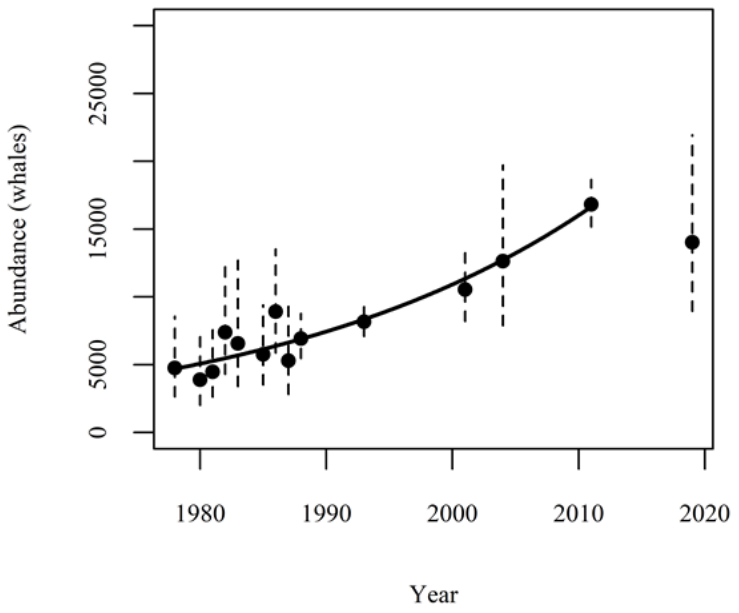


**Figure 2.** Estimated abundance and trend of Western Arctic bowhead whales, 1978-2011 (Givens et al. 2016), as computed from ice-based counts and acoustic data collected during bowhead whale spring migrations past Point Barrow, Alaska. The 2019 ice-based abundance estimate and confidence interval (Givens et al. 2021a, 2021b) are also shown; however, the trend line has not been extended because a formal analysis has not been conducted to determine whether the population is likely to have continued to increase exponentially.

**CURRENT AND MAXIMUM NET PRODUCTIVITY RATES**

The presumed current estimate for the rate of increase for the Western Arctic stock of bowhead whales (3.7%: 95% CI = 2.9-4.6%: Givens et al. 2016) should not be used as an estimate of the maximum net productivity rate ($R_{MAX}$) because the population is currently being harvested and the population has been estimated to be at a substantial fraction of its carrying capacity (Brandon and Wade 2006); therefore, this stock may not be growing at its maximum rate. Thus, the cetacean maximum theoretical net productivity rate of 4% will be used for the Western Arctic stock of bowhead whales (NMFS 2023a).

**POTENTIAL BIOLOGICAL REMOVAL**

PBR is defined as the product of the minimum population estimate, one-half the maximum theoretical net productivity rate, and a recovery factor: $PBR = N_{MIN} \times 0.5R_{MAX} \times F_R$. The recovery factor ($F_R$) for this stock has been set at 0.5 rather than the default value of 0.1 for endangered species because population levels are not known to be decreasing (Givens et al. 2021a, 2021b) in the presence of a known take (NMFS 2023a). Thus, PBR is 116 whales (11,603 × 0.02 × 0.5). The calculation of a PBR level for the Western Arctic bowhead whale stock is required by the MMPA even though the subsistence harvest quota is established under the authority of the IWC based on an extensively tested SLA (IWC 2003). The quota is based on subsistence need or the ability of the bowhead whale population to sustain a harvest, whichever is smaller. The IWC bowhead whale quota takes precedence over the PBR estimate for the purpose of managing the Alaska Native subsistence harvest from this stock, because it is managed under the Whaling Convention Act, an international treaty. In 2018, the IWC revised the bowhead whale subsistence quota (IWC 2018 Schedule amendment). Under the revisions, the total block quota for 2019 to 2025 is 392 landed whales (an average of 56/year), with no more than 67 strikes per year, except that any unused portion of a strike quota from the three prior quota blocks can be carried forward and added to the strike quotas of subsequent years, provided that no more than 50% of the annual strike limit (i.e., no more than 33 strikes) is added to the strike quota for any one year (IWC 2018 Schedule amendment, section 13(b)1). Hence, 67 strikes are allocated annually, with the possibility of adding 33 strikes if they are available from the prior three quota blocks. A bilateral agreement between the United States and the Russian Federation ensures that the total quota of bowhead whales struck will not exceed the limits set by the IWC. Under this bilateral arrangement, the Chukotka Natives in Russia may use no more than seven strikes and Alaska Natives may use no more than 93 strikes per year.

