Revised 12/30/2019

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 have been 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). 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). The only stock found within U.S. waters is the Western Arctic stock (Fig. 1), also known as the Bering-Chukchi-Beaufort 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).

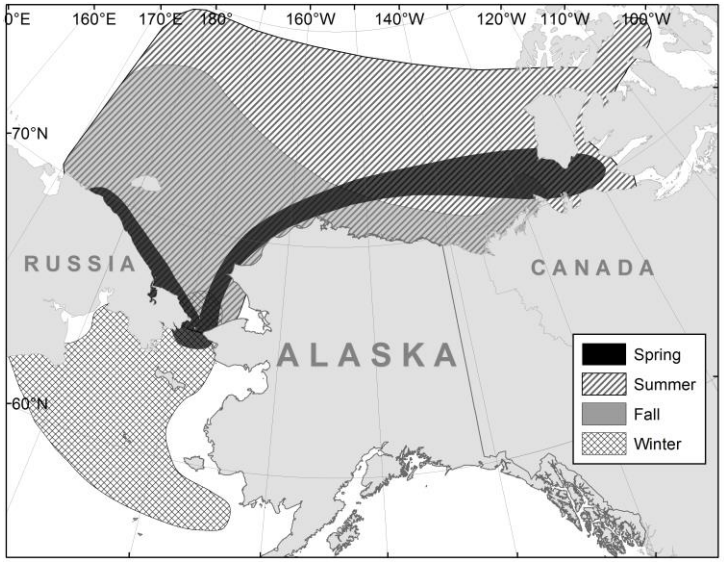

Figure 1. Annual range of the Western Arctic stock of bowhead whales by season from satellite tracking data, 2006-2017 (map based on Quakenbush et al. (2018): Fig. 2).

The majority of the Western Arctic stock migrates annually from wintering areas (December to March) in the northern Bering Sea, 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 summer (June through early to mid-October) before returning again to the Bering Sea (Fig. 1) in the fall (September through December) to overwinter (Braham et al. 1980; Moore and Reeves 1993; Quakenbush et al. 2010a, 2018; Citta et al. 2015). Increasing numbers of bowhead whales are found in the western Beaufort and Chukchi seas in summer and fall, and these are thought to be a part of the expanding Western Arctic stock (Rugh et al. 2003, Citta et al. 2015, Clarke et al. 2017).

During winter and spring, bowhead whales are closely associated with sea ice (Moore and Reeves 1993, Quakenbush et al. 2010a, Citta et al. 2015). 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. In most years, during summer, most of the population is in relatively ice-free waters of Amundsen Gulf in the eastern Canadian Beaufort Sea (Citta et al. 2015), an area often exposed to industrial activity related to petroleum exploration (e.g., Richardson et al. 1987, Davies 1997). However, 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 summer distribution. During the autumn migration through the Beaufort Sea, bowhead whales generally select shelf waters (Citta et al. 2015). During the autumn migration across the Chukchi Sea, bowhead whales generally select cold, saline waters that are mostly of Bering Sea origin (Citta et al. 2017). In winter in the Bering Sea, bowhead whales often use areas with nearly 100% sea-ice cover, even when polynyas are available (Quakenbush et al. 2010a, Citta et al. 2015).

Evidence suggests that Western Arctic bowhead whales feed on concentrations of zooplankton throughout their range. Likely or confirmed feeding areas include Amundsen Gulf and the eastern Canadian Beaufort Sea; the central and western U.S. Beaufort Sea; Wrangel Island; and the coast of Chukotka between Wrangel Island and the Bering Strait (Lowry et al. 2004; Ashjian et al. 2010; Clarke and Ferguson 2010; Quakenbush et al. 2010a, 2010b; Okkonen et al. 2011; Citta et al. 2015, 2017; Clarke et al. 2017). Bowhead whales have also been observed feeding during the summer in the northeastern Chukchi Sea (Clarke et al. 2016). In winter, dive behavior suggests that bowhead whales are feeding in the Bering Sea shelf waters, from Bering Strait south through Anadyr Strait, and near the entrance of the Gulf of Anadyr (Citta et al. 2012, 2015). Three of four bowhead whales harvested in winter (two in December 2010 and two in November 2012) near St. Lawrence Island, in the northern Bering Sea, had been feeding (Sheffield and George 2013).

Clarke et al. (2015) evaluated biologically important areas (BIAs) for bowheads in the U.S. Arctic region and identified nine BIAs. The four reproductive BIAs encompass areas where the majority of bowhead whales identified as calves were observed each season. In addition, three feeding BIAs for bowhead whales were identified in the Beaufort Sea. In most years, the area from Smith Bay to Point Barrow is the most consistent feeding area for bowhead whales from August to October (Clarke et al. 2015). In other areas of the western Beaufort Sea, bowhead whales may feed on the continental shelf, out to approximately the 50 m isobath, in September and October.

