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2020-2021 Health Report for the Bering-Chukchi-Beaufort Seas Bowhead Whale

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2020-2021 HEALTH REPORT FOR THE BERING-CHUKCHI-BEAUFORT SEAS BOWHEAD WHALES

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ABSTRACT

At the 2016 IWC Scientific Committee meeting, it was agreed that an annual or biannual report on the Bering-Chukchi-Beaufort Seas (BCB) bowhead whale stock would be submitted that summarizes health-related data from multiple disciplines. This summary is intended to provide ancillary but pertinent information for informing management recommendations and tracking the status of the BCB bowhead stock. This report is the fourth of the series and summarizes general information on population indices, whale health, and hunter observations of bowhead whales for 2020 and 2021. We provide new information on 12 indices: *(1) population size and trends; (2) adult survival rate; (3) acoustic index of relative abundance of migrating whales; (4) distribution and migration; (5) calf production (aerial surveys); (6) pregnancy rates of landed adult females; (7) body condition; (8) whale lice burden of landed whales; (9) proportion of landed whales showing evidence of feeding; (10) proportion of landed whales with injuries consistent with line entanglement, killer whale attacks and/or vessel collisions; (11) non-harvest related mortality of bowhead whales; (12) pathological findings from postmortem examinations of landed whales; and (13) hunter observations.* These indices suggest that the bowhead population remains robust and that the subsistence harvest is sustainable. We will continue to monitor these indices in the coming years.

INTRODUCTION

At the 2016 IWC Scientific Committee meeting, it was agreed that an annual or biannual report on the Bering-Chukchi-Beaufort Seas (BCB) bowhead whale (*Balaena mysticetus*) stock would be submitted by the North Slope Borough and collaborators that summarizes various health-related data (George et al. 2016). This summary is intended to provide ancillary but pertinent information to inform management recommendations and track the status of the BCB stock. This report is the fourth of the series (George et al. 2017a; Stimmelmayr et al. 2018, 2020) and summarizes general information on population indices, distribution and migration, whale health, and hunter observations of bowhead whales. Taken together, these different indices provide timely information on bowhead whale resilience in an era of rapid ecosystem alteration in the Pacific Arctic (e.g., Moore and Reeves 2018; Huntington et al. 2020; Gulland et al. 2022).

Population Size and Trend

In 2019, two abundance surveys were conducted to derive updated estimates of the BCB bowhead whale population. The first was an ice-based visual survey conducted near Utqiaġvik , Alaska, during the spring migration (Givens et al., 2021a). Such surveys have been conducted since 1978. Observers stand on a perch at the ice edge and count whales migrating through the open lead. This count is adjusted to account for visual detection probability and whale availability, including the proportion of whales swimming within visual range (denoted P4). In some past surveys, P4 has been estimated from simultaneous acoustic data. In 2019, no acoustic monitoring was completed, so P4 was estimated from a regression of P4 on perch location, using data from other years. This approach is an improvement from some prior estimates where P4 was estimated from a simple average of past values. The resulting abundance estimate was 12,505 bowhead whales (CV=0.228, 95% CI 7,994 to 19,560). However, the authors noted that they are of the opinion that the estimate had significant downward bias due to several factors, including: highly unusual ice conditions in 2019, failure to conduct watch because of closed leads during the early weeks of the migration when numerous whales likely passed, an unusually short perch, and hunters use of powered skiffs near the observation perch, that likely disturbed the whales during the survey.

Givens et al. (2021b) developed a post hoc bias correction approach to adjust the estimate of Givens et al. (2021a) for the downward bias attributed to disturbance from hunters' powered skiffs, using contemporaneous data on boat excursions. Indices of short-term bowhead whale abundance at the survey perch and short-term boat noise disturbance were computed from the available data, where 'short term' refers to a few hours. A generalized additive model (GAM) was fit to the results, predicting short-term whale abundance as a smooth function of the boat noise disturbance index, after controlling for long-term variation in the whale passage rate over the course of the season. The fitted GAM was then used to predict passage with and without the presence of boat noise. The ratio of the integrals of these two predicted passage curves provided a correction factor. Variance of this correction factor was estimated using two approaches, and found to be small. The estimated correction factor would increase the abundance estimate from Givens et al. (2021a) by about 12%, yielding a corrected abundance estimate of 14,025 (CV=0.228, 95% CI 8,964 to 21,942). The IWC Scientific Committee reviewed this corrected estimate in 2021 and endorsed it as the best available estimate from the 2019 ice-based survey, and appropriate for use with the Aboriginal Whaling Management Procedure and for inclusion in the Scientific Committee's Table of Agreed Abundance Estimates as Category 1A ('acceptable for use in In-depth Assessments or for providing management advice') (IWC, 2022).

The second survey was conducted by the Aerial Survey of Arctic Marine Mammals (ASAMM) project in August 2019. The study area for this aerial line-transect survey extended from 117°W-158°W, focusing on the Beaufort Sea shelf and Amundsen Gulf, with secondary priority west of Banks Island. The spatial and temporal scope were chosen to coincide with the time period when the majority of the BCB bowhead whale stock is believed to be in a region that could be effectively surveyed using aerial line-transect methods. Based on this survey, Ferguson et al. (2022) used a spatially-explicit model to estimate the abundance of BCB bowhead whales in 2019 to be 17,175 whales (CV = 0.237; 95% CI 10,793 to 27,330). This abundance estimate incorporates correction factors for perception bias (including transect detection probability) and availability bias (accounting for observer field-of-view and bowhead whale surface and dive duration). The spatially-explicit model was a hierarchical generalized additive model (Pedersen et al. 2019) that incorporated soap film smooths (Wood et al. 2008) of space, with factor-smooth interactions to accommodate activity state-specific estimates of availability bias.

The two 2019 estimates provide an update of the abundance of BCB bowhead whales as required every 10 years by the IWC's Aboriginal Whaling Scheme (IWC 2019). Although the estimated abundance for the 2019 ice-based survey is lower than the 2011 estimate of 16,820, both ice based and aerial surveys provide confidence intervals for abundance that wholly encompass the 2011 interval (Figure 1, Givens et al. 2016, 2021b). It is not clear whether the apparent stabilization or slight decline in the point estimates for abundance from 2011 to 2019 is due to: sampling variability; uncorrected negative bias in both 2019 estimates or positive bias in 2011; reduction in productivity and/or survival for unknown reasons; or some combination of these and/or other factors. The authors of both 2019 abundance estimates assert in their papers that they do not interpret the 2019 results as indicative of population decline, for a variety of biological, ecological, and statistical reasons, and also because the differences between the 2011 and 2019 confidence intervals are nowhere close to statistical significance.

Using 12 abundance estimates from 1978 through 2011, Givens et al. (2016) estimated the annual rate of population growth to be 3.7% (95% CI 2.9% to 4.6%). Figure 1 illustrates how the apparent trend is affected by the two abundance estimates for 2019. The solid curve is fit to the data through 2011, including the estimate of Koski et al. (2010) for 2004, not used in the prior analysis. The dashed curve incorporates both 2019 estimates. These curves are estimated using a simple, inverse variance weighted regression on log abundance to fit an exponential growth model. They do not incorporate the small correlations between some prior abundance estimates (as Givens et al. 2016 did); therefore we don't update the growth rate estimate here. It is apparent that the 2019 abundance estimates do not substantially reduce estimated population growth.

Plans for both a future ice-based visual/acoustic survey and a new aerial survey are at early stages, with a first attempt at the ice-based survey tentatively planned for spring 2024 or 2025. Given rapidly changing ice conditions in the Arctic, it will be prudent to pursue an aerial survey on approximately the same timeline, in case the ice-based visual/acoustic survey is unsuccessful at providing the data needed to produce a reliable abundance estimate.

