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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). 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 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).

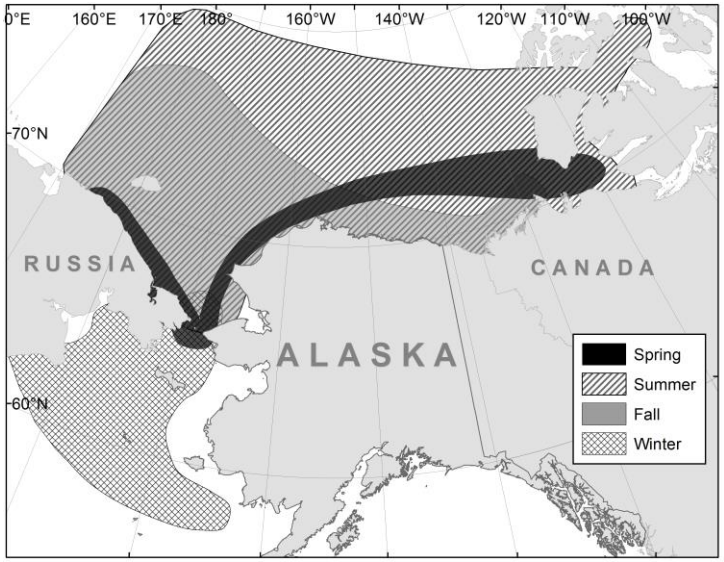

Figure 1. Annual range of the Western Arctic stock of bowhead whales by season from satellite tracking data, 2006-2017 (map based on Quakenbush et al. (2018): Fig. 2).

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. 2010a, 2018; Citta et al. 2015). During winter and spring, bowhead whales are closely associated with sea ice (Moore and Reeves 1993, Quakenbush et al. 2010a, 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 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 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); here, bowhead whales generally prefer cold, saline waters that are mostly of Bering Sea origin (Citta et al. 2018). 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. 2010a, Citta et al. 2015).

Evidence from stomach contents and habitat associations 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 Beaufort Sea; the central and western Beaufort Sea; the Chukchi shelf break, especially Herald Valley and the Central Channel; and the coast of Chukotka between Wrangel Island and Bering Strait (Lowry et al. 2004; Ashjian et al. 2010; Clarke and Ferguson 2010; Quakenbush et al. 2010a, 2010b; Okkonen et al. 2011; Fish et al. 2013; Citta et al. 2015, 2018; Clarke et al. 2017; Harwood et al. 2017). Citta et al. (2015) identified six core use areas for Western Arctic bowhead whales based on bowhead whale satellite telemetry, oceanography, sea ice, and winds. During spring in the Cape Bathurst polyna, whales are found in water <75 m deep where calanoid copepods are ascending after diapause. In summer and into fall, bowhead whales inhabit shelf waters in the Beaufort Sea, including the Tuktoyaktuk shelf and areas farther west, where episodic wind-driven upwelling and high river discharge results in high densities of zooplankton (Citta et al. 2015, Harwood et al. 2017, Okkonen et al. 2018, Clarke et al. 2018b). During summer and fall, Western Arctic bowhead whales may congregate on the shallow shelf east of Point Barrow, where variable wind dynamics promote large aggregations of zooplankton onto the shelf (Ashjian et al. 2010, Okkonen et al. 2011, Citta et al. 2015). In winter, dive behavior suggests that bowhead whales feed in shelf waters of the Bering Sea, from Bering Strait south through Anadyr Strait, and near the seafloor in the Gulf of Anadyr (Citta et al. 2012, 2015). Of four bowhead whales harvested in November (two in 2012) and December (two in 2010) near St. Lawrence Island, in the northern Bering Sea, three had been feeding (Sheffield and George 2013). Results from mercury and stable isotope analysis are consistent with year-round foraging and seasonal migration of bowhead whales (Pomerleau et al. 2018).

Clarke et al. (2015) evaluated biologically important areas (BIAs) for bowhead whales in the U.S. Arctic region and identified nine BIAs based on satellite telemetry and aerial survey data. The four reproductive BIAs encompass areas where the majority of bowhead whales identified as calves were observed each season. The three feeding BIAs were located in the western Beaufort Sea. In most years, the krill trap area (Ashjian et al. 2010) 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 in ephemeral prey patches on the continental shelf, out to approximately the 50 m isobath, in September and October. These ephemeral foraging areas are also evident in satellite telemetry data (Quakenbush and Citta 2019).

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.

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). 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.

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 (2005). 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)

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

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)

IWC Scientific Committee considered this estimate the most appropriate for management and use in the SLA (IWC 2018). This estimate is more than 8 years old and is outdated for use in stock assessments; however, because this population is increasing, this is still considered a valid minimum population estimate (NMFS 2016).

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 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 this stock of bowhead whales is 16,100 whales. The 2016 guidelines for preparing Stock Assessment Reports (NMFS 2016) recommend that N_{MIN} be considered unknown if the abundance estimate is more than 8 years old, unless there is compelling evidence that the stock has not declined since the last estimate. Because this population is increasing, this is still considered a valid minimum population estimate.

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.