## ANNUAL HUMAN-CAUSED MORTALITY AND SERIOUS INJURY

Information for each human-caused mortality, serious injury, and non-serious injury reported for NMFS-managed Alaska marine mammals between 2016 and 2020 is listed, by marine mammal stock, in Freed et al. (2022); however, only the mortality and serious injury data are included in the Stock Assessment Reports. The minimum estimated mean annual level of human-caused mortality and serious injury for Western Arctic bowhead whales between 2016 and 2020 is 56 whales: calculated as the sum of subsistence takes by Alaska Natives (55; (mean actual number of landed whales plus mean annual struck and lost mortality) plus whales landed in subsistence takes by Natives of Russia (0.8; struck and lost whales not reported). Several bowhead whales harvested by Alaska Natives were found to have been seriously injured by unknown (commercial, recreational, or subsistence) fisheries prior to harvest (mean of 0.6/year; Freed et al. 2022); to avoid double counting, these are not added to the total mortality and serious injury for the stock. Potential threats most likely to result in direct human-caused mortality or serious injury of individuals in this stock include entanglement in fishing gear and vessel strikes due to increased vessel traffic (from increased commercial shipping in Bering Strait and the Chukchi and Beaufort seas).

### Fisheries Information

Information for federally-managed and state-managed U.S. commercial fisheries in Alaska waters is available in Appendix 3 of the Alaska Stock Assessment Reports (observer coverage) and in the NMFS List of Fisheries (LOF) and the fact sheets linked to fishery names in the LOF (observer coverage and reported incidental takes of marine mammals: https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-protection-act-list-fisheries, accessed May 2023).

Based on historical reports and the stock's geographic range, pot fishery gear is the only documented source of fisheries-caused bowhead whale mortality and serious injury. The levels of interactions are unknown, even for observed fisheries. While some finfish pot and crab pot fisheries have onboard observers, the observers are unlikely to observe interactions unless an animal is anchored in gear. In most cases, large whale interactions occur while the pots are left untended to fish or "soak" and the whale swims away with gear attached. Because an observer generally cannot determine if a missing pot was lost due to whale entanglement, mortality and serious injury events are seldom reported in these fisheries. Therefore, the potential for fisheries-caused mortality and serious injury may be greater than is reflected in existing observer data. Additionally, bowhead whales may become entangled in derelict pot gear and such interactions would also not be reflected in observer data.

There are no observer program records of bowhead whale mortality or serious injury incidental to U.S. commercial fisheries in Alaska; however, there have been reports of bowhead whale mortality and serious injury due to entanglement in fishing gear (Table 3). Because no U.S. commercial fisheries occur in the Beaufort or Chukchi seas, bowhead whale mortality or injury that can be associated with U.S. commercial fisheries is currently attributed to interactions with fisheries in the Bering Sea. Citta et al. (2014) found that the distribution of satellite-tagged bowhead whales in the Bering Sea spatially, but not temporally, overlapped areas where commercial pot fisheries occurred and noted the potential risk of entanglement in lost gear. George et al. (2017) analyzed scarring data for bowhead whales harvested between 1990 and 2012 to estimate the frequency of line entanglement. Approximately 12.2% of the harvested whales examined for signs of entanglement (59/485) had scar patterns that were identified as definite entanglement injuries (29 whales with possible entanglement scars were excluded). Most of the entanglement scars occurred on the peduncle, and entanglement scars were rare on smaller subadult and juvenile whales (body length <10 m), possibly because young whales are less likely to survive entanglements and have had fewer years during which to acquire entanglement scars (George et al. 2017). The authors suspected the entanglement scars were largely the result of interactions with commercial pot gear (including derelict gear) in the Bering Sea. A review of the photo-identification catalog from 1985 to 2011 found the probability of scarring due to entanglement was about 2.2% per year (95% CI: 1.1-3.3%), with 12.4% of living bowhead whales photographed in 2011 showing evidence of entanglement (George et al. 2019).