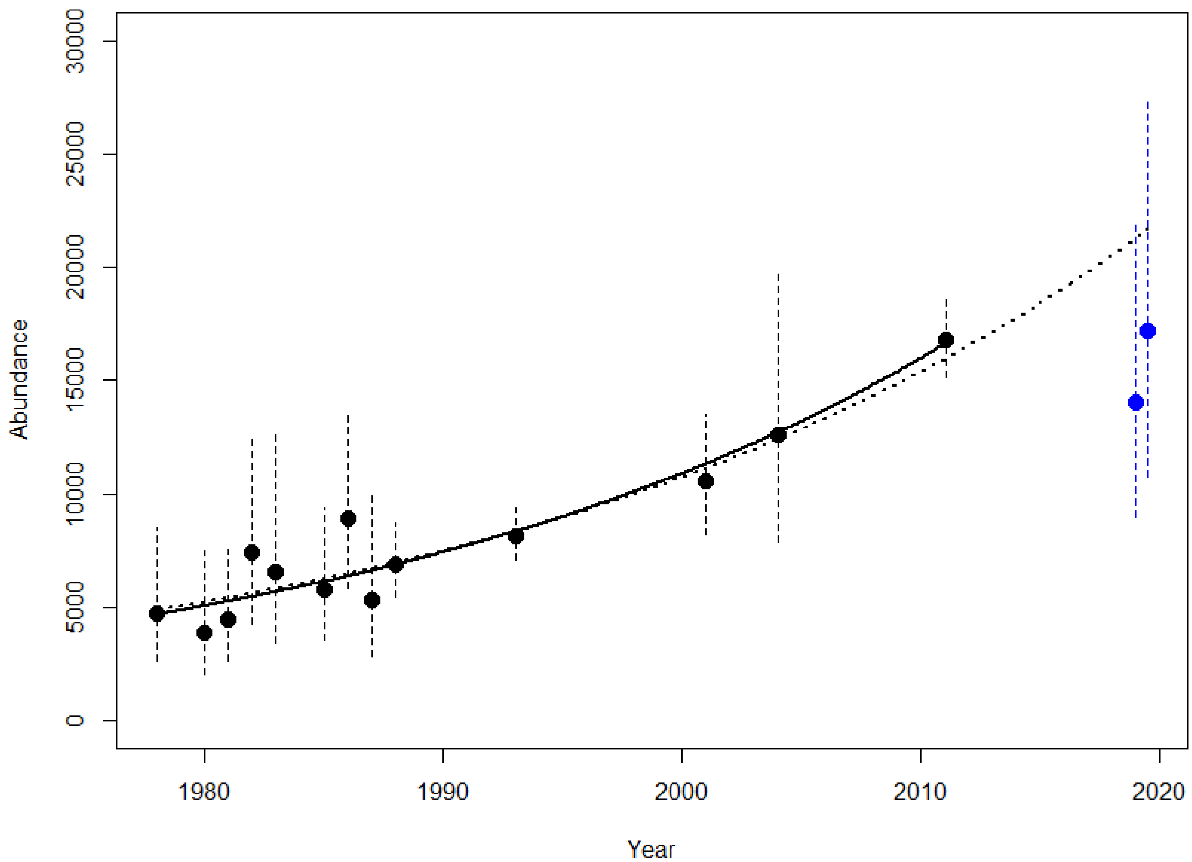


Figure 1. Estimated population growth, with (dashed curve) and without (solid curve) the two new abundance estimates for 2019. The abundance estimates are shown with 95% confidence intervals. The 2019 estimates are blue, and horizontally jittered in the display for clarity.

Adult Survival Rate

Bowhead whales are among the longest-living mammals (George et al. 2021a). We previously reported an estimate of adult survival rate of 0.996 (with an approximate lower confidence bound of 0.976) based on the 2011 photo-ID analysis that used photo matches of re-identified whales as far back as 1985 (Givens et al. 2017; Stimmelmayr et al. 2017). This estimated high survival rate is supported by other biological data on longevity (Keane et al. 2015). No new formal analysis of aerial photographs has been conducted. However, in fall 2021, a photographed cow-calf pair was matched to an image of the adult taken in 1985 (B. Tudor pers. comm.) and represents the longest recorded (36 year) recapture of a bowhead whale (J.C. George, pers. comm.). In 1985, white pigmentation of the peduncle was already present on the adult, suggesting advanced age of this particular female. (George et al. 2021a). This resighting provides additional support for extended longevity among bowhead whales and for delayed reproductive senescence in female bowhead whales in comparison to other baleen whales (Tarpley et al. 2021).

Acoustic Index from Spring short-term moorings

Acoustic data collected by NOAA within the Pacific Arctic have yet to be formally analyzed. Here we briefly report on hydrophone recordings collected opportunistically in 2020 and 2021. On 24 April 2020, a dipping hydrophone was deployed briefly in the spring lead near Utqiaġvik but no bowheads were detected. This was the only time that acoustics data were collected at Utqiaġvik during 2020 due to the Covid-19 pandemic.

During 2021, bowhead calls were detected via a dipping hydrophone of the spring lead near Utqiaġvik on 10 January, 1 April, and 3 April. No bowhead calls were detected on 25 January, 10 April 16 April, 18 April, and 22 April. The bowhead whale detections on 10 January 2021 support other acoustic and telemetry studies as well as community observations that suggest bowhead whales are generally migrating later in fall (e.g., Stafford et al. 2021a,b), may winter farther north in the Chukchi Sea in light ice years (e.g., Citta et al. 2021), and that some individuals may remain on traditional summering grounds over winter (e.g., Insley et al. 2021).

2020-2021 Distribution and Migration

No satellite transmitters were active during the period summarized in this report. However, aerial surveys were flown over the Beaufort Sea in both 2020 and 2021. These aerial surveys used the same survey design and protocols as the long-term Aerial Surveys of Arctic Marine Mammals (ASAMM) project that provided aerial survey information in the Chukchi and Beaufort seas for 41 years, but ended in fall 2019. In 2020 and 2021, the North Slope Borough (NSB) funded aerial surveys of the bowhead whale autumn migration (15 September – 15 October) across the western Beaufort Sea. The objectives of the NSB Autumn Aerial Survey studies were to: 1) conduct line-transect aerial surveys in the western Beaufort Sea to collect data on bowhead whale density, distribution, activities, and calves using survey methods consistent with the existing 41-year ASAMM time series; and 2) analyze the autumn aerial survey data with the ASAMM historical database to investigate spatial and temporal patterns, variability, and trends in bowhead whale density and habitat use in the western Alaskan Beaufort Sea. Preliminary findings for calf sightings and calf production are summarized below. Data for the 2020 and 2021 bowhead whale distribution are currently being analyzed (Brower et al. in review; in prep.) and will be presented at a later date.

Calf Production

Two bowhead whale calf production indices, calf ratio and calf sighting rate were derived from aerial line-transect survey data collected during the NSB Autumn Aerial Surveys reported above, and interpreted in the context of the long time series of ASAMM data (Clarke et al. 2022). The calf production indices summarize data collected in the bowhead whale calf analysis area from 140°W to 160°W, during the period from 15 September to 15 October in each year from 2009 to 2021 (Figure 2). Both indices use "on-effort" data, meaning that the data were collected during straight and level flight, at survey altitude and speed, on predefined transect lines, when observers were actively searching and recording all bowhead whale detections. The bowhead whale calf ratio is the proportion of observed bowhead whales that were calves. Calf ratios provide an index of calf production and were calculated using the number of calves sighted on effort, relative to the number of total bowhead whales sighted on effort (calves/total whales). Calf sighting rates normalize the number of observed calves by the amount of survey effort, providing an index of relative density. Calf sighting rates were calculated using the number of on-effort calves per 1,000 km flown on effort.

The 2020 bowhead whale calf ratio was 0.038 (22 calves/589 whales). In 2021, the calf ratio was 0.083 (11 calves/131 whales), more than twice as high as 2020 (Table 1, Figure 3). Annual bowhead whale calf ratios for the analysis area (140°W–160°W) varied. Using data collected since 2009, calf ratios were highest in 2019, and have been higher on average in recent years, compared to the first portion of the time series (Table 1, Figure 3).