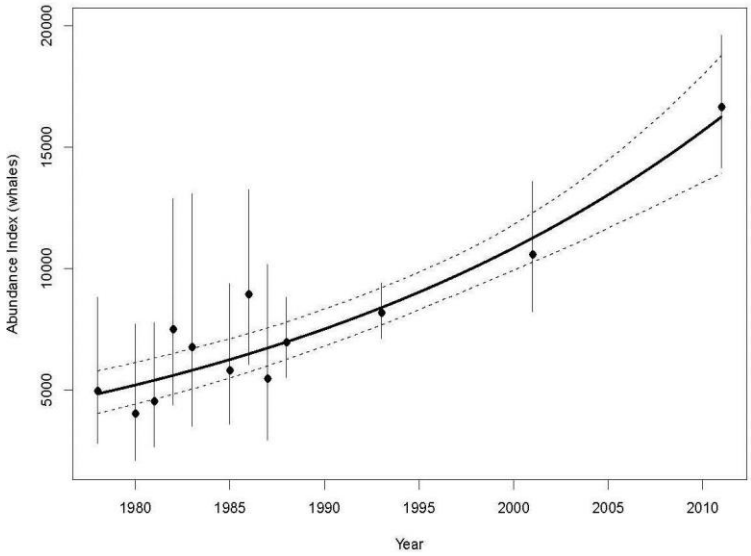

Figure 2. Abundance estimates (points with confidence interval lines) and trend (black line with confidence range) for the Western Arctic stock of bowhead whales, 1978-2011 (Givens et al. 2013), as computed from ice-based counts and acoustic data collected during bowhead whale spring migrations past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

CURRENT AND MAXIMUM NET PRODUCTIVITY RATES

The current estimate for the rate of increase for the Western Arctic 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); 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 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 is 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. From 2013 to 2018, the IWC established a block quota of 336 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 Alaska Natives may use

no more than 75 strikes. The total block quota for 2019 to 2025 is 392 whales, 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 is added to the strike quota for any one 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 2014 and 2018 is listed, by marine mammal stock, in Young 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 2014 and 2018 is 56 whales: 0.2 in U.S. commercial fisheries (Table 3) and 56 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 individuals in 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 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 December 2020).

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. Approximately 12% of the bowhead whales taken in the subsistence hunt between 1990 and 2012 showed evidence of entanglement in line or net (Philo et al. 1993). George et al. (2017) examined 904 records of 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; 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) and have presumably had fewer years during which to acquire entanglement scars. A review of the photo-identification catalogue from 1985 to 2011 found the probability of scarring due to entanglement at 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).

One dead bowhead 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 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 (Young et al. 2020) and a third whale taken during the subsistence hunt on 5 May 2017 was reported as “lethargic” and was later found to have 84 m of 19-mm rope attached to the baleen rack, left pectoral flipper, and peduncle, penetrating up to 10 cm through the epidermis (Rolland et al. 2019); 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 2014 and 2018 is 0.2 bowhead whales (Table 3; Young 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 2014 and 2018 (Young et al. 2020).

Cause of injury	2014	2015	2016	2017	2018	Mean annual mortality
Entangled in Bering Sea/Aleutian Is. commercial blue king crab pot gear	0	1	0	0	0	0.2
Total in commercial fisheries						0.2

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 Eskimo 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 December 2020).

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 annum (Philo et al. 1993, Suydam et al. 2011). Under this quota, the number of bowhead whales landed by Alaska Natives between 1974 and 2018 ranged from 8 to 55 whales per year (Suydam and George 2012; Suydam et al. 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019; 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 221 bowhead whales between 2014 and 2018 and 52 of the 65 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 55 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 2018, 47 of 68 whales struck were landed, resulting in an efficiency of 69% and the mean efficiency for 2008 to 2017 was 77% (Suydam et al. 2019).

Canadian and Russian Natives also take whales from this stock. No catches of Western Arctic bowhead whales were reported by Canadian hunters between 2014 and 2018; however, two bowhead whales were landed in Russia in 2016 (Ilyashenko and Zharikov 2017), one in 2017 (Zharikov 2018), and none in 2018 (Zharikov et al. 2019), resulting in an average annual take of 0.6 (landed) whales.

The total average annual subsistence take for 2014 to 2018 is 56 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 2014 and 2018.

Year	Landed	Struck and lost	Struck and lost mortality	Total (landed + struck and lost mortality)
2014[a]	38	15	12	50
2015[b]	39	10	6	45
2016[c]	47	12	12	59
2017[d]	50	7	5	55
2018[e]	47	21	17	64
Mean annual number taken (landed + struck and lost mortality)				55

[a]Suydam et al. (2015); [b]Suydam et al. (2016); [c]Suydam et al. (2017); [d]Suydam et al. (2018); [e]Suydam et al. (2019).

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 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, ship strikes may pose a greater risk to bowhead whales. Currently, ship-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 ship propellers, while only seven whales from the photo-identification catalogue from 1985 to 2011 (1% of the sample) had evidence of ship-inflicted scars.

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 (56 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. The current abundance estimate is calculated using data from 2011; however, the N_{MIN} is still considered a valid minimum population estimate because the population is increasing (NMFS 2016). 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 facilitated by the lack of sea ice. 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, 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 (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. 2013, 2015).

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. 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, thermal stress resulting from increased sea surface temperatures has not been observed in the Western Arctic stock of bowhead whales. On the contrary, 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. Additionally, 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. 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.

Ocean acidification, driven primarily by the production 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.

CITATIONS

Ashjian, C. J., S. R. Braund, R. G. Campbell, J. C. George, J. Kruse, W. Maslowski, S. E. Moore, C. R. Nicolson, S. R. Okkonen, B. F. Sherr, E. B. Sherr, and Y. H. Spitz. 2010. Climate variability, oceanography, bowhead whale distribution, and Iñupiat subsistence whaling near Barrow, Alaska. Arctic 63(2):179-194.

Bachmann, L., Ø. Wiig, M. P. Heide-Jørgensen, K. L. Laidre, L. D. Postma, L. Dueck, and P. J. Palsbøl. 2010. Genetic diversity in Eastern Canadian and Western Greenland bowhead whales (*Balaena mysticetus*). Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/62/BRG26). 6 p.

Blackwell, S. B., C. S. Nations, T. L. McDonald, C. R. Greene, A. M. Thode, M. Guerra, and A. M. Macrander. 2013. Effects of airgun sounds on bowhead whale calling rates in the Alaskan Beaufort Sea. Mar. Mammal Sci. 29(4):E342-E365. DOI: dx.doi.org/10.1111/mms.12001 .

Blackwell, S. B., C. S. Nations, T. L. McDonald, A. M. Thode, D. Mathias, K. H. Kim, C. R. Greene, Jr., and A. M. Macrander. 2015. Effects of airgun sounds on bowhead whale calling rates: evidence for two behavioral thresholds. PLoS ONE 10(6):e0125720. DOI: dx.doi.org/10.1371/journal.pone.0125720 .