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. All other estimates were developed by corrected ice-based census counts. Historical estimates are from Woodby and Botkin (1993); 1978-2001 estimates are from George et al. (2004) and Zeh and Punt (2004). The 2011 estimate is reported in Givens et al. (2016).

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)

The recently adopted Aboriginal Whaling Scheme (IWC 2018) requires that abundance estimates be conducted 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), whales missed when no watch was in effect (through interpolations from sampled periods), and whales missed during a watch (estimated as a function of visibility, number of observers, and distance offshore: Zeh et al. 1993, Givens et al. 2016). These 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.

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). However, because of its lower coefficient of variation (CV), the IWC Scientific Committee considered the 2011 ice-based 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 interval.

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)

Minimum Population Estimate

The minimum population estimate (N_{MIN}) for this stock is calculated from Equation 1 from the potential biological removal (PBR) guidelines (NMFS 2016): $N_{MIN} = N/\exp(0.842\times[\ln(1+[CV(N)]^2)]^{½})$. Using the 2011 population estimate (N) from the ice-based survey of 16,820 and its associated CV(N) of 0.052 (Table 1), N_{MIN} for the Western Arctic stock of bowhead whales is 16,100 whales.

Current Population Trend

Based on concurrent passive acoustic and ice-based visual surveys, Givens et al. (2013) 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). 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.

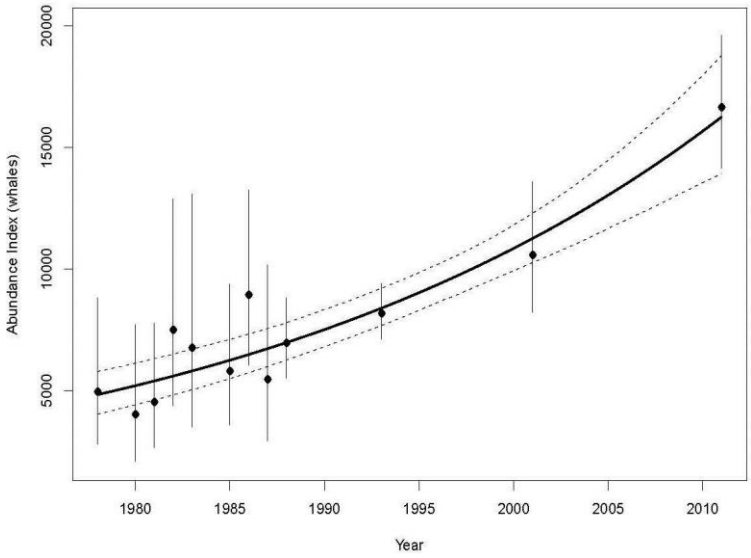

Figure 2. Abundance estimates (points with confidence interval lines) and trend (black line with confidence range) for the Western Arctic stock of bowhead whales, 1978-2011 (Givens et al. 2013), as computed from ice-based counts and acoustic data collected during bowhead whale spring migrations past Point Barrow, Alaska.

CURRENT AND MAXIMUM NET PRODUCTIVITY RATES

The current estimate for the rate of increase for this stock of bowhead whales (3.7%: 95% CI = 2.9-4.6%) 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) and so may not be growing at its maximum rate. Therefore, the cetacean maximum theoretical net productivity rate of 4% will be used for the Western Arctic stock of bowhead whales (NMFS 2016).

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 increasing in the presence of a known take (NMFS 2016). Thus, PBR = 161 whales (16,100 × 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. For 2013 to 2018, the IWC established a block quota of 306 landed bowhead whales. Because some whales are struck and lost, the IWC set a strike limit of 67 (plus up to 15 previously unused strikes) per year. In recent years, an arrangement 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 arrangement, the Chukotka Natives in Russia may use no more than seven strikes, and the Alaska Eskimos may use no more than 75 strikes. The block quota for 2019 to 2025 is 67 strikes per year plus up to 33 previously unused strikes.

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 2013 and 2017 is listed, by marine mammal stock, in Delean et al. (2020); 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 2013 and 2017 is 53 whales: 0.2 in U.S. commercial fisheries and 53 in subsistence takes by Natives of Alaska (number landed + struck and lost mortality) and Russia (number landed, struck and lost not reported). Potential threats most likely to result in direct human-caused mortality or serious injury of this stock include entanglement in fishing gear and ship strikes due to increased vessel traffic (from increased commercial shipping in the Chukchi and Beaufort seas) (Smith and Stephenson 2013).