The 2020 calf sighting rate was 5.1 calves per 1,000 km flown on effort and almost three times more than 2021 (Table 1, Figure 3). Annual bowhead whale calf sighting rates for the analysis area (140°W–160°W) varied. Using data collected since 2009, calf sighting rates were highest in 2020, and have been higher on average in recent years. This is likely because an extraordinary number of bowhead whales were encountered in 2020, and by many accounts this was the densest aggregations of bowhead whales recorded in the history of the annual ASAMM and preceding (1982–2019) aerial surveys in the western Beaufort Sea (Brower et al. *in review*, *in prep*) (Table 1, Figure 3). Further information on calf production derived from aerial surveys from 2009 to 2021 is included in Willoughby et al. (2022a).

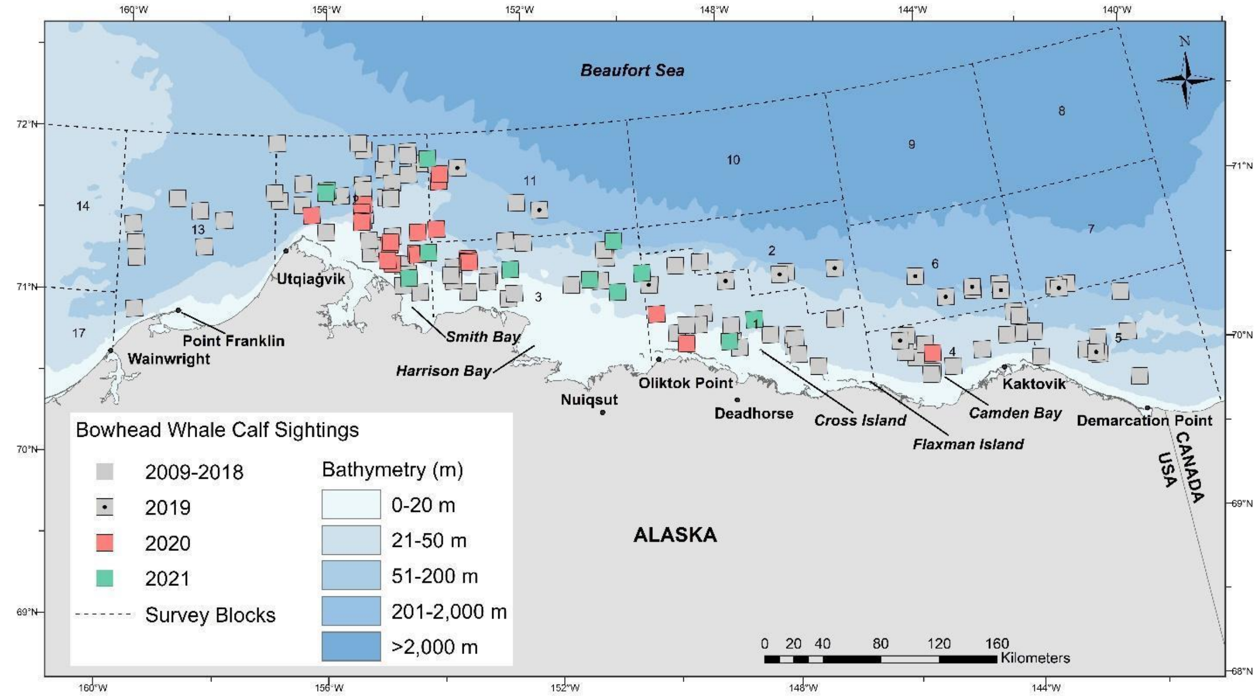


Figure 2. Bowhead whale calf sightings, on effort, by primary observers, from 15 September to 15 October 2009–2021, in the analysis area (140°W–160°W).

Table 1. Bowhead whale calf ratios (CR, on-effort calves/whales) and sighting rates (SR, on-effort calves per 1,000 km), in the analysis area (140°W–160°W), from 15 September to 15 October 2009–2021.

Year	Whales	Calves	CR	1,000 km	Calves	SR
2009	145	11	0.076	6.5	11	1.7
2010	94	4	0.043	6.8	4	0.6
2011	54	3	0.056	6.8	3	0.4
2012	95	4	0.042	10.2	4	0.4
2013	57	6	0.105	4.7	6	1.3
2014	232	7	0.030	7.4	7	1.0
2015	253	10	0.040	14.1	10	0.7
2016	153	21	0.137	9.1	21	2.3
2017	174	18	0.103	6.6	18	2.7
2018	256	12	0.045	9.1	12	1.3
2019	77	19	0.247	14.7	19	1.3
2020	589	22	0.038	4.3	22	5.1
2021	131	11	0.083	5.8	11	1.9
Total	2,310	148		106	148	

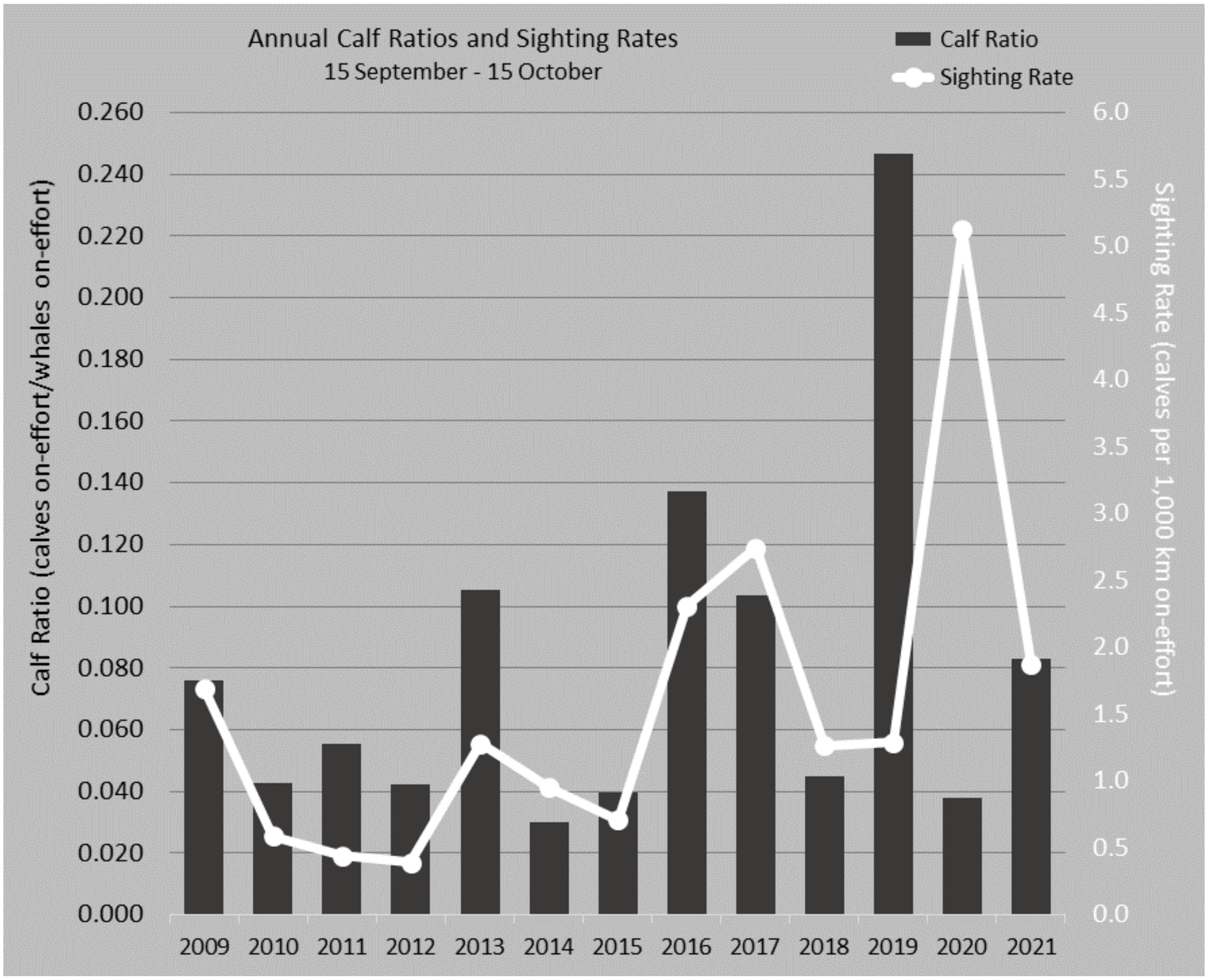


Figure 3. Annual bowhead whale calf ratios (on-effort calves/total whales), in the analysis area (140°W–160°W), from 15 September to 15 October (left y-axis). Annual bowhead whale calf sighting rates (on-effort calves per 1,000 km) are depicted by the white trend line with markers, for the analysis area (140°W–160°W), from 15 September to 15 October (right y-axis).