Blackwell, S. B., C. S. Nations, A. M. Thode, M. E. Kauffman, A. S. Conrad, R. G. Norman, and K. H. Kim. 2017. Effects of tones associated with drilling activities on bowhead whales calling rates. PLoS ONE 12(11):e0188459. DOI: dx.doi.org/10.1371/journal.pone.0188459 .

Bockstoce, J. R., and J. J. Burns. 1993. Commercial whaling in the North Pacific sector, p. 563-577. *In* J. J. Burns, J. J. Montague, and C. J. Cowles (eds.), The Bowhead Whale. Soc. Mar. Mammal., Spec. Publ. No. 2.

Bockstoce, J. R., D. B. Botkin, A. Philp, B. W. Collins, and J. C. George. 2007. The geographic distribution of bowhead whales (*Balaena mysticetus*) in the Bering, Chukchi, and Beaufort seas: evidence from whaleship records, 1849-1914. Mar. Fish. Rev. 67(3):1-43.

Boertmann, D., L. A. Kyhn, L. Witting, and M. P. Heide-Jorgensen. 2015. A hidden getaway for bowhead whales in the Greenland Sea. Polar Biol. 38(8):1315-1319. DOI: dx.doi.org/10.1007/s00300-015-1695-y .

Braham, H. W. 1984. The bowhead whale, *Balaena mysticetus*. Mar. Fish. Rev. 46(4):45-53.

Braham, H. W., M. A. Fraker, and B. D. Krogman. 1980. Spring migration of the Western Arctic population of bowhead whales. Mar. Fish. Rev. 42(9-10):36-46.

Brandon, J., and P. R. Wade. 2004. Assessment of the Bering-Chukchi-Beaufort Seas stock of bowhead whales. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/56/BRG20). 32 p.

Brandon, J., and P. R. Wade. 2006. Assessment of the Bering-Chukchi-Beaufort Seas stock of bowhead whales using Bayesian model averaging. J. Cetacean Res. Manage. 8(3):225-239.

Burns, J. J., J. J. Montague, and C. J. Cowles (eds.). 1993. The Bowhead Whale. Soc. Mar. Mammal., Spec. Publ. No. 2. 787 p.

Chambault, P., C. M. Albertsen, T. A. Patterson, R. G. Hansen, O. Tervo, K. L. Laidre, and M. P. Heide-Jørgensen. 2018. Sea surface temperature predicts the movements of an Arctic cetacean: the bowhead whale. Scientific Reports 8(1):9658. DOI: dx.doi.org/10.1038/s41598-018-27966-1 .

Chapman, W. L., and J. E. Walsh. 2007. Simulations of arctic temperature and pressure by global coupled models. J. Climate 20:609-632.

Citta, J. J., L. T. Quakenbush, J. C. George, R. J. Small, M P. Heide-Jørgensen, H. Brower, B. Adams, and L. Brower. 2012. Winter movements of bowhead whales (*Balaena mysticetus*) in the Bering Sea. Arctic 65(1):13-34.

Citta, J. J., J. J. Burns, L. T. Quakenbush, V. Vanek, J. C. George, R. J. Small, M. P. Heide-Jørgensen, and H. Brower. 2014. Potential for bowhead whale entanglement in cod and crab pot gear in the Bering Sea. Mar. Mammal Sci. 30(2):445-459. DOI: dx.doi.org/10.1111/mms.12047 .

Citta, J. J., L. T. Quakenbush, S. R. Okkonen, M. L. Druckenmiller, W. Maslowski, J. Clement-Kinney, J. C. George, H. Brower, R. J. Small, C. J. Ashjian, L. A. Harwood, and M. P. Heide-Jørgensen. 2015. Ecological characteristics of core-use areas used by Bering-Chukchi-Beaufort (BCB) bowhead whales, 2006-2012. Prog. Oceanogr. 136:201-222. DOI: dx.doi.org/10.1016/j.pocean.2014.08.012 .

Citta, J. J., S. R. Okkonen, L. T. Quakenbush, W. Maslowski, R. Osinski, J. C. George, R. J. Small, H. Brower, Jr., M. P. Heide-Jørgensen, and L. A. Harwood. 2018. Oceanographic characteristics associated with autumn movements of bowhead whales in the Chukchi Sea. Deep Sea Research II 152:121-131. DOI: dx.doi.org/10.1016/j.dsr2.2017.03.009 .

Clark, C. W., S. Mitchell, and R. Charif. 1994. Distribution and behavior of the bowhead whale, *Balaena mysticetus*, based on preliminary analysis of acoustic data collected during the 1993 spring migration off Point Barrow, Alaska. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/46/AS19). 24 p.

Clarke, J. T., and M. C. Ferguson. 2010. Aerial surveys for bowhead whales in the Alaskan Beaufort Sea: BWASP update 2000-2009 with comparisons to historical data. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/62/BRG14). 11 p.

Clarke, J., K. Stafford, S. E. Moore, B. Rone, L. Aerts, and J. Crance. 2013. Subarctic cetaceans in the southern Chukchi Sea: evidence of recovery or response to a changing ecosystem. Oceanography 26(4):136-149. DOI: dx.doi.org/10.5670/oceanog.2013.81 .

Clarke, J. T., M. C. Ferguson, C. Curtice, and J. Harrison. 2015. Biologically important areas for cetaceans within US waters - Arctic region. Aquat. Mamm. (Special Issue) 41(1):94-103.

Clarke, J. T., A. S. Kennedy, and M. C. Ferguson. 2016. Bowhead and gray whale distributions, sighting rates, and habitat associations in the eastern Chukchi Sea, summer and fall 2009-15, with a retrospective comparison to 1982-91. Arctic 69(4):359-377.