Between 2016 and 2020, there were three reports of bowhead whale mortality or serious injury caused by interactions with fishing gear (Table 3). Three of the bowhead whales taken in the Alaska Native subsistence hunt in 2017 were seriously injured prior to harvest due to entanglement in pot gear suspected (but not confirmed) to be from Bering Sea commercial pot fisheries (Rolland et al. 2019, Freed et al. 2022), resulting in a mean annual mortality and serious injury rate of 0.6 bowhead whales in unknown (commercial, recreational, or subsistence) fisheries between 2016 and 2020 (Table 3). These three whales are also included in the Alaska Native subsistence harvest for 2017 (Table 4).

Thus, the minimum estimated mean annual mortality and serious injury rate in unknown (commercial, recreational, or subsistence) fisheries between 2016 and 2020 is 0.6 whales (Table 3; Freed et al. 2022), although the actual rates are currently unknown. These mortality and serious injury estimates result from actual counts of verified

human-caused deaths and serious injuries and are minimums because not all entangled animals are found, reported, or have the cause of death determined.

**Table 3.** Summary of mortality and serious injury of Western Arctic bowhead whales, by year and type, reported between 2016 and 2020 (NMFS Alaska Region marine mammal stranding network, Rolland et al. 2019, Freed et al. 2022).

| Cause of injury | | 2016 | 2017 | 2018 | 2019 | 2020 | Mean annual mortality |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| Entangled in Bering Sea/Aleutian Is. pot gear* | | 0 | 3 | 0 | 0 | 0 | 0.6 |
| *Total in unknown (commercial, recreational, or subsistence) fisheries | | | | | | | 0.6 |

**Alaska Native Subsistence/Harvest Information**

NMFS signed an agreement with the Alaska Eskimo Whaling Commission (in 1998, as last amended in 2019) to protect the bowhead whale and the Alaska Native culture. This co-management agreement promotes full and equal participation by Alaska Natives in decisions affecting the subsistence management of marine mammals (to the maximum extent allowed by law) as a tool for conserving marine mammal populations in Alaska (https://www.fisheries.noaa.gov/alaska/marine-mammal-protection/co-management-marine-mammals-alaska, accessed May 2023).

Alaska Natives have been taking bowhead whales for subsistence purposes for at least 2,000 years (Marquette and Bockstoce 1980, Stoker and Krupnik 1993). Subsistence takes have been regulated by a quota system under the authority of the IWC since 1977. Alaska Native subsistence hunters, primarily from 11 Alaska communities, take approximately 0.1-0.5% of the Western Arctic bowhead whale stock per year (Philo et al. 1993, Suydam et al. 2011). Under this quota, the number of bowhead whales landed by Alaska Natives between 1974 and 2020 ranged from 8 to 55 whales per year (Suydam and George 2012; Suydam et al. 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020; George and Suydam 2014; Scheimreif et al. 2021). The maximum number of strikes per year is set by a quota which is determined by subsistence needs and bowhead whale abundance and trend estimates (Stoker and Krupnik 1993) (see the Potential Biological Removal section). Suydam and George (2012) summarized Alaska subsistence harvests of bowhead whales from 1974 to 2011 and reported a total of 1,149 whales landed by hunters from 12 villages, with Utqiaġvik (formerly Barrow) landing the most whales (n = 590) and Shaktoolik landing only one. Alaska Natives landed 228 bowhead whales between 2016 and 2020 and 49 of the 61 whales that were struck and lost were determined to have died or had a poor chance of survival, resulting in a mean annual take (number of whales landed + struck and lost mortality) of 55 whales (Table 4); however, because a mean annual 0.6 whales were determined to have been seriously injured in fishery interactions prior to harvest, the total subsistence harvest by Alaska Natives between 2016 and 2020 is 54 whales. Unlike the NMFS process for determining serious injuries (described in NMFS 2023b), the estimates of struck and lost mortality in the subsistence harvest are based on the Whaling Captains' assessment of the likelihood of survival (see criteria described in Suydam et al. 1995). The number of whales landed at each village varies greatly from year to year, as success is influenced by village size and ice and weather conditions. The efficiency of the hunt (the percent of whales struck that are retrieved) has increased since the implementation of the bowhead whale quota in 1978. In 1978, the efficiency was about 50%. In 2020, 54 of 69 whales struck were landed, resulting in an efficiency of 78% and the mean efficiency for 2010 to 2019 was 77% (Scheimreif et al. 2021).