Pregnancy Rates of Landed Adult Females

Until recently, George et al. (2018) provided the most current pregnancy rate estimate for BCB bowheads. George et al. (in prep) calculated pregnancy rates for BCB bowheads using data from 1973-2021, and presented two estimates. One estimate for the proportion of mature females that were pregnant, 0.46, 95% CI [0.36, 0.55], was derived from a full dataset of harvested bowheads examined by biologists (n=125) and includes two cohorts of pregnant whales in the spring (as bowhead pregnancies extend longer than one year). The second, more conservative estimate was calculated from a subset of whales (n=37) and resulted in a somewhat lower pregnancy rate estimate: 0.38, 95% CI [0.20, 0.51]. This estimate includes only a single cohort of pregnant whales, all landed in the fall. Accounting for the differing datasets and potential double-counting, the authors show that both estimates are consistent with the 1976-2016 estimate of 0.317, 95% CI [0.25, 0.39] with a minimum 3-year calving interval presented in the 2018-2019 health report to the IWC (Stimmelmayr et al. 2020). The results of George et al. (in prep) will be presented at the 2023 SC meeting.

Body Condition of Landed Whales

Bowhead whales compared to other cetaceans maintain a very high level of body condition year-round (George et al. 2015) and different indices for body condition exist (see examples in George et al. 2015). Here we use a simple body condition index (BCI_g), where BCI_g = axillary girth (cm) / body length (cm). George et al. (2015) show that this index of body condition is highly correlated with more complex indices.

It is important to consider both age class and season when calculating body condition. Bowhead whales accumulate mass differently as they age (George et al. 2021a) and, although BCB bowhead whales are thought to feed year-round (Citta et al. 2021; Sheffield et al. 2021a), there is no *a priori* reason to assume that food availability or feeding effort are seasonally equal. Indeed, bowhead stomachs are often empty during the spring migration (Sheffield and George 2021a). Here we limit our consideration to subadult whales (baleen length between 140 to 250 cm) (Lubetkin et al. 2008, 2012), the age class for which we have the most data. Formal training in how to measure bowhead whales began in 1990; hence, we consider linear trends in BCI_g since 1990. There is no statistically significant, long-term (1990–2021) linear trend in BCI_g for subadult whales harvested in spring (p=0.61) or autumn (p=0.56); however, there is a statistically significant effect of season (p<0.001). Average BCI_g (1990–2021) was 0.629 (SE=0.006) in spring and 0.667 (SE=0.003) in autumn. To put the seasonal difference into context, a subadult whale of average length (1,035 cm) harvested in autumn has ~39 cm or ~4% more axillary girth than in spring.

To visualize BCI_g over time, we split the harvest data into 5-year periods (noting that only 2 years of the 2020–2024 period have been sampled at the time of writing) and plotted them relative to the 2020–2021 mean (Figures 4 and 5). For spring, during the most recent period (2020–21), BCI_g falls below the long-term mean; however, sample size is limited (n=3) and both the mean and median are similar to observations during 1990–95 and 2010–15. For autumn, BCI_g during the most recent period (2020–21) also falls below the long-term average; however, the median is similar to that observed during 1990–94, 2000–04, and 2015–19. The mean is lower than any other 5-year period, but similar to that observed during 1990–94 and 2000–04. To put recent measurements into context, subadult whales harvested since 2020 have on average ~18 cm or ~3% less girth than the 1990-2021 average for autumn. Average BCI_g has slowly declined since 2005 (Figures 3 and 4); however, this pattern is not visible in the median values and is within the long-term range of variation.

Bowhead whales maintain a very high level of body condition year-round compared to other cetaceans (George et al. 2015) and body condition is currently within the long-term range of variability, both for spring and autumn. The interannual variation in bowhead whale body condition can be viewed as a sensitive indicator for the Pacific Arctic food web and primary productivity (see George et al. 2015). The latter remains highly dynamic reflecting the complex interplay between sea ice reduction and increases in seawater temperature (Frey et al. 2021). A formal analysis of body condition is warranted, especially if more samples can be collected over the next few years. We are planning to repeat and improve upon the analysis of George et al. (2015), sometime within the next 2–3 years.