Clarke, J. T., A. A. Brower, M. C. Ferguson, and A. L. Willoughby. 2017. Distribution and relative abundance of marine mammals in the eastern Chukchi and western Beaufort seas, 2016. Annual Report, OCS Study BOEM 2017-078. Marine Mammal Laboratory, AFSC, NMFS, 7600 Sand Point Way NE, Seattle, WA 98115.

Clarke, J. T., M. C. Ferguson, A. A. Brower, and A. L. Willoughby. 2018a. Bowhead whale calves in the western Beaufort Sea, 2012-2017. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/67b/AWMP3). 11 p.

Clarke, J. T., M. C. Ferguson, A. L. Willoughby, and A. A. Brower. 2018b. Bowhead and beluga whale distributions, sighting rates, and habitat associations in the western Beaufort Sea in summer and fall 2009-16, with comparison to 1982-91. Arctic 71(2):115-138.

Cosens, S. E., H. Cleator, and P. Richard. 2006. Numbers of bowhead whales (*Balaena mysticetus*) in the eastern Canadian Arctic, based on aerial surveys in August 2002, 2003 and 2004. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/58/BRG7). 19 p.

da Silva, C. Q., J. Zeh, D. Madigan, J. Laake, D. Rugh, L. Baraff, W. Koski, and G. Miller. 2000. Capture-recapture estimation of bowhead whale population size using photo-identification data. J. Cetacean Res. Manage. 2(1):45-61.

da Silva, C. Q., P. V. S. Gomes, and M. A. Stradioto. 2007. Bayesian estimation of survival and capture probabilities using logit link and photoidentification data. Comput. Stat. Data Anal. 51:6521-6534.

Davies, J. R. 1997. The impact of an offshore drilling platform on the fall migration path of bowhead whales: a GIS-based assessment. Unpubl. MS Thesis, Western Washington University, Bellingham, WA. 51 p.

Doniol-Valcroze, T., J. -F. Gosselin, D. Pike, J. Lawson, N. Asselin, K. Hedges, and S. Ferguson. 2015. Abundance estimate of the Eastern Canada – West Greenland bowhead whale population based on the 2013 High Arctic Cetacean Survey. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/058. v + 27 p.

Dueck, L. P., M. P. Heide-Jørgensen, M. V. Jensen, and L. D. Postma. 2006. Update on investigations of bowhead whale (*Balaena mysticetus*) movements in the eastern Arctic, 2003-2005, based on satellite-linked telemetry. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/58/BRG5). 17 p.

Druckenmiller, M. L., J. J. Citta, M. C. Ferguson, J. T. Clarke, J. C. George, and L. Quakenbush. 2018. Trends in sea-ice cover within bowhead whale habitats in the Pacific Arctic. Deep Sea Research II 152:95-107. DOI: dx.doi.org/10.1016/j.dsr2.2017.10.017 .

Fish, F. E., K. T. Goetz, D. J. Rugh, and L. Vate Brattström. 2013. Hydrodynamic patterns associated with echelon formation swimming by feeding bowhead whales (*Balaena mysticetus*). Mar. Mammal Sci. 29(4):E498-E507. DOI: dx.doi.org/10.1111/mms.12004 .

Frasier, T. R., S. D. Petersen, L. Postma, L. Johnson, M P. Heide-Jørgensen, and S. H. Ferguson. 2015. Abundance estimates of the Eastern Canada-West Greenland bowhead whale (*Balaena mysticetus*) population based on genetic capture-mark-recapture analyses. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/008. iv + 21 p.

Funk, D. W., R. Rodrigues, D. S. Ireland, and W. R. Koski. 2010. Summary and assessment of potential effects on marine mammals, Chapter 11. *In* D. W. Funk, D. S. Ireland, R. Rodrigues, and W. R. Koski (eds.), Joint monitoring program in the Chukchi and Beaufort seas, open water seasons, 2006–2008. LGL Alaska Report P1050-2, Report from LGL Alaska Research Associates, Inc., LGL, Ltd., Greeneridge Sciences, Inc., and JASCO Research, Ltd., for Shell Offshore, Inc., and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 506 p. + appendices.

George, J. C., and R. S. Suydam. 2014. Update on characteristics of bowhead whale (*Balaena mysticetus*) calves. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/65b/BRG20Rev). 7 p.

George, J. C., L. Philo, K. Hazard, D. Withrow, G. Carroll, and R. Suydam. 1994. Frequency of killer whale (*Orcinus orca*) attacks and ship collisions based on scarring on bowhead whales (*Balaena mysticetus*) of the Bering-Chukchi-Beaufort Seas stock. Arctic 47(3):247-55.

George, J. C., J. Zeh, R. Suydam, and C. Clark. 2004. Abundance and population trend (1978-2001) of Western Arctic bowhead whales surveyed near Barrow, Alaska. Mar. Mammal Sci. 20:755-773.

George, J. C., C. Nicolson, S. Drobot, J. Maslanik, and R. Suydam. 2006. Sea ice density and bowhead whale body condition preliminary findings. Poster presented to the Society for Marine Mammalogy, San Diego, CA.

George, J. C., M. L. Druckenmiller, K. L. Laidre, R. Suydam, and B. Person. 2015. Bowhead whale body condition and links to summer sea ice and upwelling in the Beaufort Sea. Prog. Oceanogr. 136:250-262.

George, J. C., G. Sheffield, D. J. Reed, B. Tudor, R. Stimmelmayr, B. T. Person, T. Sformo, and R. Suydam. 2017. Frequency of injuries from line entanglements, killer whales, and ship strikes on Bering-Chukchi-Beaufort Sea bowhead whales. Arctic 70(1):37-46. DOI: dx.doi.org/10.14430/arctic4631 .

George, J. C., B. Tudor, G. H. Givens, J. Mocklin, and L. Vate Brattström. 2019. Entanglement-scar acquisition rates and scar frequency for Bering-Chukchi-Beaufort Seas bowhead whales using aerial photography. Mar. Mammal Sci. 35(4):1304-1321. DOI: dx.doi.org/10.1111/mms.12597 .