Indigenous Peoples in Canada and Russia also take whales from this stock. No catches of Western Arctic bowhead whales were reported by Canadian hunters between 2016 and 2020; however, two bowhead whales were landed in Russia in 2016 (Ilyashenko and Zharikov 2017), one in 2017 (Zharikov 2018), none in 2018 (Zharikov et al. 2019), and one in 2019 (Zharikov et al. 2020), resulting in an average annual take of 0.8 (landed) whales by Indigenous Russians between 2015 and 2019, which are the most recent data available.

The total mean annual subsistence take is 56 bowhead whales: 55 whales taken by Alaska Natives between 2016 and 2020 (equals the number of landed whales plus the struck and lost mortality; Table 4) plus 0.8 whales landed by Indigenous Russians (struck and lost whales not reported) between 2015 and 2019.

**Table 4.** Summary of the Alaska Native subsistence harvest of Western Arctic bowhead whales between 2016 and 2020.

| Year | Landed | Struck and lost | Struck and lost mortality[a] | Total (landed + struck and lost mortality) |
|---|---|---|---|---|
| | | | | |
| 2016[b] | 47 | 12 | 12 | 59 |
| 2017[c] | 50 | 7 | 5 | 55 |
| 2018[d] | 47 | 21 | 17 | 64 |
| 2019[e] | 30 | 6 | 2 | 32 |
| 2020[f] | 54 | 15 | 13 | 67 |
| Mean annual number taken (landed + struck and lost mortality) | | | | 55 |

[a]Struck and lost mortality includes animals determined to have died or had a poor chance of survival (per the criteria described in Suydam et al. 1995); [b]Suydam et al. (2017); [c]Suydam et al. (2018); [d]Suydam et al. (2019); [e]Suydam et al. (2020); [f]Scheimreif et al. (2021).

**Other Mortality**

Pelagic commercial whaling for bowhead whales was conducted from 1849 to 1914 in the Bering, Chukchi, and Beaufort seas (Bockstoce et al. 2007). During the first two decades of the fishery (1850-1870), over 60% of the estimated pre-whaling population was killed, and effort remained high into the 20th century (Braham 1984). Woodby and Botkin (1993) estimated that the pelagic whaling industry harvested 18,684 whales from this stock. From 1848 to 1919, shore-based whaling operations (including landings as well as struck and lost estimates from the U.S., Canada, and Russia) took an additional 1,527 whales (Woodby and Botkin 1993). An unknown percentage of the whales taken by the shore-based operations were harvested for subsistence purposes. Historical harvest estimates likely underestimate the actual harvest as a result of under-reporting of the Soviet catches (Yablokov 1994) and incomplete reporting of struck and lost whales.

Transient killer whales are known to prey on bowhead whales. In a study of marks on bowhead whales taken in the subsistence harvest between spring 1976 and fall 1992, 4.1% to 7.9% had scars indicating that they had survived attacks by killer whales (George et al. 1994). Of 377 complete records for killer whale scars collected from 1990 to 2012, 29 whales (7.9%) had scarring "rake marks" consistent with killer whale injuries and another 10 had possible injuries (George et al. 2017). A higher rate of killer whale rake mark scars occurred from 2002 to 2012 than in the previous decade. George et al. (2017) noted this may be due to better reporting and/or sampling bias, an increase in killer whale population size, an increase in occurrence of killer whales at high latitudes (Clarke et al. 2013), or a longer open water period offering more opportunities to attack bowhead whales. The Aerial Surveys of Arctic Marine Mammals (ASAMM) project photo-documented bowhead whale carcasses that had injuries consistent with killer whale predation in 2010 (one carcass), 2012 (two), 2013 (three), 2015 (three), 2016 (four), 2017 (one), 2018 (four), and 2019 (six) (Willoughby et al. 2020a, 2020b).