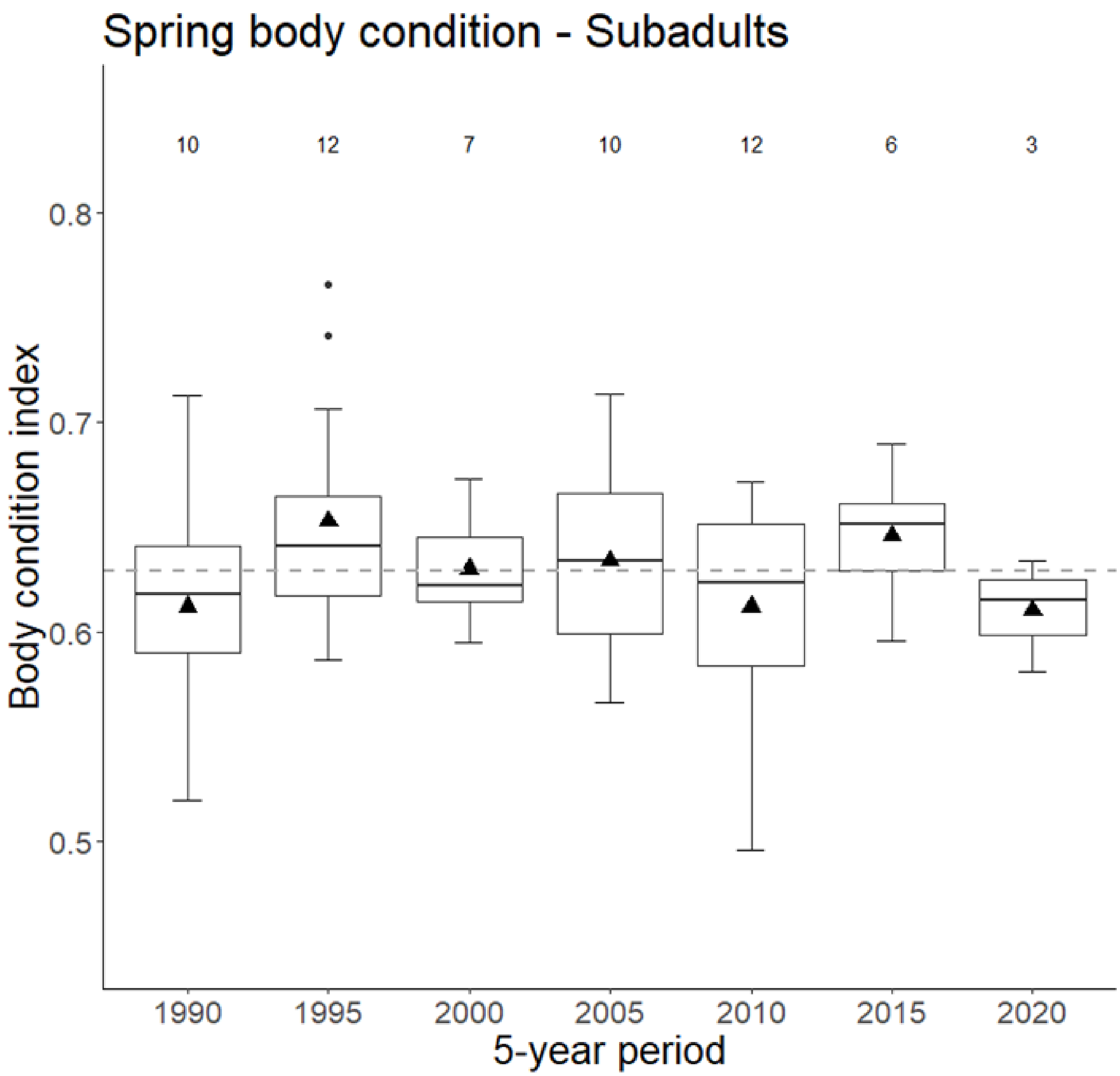


Figure 4. BCI_g for subadult whales harvested during spring (1990–2021) in Utqiaġvik . Boxes are bounded by the 1st and 3rd quartiles and whiskers are 1.5 IQR minus the 1st quartile or plus the 3rd quartile. Horizontal lines within boxes are medians and triangles within boxes are means. The gray dashed line is the spring 1990–2021 mean. Numbers at the top of the year represent # of subadult whales.

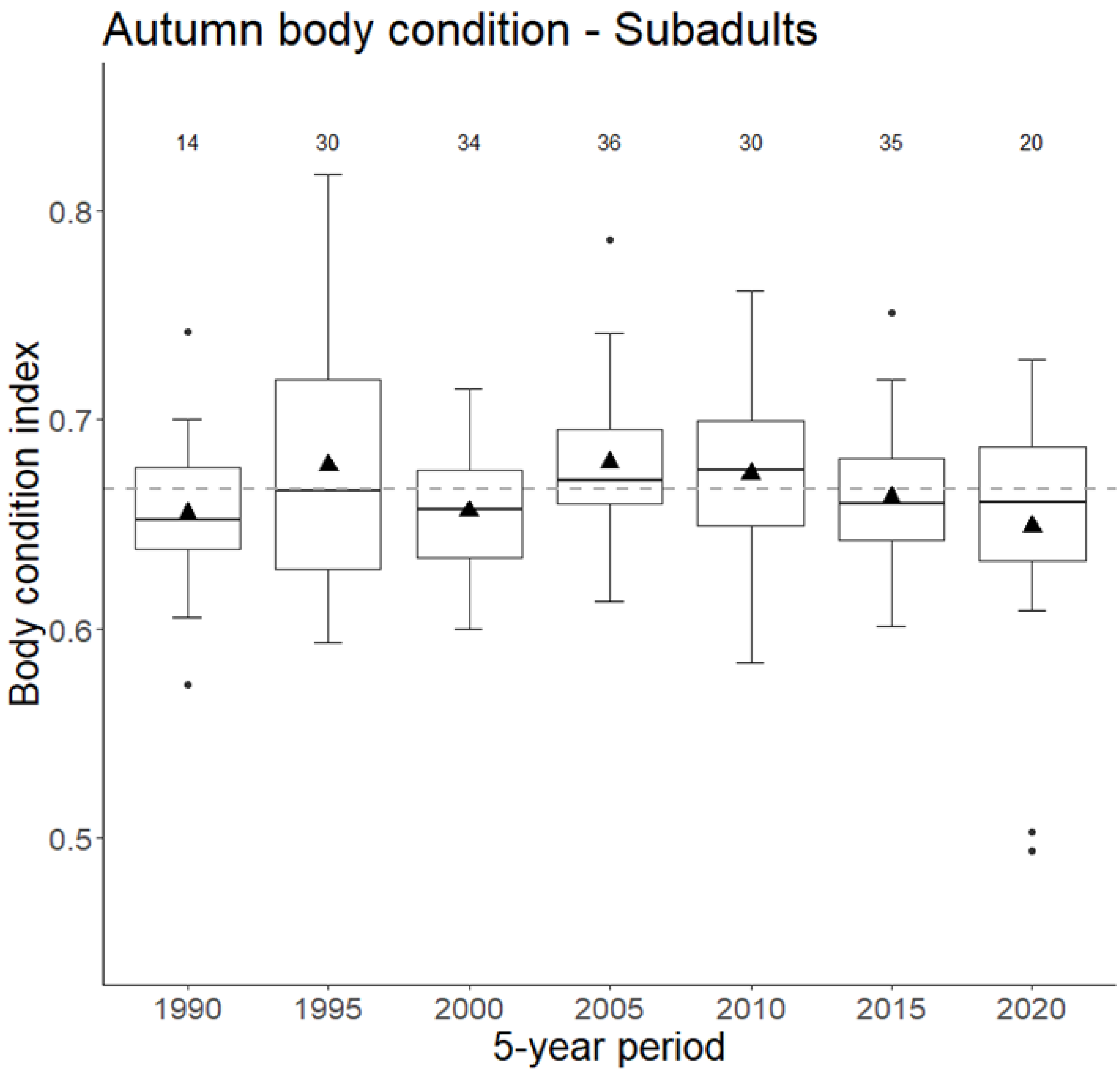


Figure 5. BCI_g for subadult whales harvested during autumn (1990–2021) in Utqiaġvik . Boxes are bounded by the 1st and 3rd quartiles and whiskers are 1.5 IQR minus the 1st quartile or plus the 3rd quartile. Horizontal lines within boxes are medians and triangles within boxes are means. The gray dashed line is the autumn 1990–2021 mean. Numbers at the top of the year represent # of subadult whales.

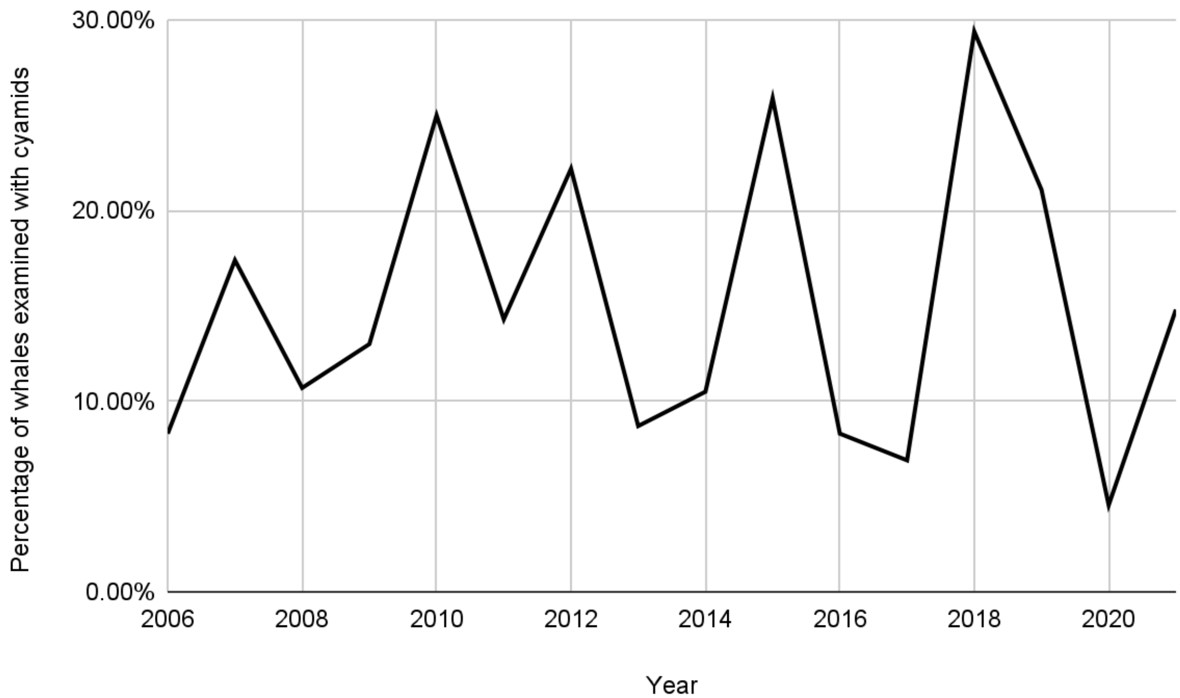
Proportion of Landed Whales Carrying Cyamids