Givens, G. H., S. L. Edmondson, J. C. George, R. Suydam, R. A. Charif, A. Rahaman, D. Hawthorne, B. Tudor, R. A. DeLong, and C. W. Clark. 2013. Estimate of 2011 abundance of the Bering-Chukchi-Beaufort Seas bowhead whale population. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/65a/BRG1). 30 p.

Givens, G. H., S. L. Edmondson, J. C. George, R. Suydam, R. A. Charif, A. Rahaman, D. Hawthorne, B. Tudor, R. A. DeLong, and C. W. Clark. 2016. Horvitz-Thompson whale abundance estimation adjusting for uncertain recapture, temporal availability variation, and intermittent effort. Environmetrics 27:134-146. DOI: dx.doi.org/10.1002/env.2379 .

Givens, G. H., J. A. Mocklin, L. Vate Brattström, B. J. Tudor, W. R. Koski, J. E. Zeh, R. Suydam, and J. C. George. 2018. Survival rate and 2011 abundance of Bering-Chukchi-Beaufort Seas bowhead whales from photo-identification data over three decades. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/67b/AWMP/01 Rev1). 24 p.

Greene, C. R., Jr., W. J. Richardson, and N. S. Altman. 1998. Bowhead whale call detection rates versus distance from airguns operating in the Alaskan Beaufort Sea during fall migration, 1996. J. Acoust. Soc. Am. 104:1826. DOI: dx.doi.org/10.1121/1.423473 .

Hannay, D. E., J. Delarue, X. Mouy, B. S. Martin, D. Leary, J. N. Oswald, and J. Vallarta. 2013. Marine mammal acoustic detections in the northeastern Chukchi Sea, September 2007–July 2011. Continental Shelf Research 67:127-46. DOI: dx.doi.org/10.1016/j.csr.2013.07.009 .

Harris, R. E., T. Elliot, and R. A. Davis. 2007. Results of mitigation and monitoring program, Beaufort Span 2-D marine seismic program, open water season 2006. LGL, Ltd., LGL Report TA4319-1, Report from LGL, Ltd., King City, Ont., for GX Technol., Houston, TX. 48 p.

Harwood, L. A., L. T. Quakenbush, R. J. Small, C. J. George, J. Pokiak, C. Pokiak, M. P. Heide-Jørgensen, E. V. Lea, and H. Brower. 2017. Movements and inferred foraging by bowhead whales in the Canadian Beaufort Sea during August and September, 2006–12. Arctic 70(2):161-76. DOI: dx.doi.org/10.14430/arctic4648 .

Heide-Jørgensen, M. P., K. L. Laidre, M. V. Jensen, L. Dueck, and L. D. Postma. 2006. Dissolving stock discreteness with satellite tracking: bowhead whales in Baffin Bay. Mar. Mammal Sci. 22:34-45.

Heide-Jørgensen, M. P., K. L. Laidre, Ø. Wiig, and L. Dueck. 2010. Large scale sexual segregation of bowhead whales. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/62/BRG23). 13 p.

Huntington, H. P., R. Daniel, A. Hartsig, K. Harun, M. Heiman, R. Meehan, G. Noongwook, L. Pearson, M. Prior-Parks, M. Robards, and G. Stetson. 2015. Vessels, risks, and rules: planning for safe shipping in Bering Strait. Marine Policy 51:119-127.

Ilyashenko, V., and K. Zharikov. 2017. Aboriginal subsistence whaling in the Russian federation in 2016. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/67a/AWMP03). 2 p.

Intergovernmental Panel on Climate Change (IPCC). 2013. Summary for policymakers. *In* T. Stocker, D. Qin, G. Plattner, M. Tignor, S. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. Midgley (eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC. Cambridge University Press, Cambridge, UK, and New York, NY. Available online: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf . Accessed December 2020.

International Whaling Commission (IWC). 2003. Report of the fourth workshop on the development of an Aboriginal Subsistence Whaling Management Procedure (AWMP). J. Cetacean Res. Manage. 5(Suppl.):489-497.

International Whaling Commission (IWC). 2008. Annex F: Report of the sub-committee on bowhead, right and gray whales. J. Cetacean Res. Manage. 10(Suppl.):150-166.

International Whaling Commission (IWC). 2010. Annex F: Report of the sub-committee on bowhead, right and gray whales. J. Cetacean Res. Manage. 11(Suppl. 2):154-179.

International Whaling Commission (IWC). 2011. Annex F: Report of the sub-committee on bowhead, right and gray whales. J. Cetacean Res. Manage. 12(Suppl.):168-184.

International Whaling Commission (IWC). 2018. Report of the Scientific Committee. Unpubl. doc. IWC/67/Rep01. Available online: www.iwc.int . Accessed December 2020.

Jeffries, M. O., J. Richter-Menge, and J. E. Overland (eds.). 2015. Arctic report card 2015. Available online: http://www.arctic.noaa.gov/reportcard . Accessed December 2020.

Koski, W., J. Zeh, J. Mocklin, A. R. Davis, D. J. Rugh, J. C. George, and R. Suydam. 2010. Abundance of Bering-Chukchi-Beaufort bowhead whales (*Balaena mysticetus*) in 2004 estimated from photo-identification data. J. Cetacean Res. Manage. 11(2):89-99.

Krogman, B., D. Rugh, R. Sonntag, J. Zeh, and D. Ko. 1989. Ice-based census of bowhead whales migrating past Point Barrow, Alaska, 1978-1983. Mar. Mammal Sci. 5:116-138.

Laidre, K. L., I. Stirling, L. Lowry, Ø. Wiig, M. P. Heide-Jørgensen, and S. Ferguson. 2008. Quantifying the sensitivity of arctic marine mammals to climate-induced habitat change. Ecol. Appl. 18(2)Suppl.:S97-S125.

Ljungblad, D. K., B. Würsig, S. L. Swartz, and J. M. Keene. 1988. Observations on the behavioral responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. Arctic 41(3):183-194.