Fisheries Information

Information (including observer programs, observer coverage, and observed incidental takes of marine mammals) for federally-managed and state-managed U.S. commercial fisheries in Alaska waters is presented in Appendices 3-6 of the Alaska Stock Assessment Reports.

While there are no observer program records of bowhead whale mortality or serious injury incidental to U.S. commercial fisheries in Alaska, 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. Several cases of line or net entanglement have been reported from whales taken in the subsistence hunt (Philo et al. 1993). George et al. (2017) examined records for 904 bowhead whales harvested between 1990 and 2012. Of these, 514 records were examined for at least one of the three types of scars indicating injuries from line entanglement wounds (514 records examined), attacks by killer whales (377 records examined), or ship strikes (and/or propeller injuries) (504 records examined). Their best estimate of the occurrence of entanglement scars was approximately 12.2% (59/485; an additional 29 records with possible entanglement scars were excluded from the analysis) with the cause most likely from fishing/crab pot gear in the Bering Sea. Most entanglement injuries occurred on the peduncle and were rarely observed on smaller subadult and juvenile whales (<10 m), possibly because young whales are less likely to survive entanglements (George et al. 2017).

One dead whale was found floating in Kotzebue Sound in early July 2010, entangled in crab pot gear similar to that used by commercial crabbers in the Bering Sea (Suydam et al. 2011), and one entangled bowhead whale was photographed during the 2011 spring aerial photographic survey of bowhead whales near Point Barrow (Mocklin et al. 2012), but it was not considered to be seriously injured. In July 2015, a dead adult female bowhead whale drifting near Saint Lawrence Island in the Bering Strait was found entangled in commercial fishing gear (Suydam et al. 2016), which included lines, two floats, and an attached color coded/numbered permit tag for the 2012/2013 winter commercial blue king crab fishery located in Saint Matthew Island waters of the northern Bering Sea (Sheffield and Savoonga Whaling Captains Association 2015) (Table 3). Two of the bowhead whales taken in the Alaska Native subsistence hunt in 2017 were seriously injured due to entanglement in pot gear suspected (but not confirmed) to be from Bering Sea commercial pot fisheries (Delean et al. 2020); however, because these whales are included in the Alaska Native subsistence harvest for 2017 (Table 4), they are not listed in Table 3. Thus, the

minimum estimated average annual mortality and serious injury rate in U.S. commercial fisheries between 2013 and 2017 is 0.2 bowhead whales (Table 3; Delean et al. 2020), although, the actual rate is currently unknown. This mortality and serious injury estimate results from an actual count of verified human-caused deaths and serious injuries and is a minimum 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 to the NMFS Alaska Region marine mammal stranding network between 2013 and 2017 (Delean et al. 2020).

Cause of injury	2013	2014	2015	2016	2017	Mean annual mortality
Entangled in Bering Sea/Aleutian Is. commercial blue king crab pot gear	0	0	1	0	0	0.2
Total in commercial fisheries						0.2

Alaska Native Subsistence/Harvest Information

Eskimos 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 annum (Philo et al. 1993, Suydam et al. 2011). Under this quota, the total number of bowhead whales landed by Alaska Natives between 1974 and 2017 ranged from 8 to 55 whales (Suydam and George 2012; Suydam et al. 2012, 2013, 2014, 2015, 2016, 2017, 2018; George and Suydam 2014). 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). 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 220 bowhead whales between 2013 and 2017 and 41 of the 55 whales that were struck and lost were determined to have died or had a poor chance of survival, resulting in an average annual take of 52 whales (Table 4). Unlike the NMFS process for determining serious injuries (described in NMFS 2012), these estimates of struck and lost mortality 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 2017, 50 of 57 whales struck were landed, resulting in an efficiency of 88% (Suydam et al. 2018). Suydam et al. (2018) reported that the mean efficiency for 2007 to 2016 was 75%.

Canadian and Russian Natives also take whales from this stock. No catches of Western Arctic bowhead whales were reported by Canadian hunters between 2013 and 2017; however, one bowhead whale was landed in Russia in 2013 (Ilyashenko and Zharikov 2014), two in 2016 (Ilyashenko and Zharikov 2017), and one in 2017 (Zharikov 2018), resulting in an average annual take of 0.8 (landed) whales.

The average annual total subsistence take for 2013 to 2017 is 53 bowhead whales, which includes the number landed (plus the struck and lost mortality) by Alaska Natives and the number landed (struck and lost not reported) by Russian Natives.

Table 4. Summary of the Alaska Native subsistence harvest of Western Arctic bowhead whales between 2013 and 2017.