Over a period spanning 1973 – 2015, the prevalence of landed bowheads carrying cyamids ``whale lice" (n = 673) was approximately 20% (Von Duyke et al. 2016). Table 2 documents the numbers bowheads examined for and carrying cyamids over the past 16 years (2006 – 2021), during which time the mean prevalence for cyamid presence on landed bowheads was 15.07 % (SD = 7.37%). Cyamid prevalence during 2020 was the lowest on record, while cyamid prevalence during 2018 remains the highest percentage since 2005 (37%) (Table 2). Consistent with 2018 and 2019 findings (Stimmelmayr et al. 2020) all of the bowheads with cyamids present during 2020 and 2021 were subadults (7.8-12.8 m). This finding is inconsistent with long-term results that indicate older whales have a higher prevalence of cyamids (Von Duyke et al. 2016). The long-term trend of cyamid prevalence continues to suggest a 2-3 year periodicity (Figure 6). Furthermore, there is an apparent widening range between maximum and minimum annual prevalence of cyamids, namely an upward trend for maximum cyamid prevalence observed from 2007 onward which is mirrored by a downward trend in minimum cyamid prevalence from 2011 forward. Given that bowhead-cyamid interactions are likely sensitive to ongoing climate change (e.g., Cizauskas et al. 2017; Gehman et al. 2018), a formal analysis of the apparent trends is warranted, especially if more samples can be collected over the next few years. We are planning to repeat and improve upon the analysis of Von Duyke et al. (2016) within the next 2–3 years.

Table 2. Prevalence of cyamids during 2006 – 2021 in landed bowhead whales from Gambell, Savoonga, Kaktovik, Nuiqsut, and Utqiaġvik , Alaska.

Year	# of whales examined	# of whales with cyamids present	Percentage of whales examined with cyamids
2006	24	2	8.30%
2007	23	4	17.40%
2008	28	3	10.70%
2009	23	3	13.00%
2010	24	6	25.00%
2011	21	3	14.30%
2012	27	6	22.20%
2013	23	2	8.70%
2014	19	2	10.50%
2015	27	7	25.90%
2016	24	2	8.30%
2017	29	2	6.90%
2018	34	10	29.40%
2019	19	4	21.10%
2020	22	1	4.55%
2021	27	4	14.81%
TOTAL	394	61	$\bar{x}$ = 15.07% (SD = 7.37%)

Figure 6. Time series of cyamid prevalence during 2006 – 2021 in landed bowhead whales from Gambell, Savoonga, Kaktovik, Nuiqsut, and Utqiaġvik, Alaska.



Proportion of Landed Whales Showing Evidence of Feeding

Long-term studies (Sheffield and George 2021a) on bowhead whale feeding provide a good framework for reporting the frequency of bowhead whales feeding and the diet in several areas across the BCB range (Saint Lawrence Island to Kaktovik, Alaska).

Gambell and Savoonga located on Saint Lawrence island (SLI) are the only Bering Strait communities that harvest bowheads during the winter months. While stomachs from whales harvested near SLI are typically examined, none were examined during 2020 or 2021 due to Covid-19 pandemic travel restrictions. During 2020, 19 stomachs (18 Utqiaġvik ; 1 Wainwright) of 54 harvested whales were examined and 14 whales (74%) had prey in their stomachs. In 2021, 24 stomachs (20 Utqiaġvik, 3 Kaktovik, 1 Wainwright) of 56 landed whales were examined and 18 individuals (75%) had prey in their stomachs. During the spring season (2021) a total of 8 stomachs were examined and 4 whales (50 %) (3 Utqiaġvik; 1 Wainwright) had been feeding on krill. During the fall season (2020 and 2021) a total of 31 stomachs were examined and 27 whales (87 %) had been feeding. Long-term data on landed whales with evidence of recent feeding are summarized in Figure 7 for spring and Figure 8 for fall.

Results presented here for the Chukchi and Beaufort seas (Figures 7 and 8) are consistent with past feeding and oceanographic studies that demonstrate that shelf waters of the Beaufort Sea are important for feeding during fall (Sheffield and George 2021a; Ashjian et al. 2021a, 2021b). The physical and biological factors that create favorable feeding environments (dense aggregations to patches of krill on the shelf) during fall are relatively well understood for shelf waters of the Beaufort Sea (Ashjian et al. 2012, 2021b; Okkonen et al. 2018). However, little is known of the mechanisms that may contribute to bowhead whale spring feeding events, which are much less frequent than feeding events in autumn (Sheffield and George 2021a).

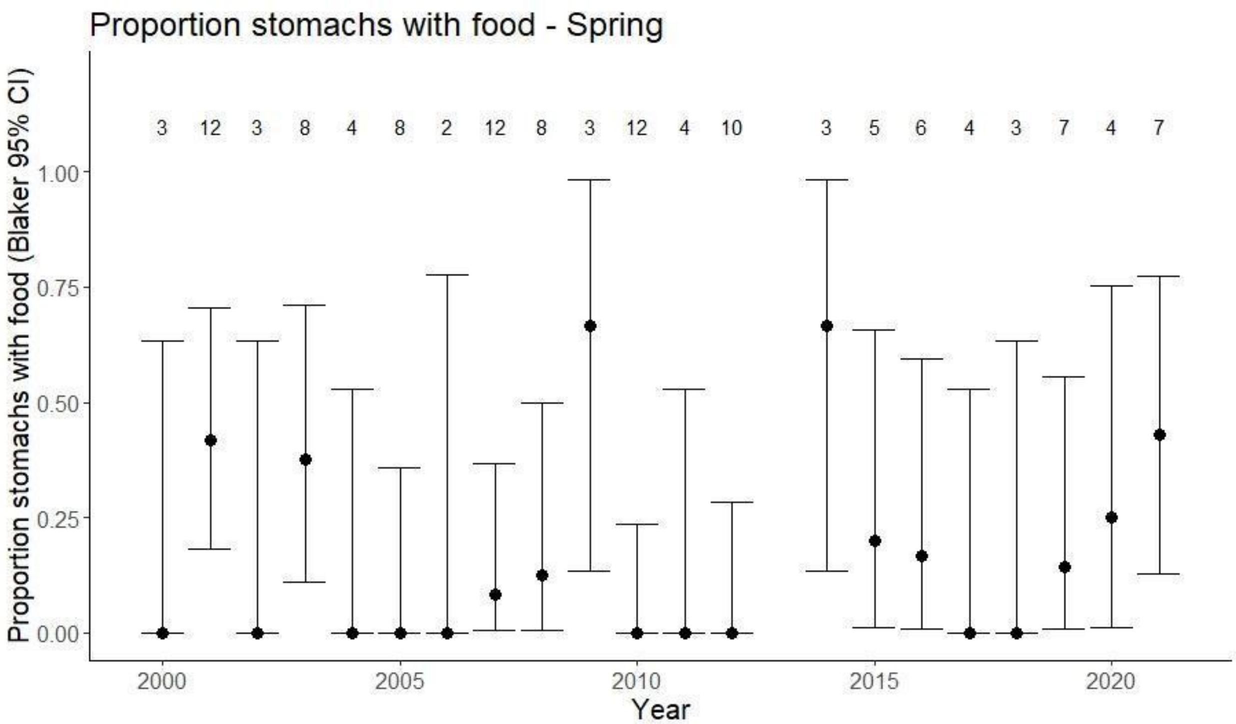


Figure 7. Proportion of bowhead whale stomachs containing food during spring, 2000-2021. Confidence limits are exact limits as proposed by Blaker (2000) and calculated using package '*binGroup*' (Zhang et al. 2018) in R. Numbers at the top of the year represent # of stomachs examined.