Lowry, L. F., G. Sheffield, and J. C. George. 2004. Bowhead whale feeding in the Alaskan Beaufort Sea, based on stomach contents analyses. J. Cetacean Res. Manage. 6(3):215-223.

Marquette, W. M., and J. R. Bockstoce. 1980. Historical shore-based catch of bowhead whales in the Bering, Chukchi, and Beaufort seas. Mar. Fish. Rev. 42(9-10):5-19.

Melnikov, V. V., and J. E. Zeh. 2007. Chukotka Peninsula counts and estimates of the number of migrating bowhead whales (*Balaena mysticetus*). J. Cetacean Res. Manage. 9(1):29-35.

Miller, G. W., R. E. Elliott, W. R. Koski, V. D. Moulton, and W. J. Richardson. 1999. Whales, p. 5-1 to 5-109. *In* W. J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Report TA2230–3. Report from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and National Marine Fisheries Service, Anchorage, AK, and Silver Spring, MD. 390 p.

Miller, G. W., V. D. Moulton, R. A. Davis, M. Holst, P. Millman, A. MacGillivray, and D. Hannay. 2005. Monitoring seismic effects on marine mammals—southeastern Beaufort Sea, 2001-2002, p. 511-542. *In* S. L. Armsworthy, P. J. Cranford, and K. Lee (eds.), Offshore Oil and Gas Development Effects Monitoring/Approaches and Technologies. Battelle Press, Columbus, OH.

Minerals Management Service (MMS). 2008. Beaufort Sea and Chukchi Sea Planning Areas, Oil and Gas Lease Sales 209, 212, 217, and 221, Draft Environmental Impact Statement: U.S. Department of the Interior, Minerals Management Service, Alaska OCS Region, MMS 2008-0055, November 2008. Available online: https://www.boem.gov/oil-gas-energy/leasing/beaufort-and-chukchi-sea-planning-areas-oil-and-gas-lease-sales-209-212-217 . Accessed December 2020.

Mocklin, J., J. C. George, M. Ferguson, L. Vate Brattström, V. Beaver, B. Rone, C. Christman, A. Brower, B. Shea, and C. Accardo. 2012. Aerial photography of bowhead whales near Barrow, Alaska, during the 2011 spring migration. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/64/BRG3). 9 p.

Moore, S. E., and R. R. Reeves. 1993. Distribution and movement, p. 313-386. *In* J. J. Burns, J. J. Montague, and C. J. Cowles (eds.), The Bowhead Whale. Soc. Mar. Mammal., Spec. Publ. No. 2.

National Marine Fisheries Service (NMFS). 2012. Process for distinguishing serious from non-serious injury of marine mammals. 42 p. Available online: https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-protection-act-policies-guidance-and-regulations . Accessed December 2020.

National Marine Fisheries Service (NMFS). 2016. Guidelines for preparing stock assessment reports pursuant to the 1994 amendments to the Marine Mammal Protection Act. 23 p. Available online: https://www.fisheries.noaa.gov/national/marine-mammal-protection/guidelines-assessing-marine-mammal-stocks . Accessed December 2020.

Okkonen, S. R., C. J. Ashjian, R. G. Campbell, J. Clarke, S. E. Moore, and K. D. Taylor. 2011. Satellite observations of circulation features associated with the Barrow area bowhead whale feeding hotspot. Remote Sens. Environ. 115:2168-2174.

Okkonen, S. R., J. T. Clarke, and R. A. Potter. 2018. Relationships among high river discharges, upwelling events, and bowhead whale (*Balaena mysticetus*) occurrence in the central Alaskan Beaufort Sea. Deep Sea Research II 152:195-202. DOI: dx.doi.org/10.1016/j.dsr2.2016.11.015 .

Philo, L. M., E. B. Shotts, and J. C. George. 1993. Morbidity and mortality, p. 275-312. *In* J. J. Burns, J. J. Montague, and C. J. Cowles (eds.), The Bowhead Whale. Soc. Mar. Mammal., Spec. Publ. No. 2.

Pomerleau, C., C. J. Matthews, C. Gobeil, G. A. Stern, S. H. Ferguson, and R. W. Macdonald. 2018. Mercury and stable isotope cycles in baleen plates are consistent with year-round feeding in two bowhead whale (*Balaena mysticetus*) populations. Polar Biol. 41(9):1881-93. DOI: dx.doi.org/10.1007/s00300-018-2329-y .

Postma, L. D., L. P. Dueck, M. P. Heide-Jørgensen, and S. E. Cosens. 2006. Molecular genetic support of a single population of bowhead whales (*Balaena mysticetus*) in Eastern Canadian Arctic and Western Greenland waters. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/58/BRG4). 15 p.

Quakenbush, L. T., and J. J. Citta. 2019. Satellite tracking of bowhead whales: habitat use, passive acoustics and environmental monitoring. Final Report. U.S. Department of the Interior, Bureau of Ocean Energy Management, Alaska Outer Continental Shelf Region, Anchorage, AK. OCS Study BOEM 2019-076. 60 p. + appendices. Available online: https://www.boem.gov/sites/default/files/documents/regions/alaska-ocs-region/environment/BOEM%202019-076.pdf . Accessed December 2020.

Quakenbush, L. T., R. J. Small, and J. J. Citta. 2010a. Satellite tracking of Western Arctic bowhead whales. Unpubl. report submitted to the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE 2010-033).

Quakenbush, L. T., J. J. Citta, J. C. George, R. J. Small, and M. P. Heide-Jørgensen. 2010b. Fall and winter movements of bowhead whales (*Balaena mysticetus*) in the Chukchi Sea and within a potential petroleum development area. Arctic 63(3):289-307.

Quakenbush, L., J. Citta, J. C. George, M. P. Heide-Jørgensen, H. Brower, L. Harwood, B. Adams, C. Pokiak, J. Pokiak, and E. Lea. 2018. Bering-Chukchi-Beaufort stock of bowhead whales: 2006-2017 satellite telemetry results with some observations on stock sub-structure. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/67B/AWMP/04). 25 p.