Currently, vessel-strike injuries on bowhead whales in Alaska are thought to be uncommon (George et al. 2017, 2019). Only 10 whales harvested between 1990 and 2012 (approximately 2% of the records examined) showed clear evidence of scarring from vessel propellers (George et al. 2017), while only seven whales from the photo-identification catalog from 1985 to 2011 (1% of the sample) had evidence of vessel-inflicted scars (George et al. 2019). One carcass observed in 2019 during the ASAMM surveys had blubber sections with straight wound edges and was likely struck by a vessel (Willoughby et al. 2020b).

**HABITAT CONCERNS**

Vessel traffic in arctic waters is increasing, largely due to an increase in commercial shipping facilitated by the lack of sea ice (Smith and Stephenson 2013, Reeves et al. 2014, Hauser et al. 2018, USCMTS 2019, George et al. 2020). For example, large vessels carrying liquefied natural gas recently transited through Anadyr Strait (west of Saint Lawrence Island) and there are plans for consistent year-round shipping through the Strait (Stolyarov 2021), including the wintering area for western Arctic bowhead whales. The increase in vessel traffic could result in an increased number of vessel collisions with bowhead whales (Huntington et al. 2015, Hauser et al. 2018) and increased acoustic disturbance (Halliday et al. 2021). Oil and gas development in the Beaufort Sea imposes risks of various forms of pollution, including oil spills, in bowhead whale habitat and the technology for effectively recovering spilled oil in icy conditions is lacking (Wilkinson et al. 2017).

Also of concern is noise produced by seismic surveys and vessel traffic resulting from shipping and offshore energy exploration, development, and production operations (Blackwell and Thode 2021). Evidence indicates that

bowhead whales are sensitive to noise from offshore drilling platforms and seismic survey operations (Richardson and Malme 1993, Richardson 1995, Davies 1997, Robertson et al. 2013, Blackwell et al. 2017). Bowhead whales often avoid sound sources associated with active drilling (Schick and Urban 2000) and seismic operations (Miller et al. 1999). Exposure to seismic operations resulted in subtle changes to dive, surfacing, and respiration behaviors (Robertson et al. 2013). Source levels, time of year, and whale behavior (migrating, feeding, etc.) all affect the extent of displacement or changes in behavior, including calling rates (reviewed in Blackwell and Thode 2021).

Global climate model projections for the next 50 to 100 years consistently show pronounced warming over the Arctic, accelerated sea-ice loss, and continued permafrost degradation (USGS 2011, IPCC 2013, Jeffries et al. 2015). Within the Arctic, some of the largest changes are projected to occur in the Bering, Beaufort, and Chukchi seas (Chapman and Walsh 2007, Walsh 2008). Ice-associated animals, including the bowhead whale, may be sensitive to changes in arctic weather, sea surface temperatures, sea-ice extent, and the concomitant effect on prey availability (Moore et al. 2019). Based on an analysis of various life-history features, Laidre et al. (2008) concluded that, on a worldwide basis, bowhead whales were likely to be moderately sensitive to climate change. Using statistical models, Chambault et al. (2018) found that bowhead whales in Baffin Bay, Greenland, targeted a narrow range of temperatures (-0.5 to 2°C) and may be exposed to thermal stress as a result of warming temperatures. However, the Western Arctic stock of bowhead whales commonly feeds in waters ranging from 4° to 6°C near Tuktoyaktuk (Citta et al. 2021); a bowhead was sighted in the relatively warm waters of the Gulf of Maine during summer 2012, 2014, and 2017 (Accardo et al. 2018); and bowhead whales in the Sea of Okhotsk are found in waters with sea surface temperatures up to 16.5°C (Shpak and Paramonov 2018). Therefore, it is possible that bowhead whales' selection of cooler waters in some regions could be primarily due to prey availability as opposed to thermal stress. Additionally, landed Western Arctic bowhead whales had better body condition during years of light ice cover (George et al. 2006). In addition, a positive correlation between body condition of Western Arctic bowhead whales and summer sea-ice loss has been observed over the last 2.5 decades in the Pacific Arctic (George et al. 2015). Ice-free areas along the shelf break are thought to create increased upwelling and likely more feeding opportunities for foraging whales. The movement and foraging behavior of bowhead whales is becoming more variable as feeding areas are altered in response to retreating sea ice. Ashjian et al. (2021) found that interannual variability in sea ice and winds in the Chukchi Sea affect krill population structure in the bowhead whale feeding hotspot near Point Barrow. Hannay et al. (2013) found that a large fraction of bowhead whale acoustic detections in the northeast Chukchi Sea occurred just in advance of the progression of sea ice formation during the fall migration, suggesting that an increase in ice-free days may lead to a delayed migration out of the Chukchi Sea during fall. Stafford et al. (2021) found that bowhead whales delayed their migration out of the Beaufort Sea by 7 days per year from 2008-2018. Insley et al. (2021) used passive acoustic monitoring to document the first known occurrence of bowhead whales overwintering in Amundsen Gulf and the eastern Beaufort Sea. Sheffield and George (2013) presented evidence that the occurrence of fish has become more prevalent in the diets of Western Arctic bowhead whales near Utqiaġvik in the autumn. However, there are insufficient data to make reliable projections about whether arctic climate change will result in negative (thermal stress, habitat loss) or positive (prey abundance) effects on this population. The reduction in sea ice may lead to increased predation of bowhead whales by killer whales. A northward shift of fish stocks and fisheries due to climate change (Morley et al. 2018) will also increase the risk of bowhead whale interactions with fishing gear.