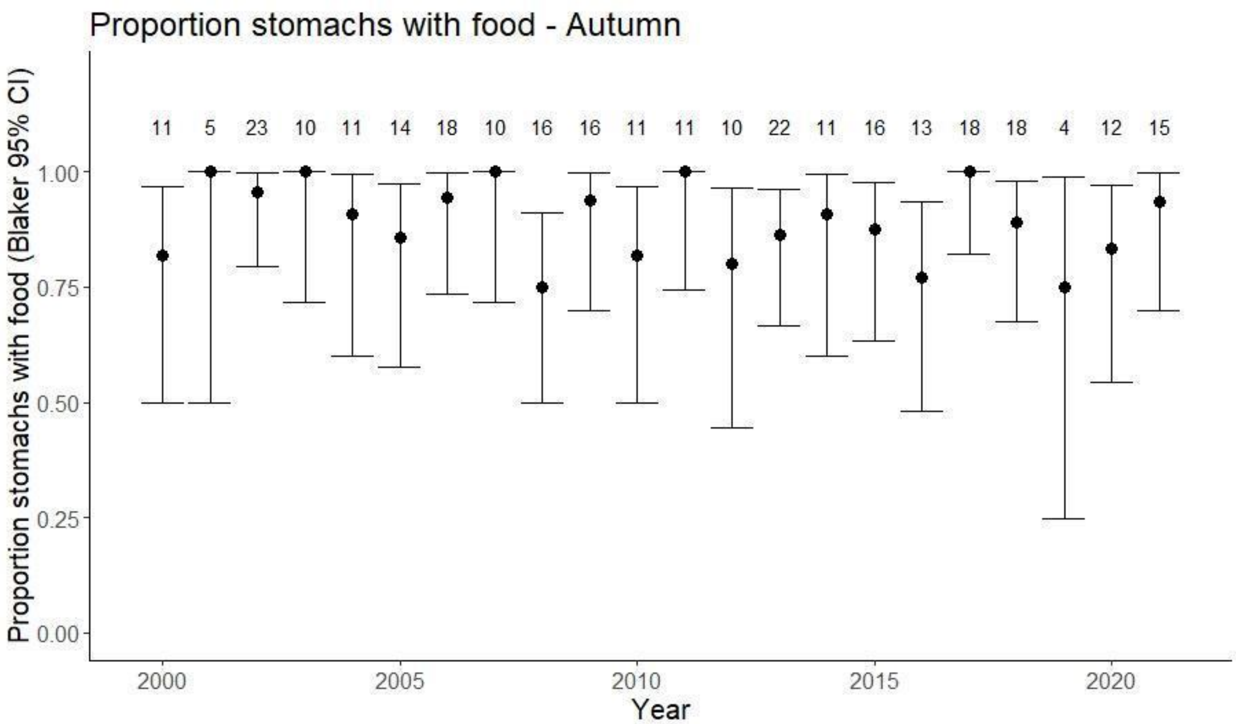


Figure 8. Proportion of bowhead whale stomachs containing food during fall, 2000-2021. Confidence limits are exact limits as proposed by Blaker (2000) and calculated using package '*binGroup*' (Zhang et al. 2018) in R. Numbers at the top of the year represent # of stomachs examined.

Proportion of landed Whales with Line Entanglement, Killer Whale, and Vessel collision Injuries

During 2020, three (13%) of the 23 whales examined for evidence of line entanglement, exhibited scars associated with large line entanglement. This is similar to the 1990-2012 baseline of 12% (George et al., 2017b). During 2021, only one (3%) of the 34 whales examined exhibited scarring associated with large line entanglement. This entanglement rate is lower than in previous years (e.g., 2019 (10%); 2018 (12%); 2017 (13%) (Stimmelmayr et al. 2017; 2020). The apparent decline in entanglement scarring could be because few large whales (>14 m) were landed during 2021. Larger bodied mature whales tend to have a higher incident of line entanglement scars due to greater exposure time at sea. It remains to be seen if 2021 is an outlier year or indicative of some longer-term change.

During 2020 and 2021 respectively, two (9%) and three (9%) of the examined whales exhibited scars associated with killer whale bite injuries. These results are consistent with the 1990-2012 baseline of 8% determined by George et al. (2017b). Two additional whales harvested near SLI during 2021 were reported by whaling captains to have scarring caused by killer whales.

During 2021, two mature whales had unusual scars suggestive of large vessel collisions. One was a mature female (14.12 m) landed in Wainwright in 2021 (21WW4) that exhibited four parallel evenly spaced linear scars (~ 10 cm wide) on the ventrum, of which two extended from the umbilical region to the pectoral region (insertion of flippers) (Figure 9). Both of the long scars were raised and originated from relatively recent deeper wounds with incomplete subcutaneous healing. Although speculative, the observed type of scars could have been caused from sharp force trauma associated with a propeller strike from a large vessel (Moore et al. 2013). Although an unusual anatomical location for a propeller strike, swimming in ventrum-up position, rolling, and surface resting with ventrum-up has been reported for bowhead whales (Wuersig and Koski 2021). Additionally, an immature female landed in Kaktovik during 2021 (21KK3) exhibited a single large crescent-shaped scar along the peduncle. Shape and size were also consistent with sharp trauma from a propeller strike. As discussed by Moore et al. (2013), single wounds are more common in cases involving contact with a large propeller, relative to the animal's size, along appendages and external protuberances, or along regions of significant convexity of the animal's surface where only one propeller blade makes contact.

Vessel collision and bycatch are two of the greatest threats to cetaceans worldwide (see IWC Strategic Plan to Mitigate Ship Strikes; IWC Bycatch Mitigation Initiative Strategic Plan 2018-2028). Industrial maritime ship traffic in the range of the BCB bowhead whale population is increasing and occurs almost year round, except for the early spring months. This is an emerging issue and brings with it an increased risk for vessel collision among other threats (Citta et al. 2012; George et al. 2021b; Stafford 2021a; Sheffield et al. 2021b). Typically, vessel strike injuries in BCB bowhead whales are uncommon (George et al. 2021b); however, with these two probable cases during 2021, the vessel collision scarring rate is 6%, which is higher than the 1990-2012 of 2% (George et al. 2017b).

Figure 9. Parallel scarring along the ventrum of a mature female whale, landed in Wainwright during fall 2021. Evident scarring is likely caused by sharp force trauma associated with a propeller strike from a large vessel.

Dead Floating and Beachcast Bowheads

North Slope Borough (NSB) Autumn Aerial Surveys project conducted line transect surveys in the northeastern Chukchi and western Beaufort Seas from mid-September to mid-October, 2020–2021. A total of three bowhead whale carcasses were documented: none in 2020 and three in 2021. Carcasses were distributed from 152.6°W to 155.1°W (Figure 10).

On 25 September 2021, a beached bowhead whale carcass was sighted approximately 150 km southeast of Point Barrow (Figure 10). The carcass had severe injuries (semilunar bite wounds on what appears to be the chin, tongue removed, long linear flensing of blubber, and eviscerated abdomen) consistent with killer whale predation. The whale was not a calf based on the presence of long baleen plates.

On 3 October 2021, a floating bowhead whale carcass was sighted approximately 50 km east of Point Barrow (Figure 10). The carcass had severe injuries (lower right mandible removed, torn throat, tongue removed, semilunar bite wounds on the chin, blubber flensing, tissue fraying on pecs and flukes) consistent with killer whale predation.