Raftery, A., and J. Zeh. 1998. Estimating bowhead whale population size and rate of increase from the 1993 census. J. Am. Stat. Assoc. 93:451-463.

Richardson, W. J. 1995. Documented disturbance reactions, p. 241-324. *In* W. J. Richardson, C. R. Greene, C. I. Malme, and D. H. Thomson (eds.), Marine Mammals and Noise. Academic Press, San Diego, CA.

Richardson, W. J., and C. I. Malme. 1993. Man-made noise and behavioral responses, p. 631-700. *In* J. J. Burns, J. J. Montague, and C. J. Cowles (eds.), The Bowhead Whale. Soc. Mar. Mammal., Spec. Publ. No. 2.

Richardson, W. J., B. Würsig, and C. R. Greene, Jr. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. J. Acoust. Soc. Am. 79(4):1117-1128.

Richardson, W. J., R. A. Davis, C. R. Evans, D. K. Ljungblad, and P. Norton. 1987. Summer distribution of bowhead whales, *Balaena mysticetus*, relative to oil industry activities in the Canadian Beaufort Sea, 1980-84. Arctic 40(2):93-104.

Richardson, W. J., G. W. Miller, and C. R. Greene, Jr. 1999. Displacement of migrating bowhead whales by sounds from seismic surveys in shallow waters of the Beaufort Sea. J. Acoust. Soc. Am. 106(4, Pt. 2):2281.

Robertson, F. C., W. R. Koski, T. A. Thomas, W. J. Richardson, B. Würsig, and A. W. Trites. 2013. Seismic operations have variable effects on dive-cycle behavior of bowhead whales in the Beaufort Sea. Endang. Species Res. 21:143-160. DOI: dx.doi.org/10.3354/esr00515 .

Rolland, R. M., K. M. Graham, R. Stimmelmayr, R. S. Suydam, and J. C. George. 2019. Chronic stress from fishing gear entanglement is recorded in baleen from a bowhead whale (*Balaena mysticetus*). Mar. Mammal Sci. 35(4):1625-1642. DOI: dx.doi.org/10.1111/mms.12596 .

Ross, W. G. 1993. Commercial whaling in the North Atlantic sector, p. 511-561. *In* J. J. Burns, J. J. Montague, and C. J. Cowles (eds.), The Bowhead Whale. Soc. Mar. Mammal., Spec. Publ. No. 2.

Rugh, D., D. DeMaster, A. Rooney, J. Breiwick, K. Shelden, and S. Moore. 2003. A review of bowhead whale (*Balaena mysticetus*) stock identity. J. Cetacean Res. Manage. 5(3):267-279.

Schick, R. S., and D. L. Urban. 2000. Spatial components of bowhead whale (*Balaena mysticetus*) distribution in the Alaskan Beaufort Sea. Can. J. Fish. Aquat. Sci. 57:2193-2200.

Schweder, T., D. Sadykova, D. Rugh, and W. Koski. 2009. Population estimates from aerial photographic surveys of naturally and variably marked bowhead whales. J. Agric. Biol. Environ. Stat. 15(1):1-19.

Sheffield, G., and J. C. George. 2013. Section V – North Slope Borough research: B - diet studies, p. 253-277. *In* K. E. W. Shelden and J. A. Mocklin (eds.), Bowhead Whale Feeding Ecology Study (BOWFEST) in the western Beaufort Sea. Final Report, OCS Study BOEM 2013-0114. Marine Mammal Laboratory, AFSC, NMFS, 7600 Sand Point Way NE, Seattle, WA 98115. Available online: https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/BOEM_Newsroom/Library/Publications/BOEM_2013-0114_BOWFEST_Final_Report.pdf . Accessed December 2020.

Sheffield, G., and Savoonga Whaling Captains Association. 2015. Bowhead whale entangled in commercial crab pot gear recovered near Saint Lawrence Island, Bering Strait. UAF Alaska Sea Grant, Marine Advisory Program, Report to the North Slope Borough Department of Wildlife Management, Barrow, AK. 8 p.

Shelden, K. E. W., and D. J. Rugh. 1995. The bowhead whale (*Balaena mysticetus*): status review. Mar. Fish. Rev. 57(3-4):1-20.

Shpak, O. V., I. G. Meschersky, A. N. Chichkina, D. M. Kuznetsova, A. Y. Paramonov, and V. V. Rozhnov. 2014. New data on the Okhotsk Sea bowhead whales. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/65b/BRG17). 5 p.

Smith, L. C., and S. R. Stephenson. 2013. New trans-Arctic shipping routes navigable by midcentury. Proc. Nat. Acad. Sci. 110(13):4871-4872. DOI: dx.doi.org/10.1073/pnas.1214212110 .

Stoker, S. W., and I. I. Krupnik. 1993. Subsistence whaling, p. 579-629. *In* J. J. Burns, J. J. Montague, and C. J. Cowles (eds.), The Bowhead Whale. Soc. Mar. Mammal., Spec. Publ. No. 2.

Suydam, R., and J. C. George. 2012. Preliminary analysis of subsistence harvest data concerning bowhead whales (*Balaena mysticetus*) taken by Alaskan Natives, 1974 to 2011. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/64/AWMP8). 13 p.

Suydam, R. S., R. P. Angliss, J. C. George, S. R. Braund, and D. P. DeMaster. 1995. Revised data on the subsistence harvest of bowhead whales (*Balaena mysticetus*) by Alaska Eskimos, 1973-1993. Rep. Int. Whal. Comm. 45:335-338.

Suydam, R., J. C. George, B. Person, C. Hanns, and G. Sheffield. 2011. Subsistence harvest of bowhead whales (*Balaena mysticetus*) by Alaskan Eskimos during 2010. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/63/BRG2). 7 p.

Suydam, R., J. C. George, B. Person, C. Hanns, R. Stimmelmayr, L. Pierce, and G. Sheffield. 2012. Subsistence harvest of bowhead whales (*Balaena mysticetus*) by Alaskan Eskimos during 2011. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/64/BRG2). 8 p.