Ocean acidification, driven primarily by the release of carbon dioxide ($CO_2$) emissions into the atmosphere, is also a concern due to potential effects on prey. Because their primary prey are small crustaceans (especially calanoid copepods, euphausiids, gammarid and hyperid amphipods, and mysids that have exoskeletons composed of chitin and calcium carbonate), bowhead whale survival and recruitment may be impacted by increased ocean acidification (Lowry et al. 2004). The nature and timing of impacts to bowhead whales from ocean acidification are extremely uncertain and will depend partially on the whales' ability to switch to alternate prey species. Ecosystem responses may have very long lags as they propagate through trophic webs.

## STATUS OF STOCK

Based on currently available data, the minimum estimated mean annual mortality and serious injury rate incidental to U.S. commercial fisheries (0 whales) is not known to exceed 10% of the PBR (10% of PBR = 12) and, therefore, can be considered insignificant and approaching a zero mortality and serious injury rate. The minimum estimated mean annual level of human-caused mortality and serious injury (56 whales) is not known to exceed the PBR (116), the IWC annual maximum strike limit (67 + up to 33 previously unused strikes), nor the IWC block-level landing limit (392 whales, or 56 landings per year). By 2011, the Western Arctic bowhead whale stock had increased to 16,820 whales; this represents between 31% and 168% of the pre-exploitation abundance of 10,000 to 55,000 whales estimated by Brandon and Wade (2004, 2006). The most recent ice-based abundance estimate from 2019 (Givens et al. 2021a, 2021b), is not statistically different from the corresponding estimate for 2011; therefore, the

abundance is not believed to have decreased. However, the stock is classified as strategic because the bowhead whale is listed as endangered under the U.S. Endangered Species Act and is, therefore, also designated as depleted under the MMPA.

There are key uncertainties in the assessment of the Western Arctic stock of bowhead whales. The current best estimate of abundance is based on the 2019 ice-based survey, which was negatively affected by disturbance from powered skiffs and anomalies in sea ice conditions that subsequently affected observation effort and the whales' migration route (Givens et al. 2021a). Givens et al. (2021b) derived a correction factor to account for the disturbance from powered skiffs, but the other known sources of negative bias were not accounted for in the best abundance estimate. Although there are few records of bowhead whales being killed or seriously injured incidental to commercial fishing, about 12.2% of harvested bowhead whales examined for scarring (59/485 records) had scars indicating line entanglement wounds (George et al. 2017) and the southern range of the population overlaps with commercial pot fisheries (Citta et al. 2014).

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