Year	Landed	Struck and lost	Struck and lost mortality	Total (landed + struck and lost mortality)
2013[a]	46	11	6	52
2014[b]	38	15	12	50
2015[c]	39	10	6	45
2016[d]	47	12	12	59
2017[e]	50	7	5	55
Mean annual number taken (landed + struck and lost mortality)				52

[a]George and Suydam (2014), Suydam et al. (2014) - A total mortality of 51 bowhead whales in 2013 is reported in Suydam et al. (2014), however, the number landed + the struck and lost mortality equals 52 whales; [b]Suydam et al. (2015); [c]Suydam et al. (2016); [d]Suydam et al. (2017); [e]Suydam et al. (2018).

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 and not commercial 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 2012 (two carcasses), 2013 (two), 2015 (two), 2016 (three), and 2017 (one) and three of these carcasses (one each in 2013, 2015, and 2017) were likely calves or yearlings (Willoughby et al. 2018).

With increasing ship traffic and oil and gas exploration and development activities in the Chukchi and Beaufort seas, bowhead whales may become increasingly at risk from ship strikes. Currently, ship-strike injuries on bowhead whales in Alaska appear to be uncommon (George et al. 2017). Only 10 whales harvested between 1990 and 2012 (approximately 2% of the records examined) showed clear evidence of scarring from ship propeller injuries.

STATUS OF STOCK

Based on currently available data, the minimum estimated mean annual mortality and serious injury rate incidental to U.S. commercial fisheries (0.2 whales) is not known to exceed 10% of the PBR (10% of PBR = 16) 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 (53 whales) is not known to exceed the PBR (161) nor the IWC annual maximum strike limit (67 + up to 15 previously unused strikes). The Western Arctic bowhead whale stock has been increasing; the estimate of 16,820 whales from 2011 is between 31% and 168% of the pre-exploitation abundance of 10,000 to 55,000 whales estimated by Brandon and Wade (2004, 2006). However, the stock is classified as a strategic stock 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. 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). The stock may be particularly sensitive to anthropogenic sound; under some circumstances, the stock changes either distribution or calling behavior in response to levels of anthropogenic sounds that are slightly above ambient (Blackwell et al. 2015). The reduction in sea ice may lead to increased predation of bowhead whales by killer whales.

HABITAT CONCERNS

Vessel traffic in arctic waters is increasing, largely due to an increase in commercial shipping. This increase in vessel traffic could result in an increased number of vessel collisions with bowhead whales (Huntington et al. 2015). Oil and gas development in the Arctic 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. 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). Bowhead whales often avoid sound sources associated with active drilling (Schick and Urban 2000) and seismic operations (Miller et al. 1999). Source levels, time of year, and whale behavior (migrating, feeding, etc.) all affect the extent of displacement or changes in behavior (e.g., Richardson et al. 1986, 1999; Ljungblad et al. 1988; Miller et al. 2005; Harris et al. 2007; MMS 2008; Funk et al. 2010) and impacts on bowhead calling rates (Greene et al. 1998, Blackwell et al. 2015).

Climate change is resulting in warming of northern latitudes at about twice the rate of more temperate latitudes, increasing the immediacy of this threat for bowhead whales and other arctic species. 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 (IPCC 2007, USGS 2011, 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. Laidre et al. (2008) concluded that on a worldwide basis bowhead whales were likely to be moderately sensitive to climate change, based on an analysis of various life-history features that could be affected by climate. Currently, there are insufficient data to make reliable projections of the effects of arctic climate change on bowhead whales. George et al. (2006) showed that landed bowhead whales had better body condition during years of light ice cover. Similarly, George et al. (2015) found an overall improvement in bowhead whale body condition and a positive correlation between body condition and summer sea-ice loss over the last 2.5 decades in the Pacific Arctic. George et al. (2015) speculated that sea-ice loss has positive effects on secondary trophic production in the short term within the Western Arctic bowhead whales' summer feeding region. Sheffield and George (2013) presented evidence that the occurrence of fish in the diets of Western Arctic bowhead whales near Utqiaġvik in the autumn may be increasing.

Another concern, driven primarily by the production of carbon dioxide (CO_2) emissions, is the modification of habitat by ocean acidification, which may alter prey populations and other important aspects of the marine ecosystem. Ocean acidification, a result of increased CO_2 in the atmosphere, may affect bowhead whale survival and recruitment because their primary prey are small crustaceans, especially calanoid copepods, euphausiids, gammarid and hyperid amphipods, and mysids (Lowry et al. 2004), that have exoskeletons composed of chitin and calcium carbonate which can be weakened by ocean acidification. 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.

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