Suydam R., J. C. George, B. Person, C. Hanns, R. Stimmelmayr, L. Pierce, and G. Sheffield. 2013. Subsistence harvest of bowhead whales (*Balaena mysticetus*) by Alaskan Eskimos during 2012. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/65a/BRG19). 7 p.

Suydam, R., J. C. George, B. Person, C. Hanns, R. Stimmelmayr, L. Pierce, and G. Sheffield. 2014. Subsistence harvest of bowhead whales (*Balaena mysticetus*) by Alaskan Eskimos during 2013. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/65b/BRG8). 10 p.

Suydam, R., J. C. George, B. Person, D. Ramey, C. Hanns, R. Stimmelmayr, L. Pierce, and G. Sheffield. 2015. Subsistence harvest of bowhead whales (*Balaena mysticetus*) by Alaskan Eskimos during 2014. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/66a/BRG6). 9 p.

Suydam, R., J. C. George, B. Person, D. Ramey, R. Stimmelmayr, T. Sformo, L. Pierce, and G. Sheffield. 2016. Subsistence harvest of bowhead whales (*Balaena mysticetus*) by Alaskan Eskimos during 2015 and other aspects of bowhead biology and science. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/66b/BRG3). 10 p.

Suydam, R., J. C. George, B. Person, D. Ramey, R. Stimmelmayr, T. Sformo, L. Pierce, and G. Sheffield. 2017. Subsistence harvest of bowhead whales (*Balaena mysticetus*) by Alaskan Eskimos during 2016. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/67a/AWMP02rev). 8 p.

Suydam, R., J. C. George, B. Person, R. Stimmelmayr, T. Sformo, L. Pierce, A. Von Duyke, L. de Sousa, and G. Sheffield. 2018. Subsistence harvest of bowhead whales (*Balaena mysticetus*) by Alaskan Natives during 2017. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/67b/AWMP/05). 8 p.

Suydam, R., J. C. George, B. T. Person, R. Stimmelmayr, T. L. Sformo, L. Pierce, A. Von Duyke, L. de Sousa, R. Acker, G. Sheffield, and A. Baird. 2019. Subsistence harvest of bowhead whales (*Balaena mysticetus*) by Alaskan Natives during 2018. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/68a/ASW02). 9 p.

U.S. Geological Survey (USGS). 2011. An evaluation of the science needs to inform decisions on Outer Continental Shelf energy development in the Chukchi and Beaufort seas. L. Holland-Bartels and B. Pierce (eds.), Alaska: U.S. Geological Survey Circular 1370. 278 p.

Walsh, J. E. 2008. Climate of the arctic marine environment. Ecol. Appl. 18(2)Suppl.:S3-S22. DOI: dx.doi.org/10.1890/06-0503.1 .

Wiig, Ø., L. Bachmann, N. Øien, K. M. Kovacs, and C. Lydersen. 2009. Observations of bowhead whales (*Balaena mysticetus*) in the Svalbard area 1940-2008. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/61/BRG2). 5 p.

Wiig, Ø., L. Bachmann, M. P. Heide-Jørgensen, K. L. Laidre, L. D. Postma, L. Dueck, and P. J. Palsbøl. 2010. Within and between stock re-identification of bowhead whales in Eastern Canada and West Greenland. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/62/BRG25). 7 p.

Wiig, Ø., M. P. Heide-Jørgensen, C. Lindqvist, K. L. Laidre, P. J. Palsbøll, and L. Bachmann. 2011. Population estimates of mark and recaptured genotyped bowhead whales (*Balaena mysticetus*) in Disko Bay, West Greenland. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/63/BRG18). 4 p.

Wilkinson, J., C. J. Beegle-Krause, K.-U. Evers, N. Hughes, A. Lewis, M. Reed, and P. Wadhams. 2017. Oil spill response capabilities and technologies for ice-covered Arctic marine waters: A review of recent developments and established practices. Ambio 46(Suppl. 3):S423–S441. DOI: dx.doi.org/10.1007/s13280-017-0958-y .

Willoughby, A. L., J. T. Clarke, M. C. Ferguson, R. Stimmelmayr, and A. B. Brower. 2018. Bowhead whale carcasses in the eastern Chukchi and western Beaufort seas, 2009-2017. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/67b/AWMP2). 10 p.

Woodby, D. A., and D. B. Botkin. 1993. Stock sizes prior to commercial whaling, p. 387-407. *In* J. J. Burns, J. J. Montague, and C. J. Cowles (eds.), The Bowhead Whale. Soc. Mar. Mammal., Spec. Publ. No. 2.

Yablokov, A. V. 1994. Validity of whaling data. Nature 367:108.

Young, N. C., B. J. Delean, V. T. Helker, J. C. Freed, M. M. Muto, K. Savage, S. Teerlink, L. A. Jemison, K. Wilkinson, and J. Jannot. 2020. Human-caused mortality and injury of NMFS-managed Alaska marine mammal stocks, 2014-2018. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-413, 142 p.

Zeh, J. E., and A. E. Punt. 2005. Updated 1978-2001 abundance estimates and their correlations for the Bering-Chukchi-Beaufort Seas stock of bowhead whales. J. Cetacean Res. Manage. 7(2):169-175.

Zeh, J. E., C. W. Clark, J. C. George, D. E. Withrow, G. M. Carroll, and W. R. Koski. 1993. Current population size and dynamics, p. 409-489. *In* J. J. Burns, J. J. Montague, and C. J. Cowles (eds.), The Bowhead Whale. Soc. Mar. Mammal., Spec. Publ. No. 2.

Zharikov, K. 2018. Aboriginal subsistence whaling in the Russian Federation in 2017. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/67b/AWMP/WP/02). 2 p.

Zharikov, K. A., D. I. Litovka, and E. V. Vereshagin. 2019. Aboriginal subsistence whaling in the Russian Federation during 2018. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/68a/ASW03). 3 p.