On 9 October 2021, a floating bowhead whale carcass was sighted approximately 85 km east of Point Barrow (Figure 10). The carcass appeared to be intact. A laceration on the ventral surface between the pectoral flippers was visible. The laceration, based on the size of a gull in the images, was at least 55 cm long and extended through hypodermis, possibly into muscle. The probable cause of death could not be determined.

Additionally, seven beach cast carcasses of bowhead whales were documented in 2021 during the month of September by the NSB DWM stranding program in Kaktovik (n=3), Wainwright (n=1), and Utqiaġvik (n=3) (NSB DWM unpubl.data). No beachcast carcasses were observed in 2020. Post-mortem examination of 2021 carcasses showed injuries consistent with killer whale predation. The 2021 findings are consistent with the frequency of probable killer whale predation on bowhead whale carcasses (2009–2018) and gray whale carcasses (2009–2019) documented in the eastern Chukchi and western Beaufort study areas (Willoughby et al. 2020, 2022b).

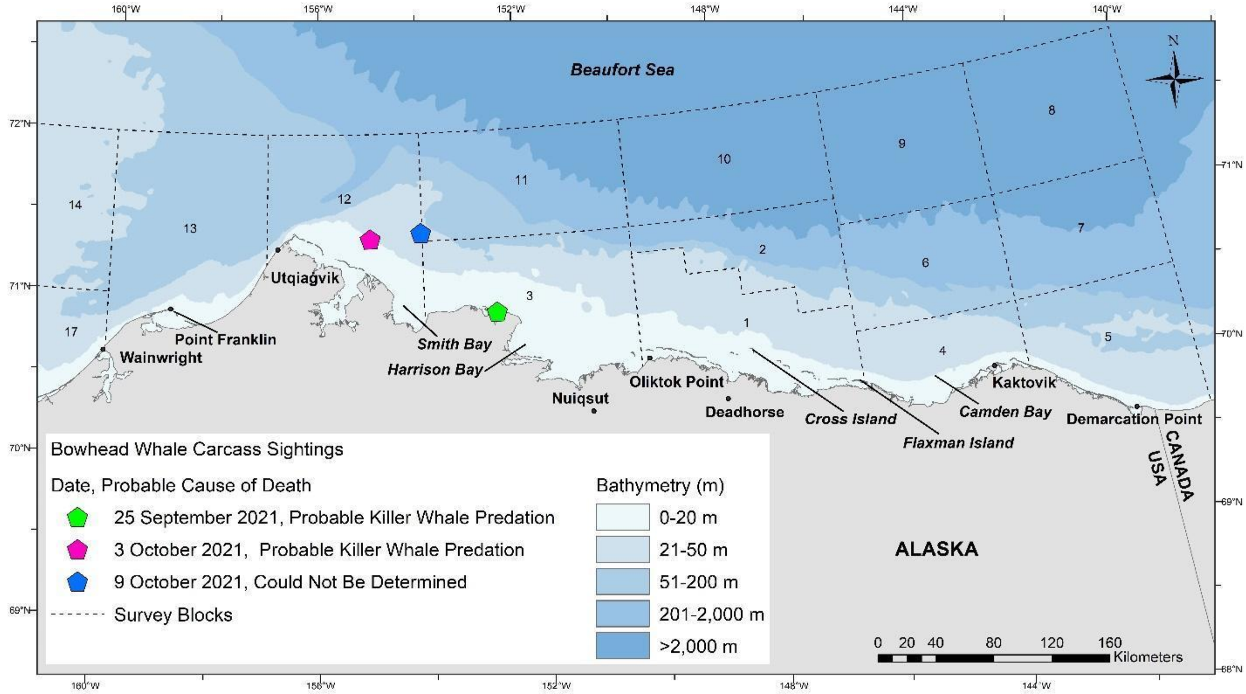


Figure 10. Bowhead whale carcass sightings listed by date and probable cause of death, all survey effort, from mid-September to mid-October, 2020–2021. No carcasses were observed during surveys in 2020.

Health Assessment of Landed Whales

A number of unusual findings (abnormal; pathological) were observed in landed bowhead whales during 2020 and 2021. Spring whales during 2020 were not examined due to Covid 19 pandemic restrictions.

In contrast to other baleen and toothed whales, infectious diseases caused by viruses tend to not play a major role in natural morbidity and mortality of bowhead whales with only a few viruses having been isolated (Smith et al. 1987; Bracht et al., 2006; De Luca et al. 2021). During 2021, two landed whales presented with single proliferative novel type ovoid cutaneous lesions (4 x 2 cm). Given the wart-like appearance (corrugated surface) of these cutaneous lesions, a viral etiology (papillomavirus) is possible and further investigations are underway.

Crassicaudosis (kidney worm infection) remains the dominant parasitic infection in landed bowhead whales (Stimmelmayr et al. 2021b?) in Utqiaġvik , with 13/13 (100%) examined whales during fall 2020 and 20/25 (80%) examined whales during 2021 (spring and fall) being infected with kidney worms. During 2021, we also had the first reports of kidney worms, one in spring and two in fall being detected in landed whales in Wainwright (3/6). Observed gross renal lesions in bowhead whales with mild to severe kidney worm infection range from renal arteritis with and without partial lumen occluding thrombi, single to multiple renal granulomas and renal cysts (Stimmelmayr et al. 2021b). Such lesions are similar to what has been described for Cuvier's beaked whales (*Ziphius cavirostris*; Díaz-Delgado et al. 2016) and less similar to what has been reported for fin (*Balaenoptera physalus*), humpback (*Megaptera novaeangliae*), and blue whales (*Balaenoptera musculus*) (Lambertsen 1986). Preliminary findings from post-mortem examination of 2 fetuses (midterm/full term) and age distribution of bowhead whales with kidney worm infection suggest that infection occurs likely post-weaning (baleen length > 50 cm). This is in contrast to findings in fin whales with kidney worm infection where adult sized worms were detected in a calf (Lambertsen 1986). To further evaluate the mode of transmission of this parasite in bowhead whales, we have completed urine sediment analysis on urine collected from 32 bowhead whales with kidney worm infection confirmed on post-mortem examination (2016-2021). Parasite eggs with larvae or embryonic mass were detected in 20/32 urine samples (Stimmelmayr et al. in prep). In several urine samples, hatching eggs and free larvae were also present. Free larvae but no eggs have been previously documented in fin whale urine (Lambertsen 1986). Our findings suggest that kidney worm transmission from one bowhead whale to another is a complex process. Environmental shedding of eggs/larvae (direct/indirect transmission via intermediate or paratenic hosts) and autoinfection may play a role. Studies are ongoing to further define the ecology of kidney worms and further assess health impacts on bowhead whales through clinical pathological investigations.

During 2020 and 2021, adult *Anisakis* roundworms (*Anisakis* spp.) were detected in 2 whales during post-mortem examination of the stomach (single nematode) and small intestines (multiple). Stomach associated parasitic nodules were absent. As discussed previously, given the size of the stomach and the limited post-mortem stomach content examination, detection of mild *Anisakis* infection is challenging (Sheffield et al. 2016). Furthermore, continuous shedding of baleen hair may aid in mechanical deworming of bowheads whales from adult nematodes present in the digestive system (Sheffield et al. 2016). With the exception of gastric nodules, health impacts from minor to moderate adult *anisakis* spp. infections in bowhead whales are unlikely (Stimmelmayr et al. 2021b).

Non-infectious disease conditions have been recently reviewed for bowhead whales (Stimmelmayr et al. 2021b) and we report on previously described and novel conditions that were observed during 2020 and 2021. In contrast to previous years a number of novel developmental anomalies were documented in landed whales including a shortened lower jaw and digital anomalies. The shortened lower jaw (Brachygnathia inferior) was associated with bone necrosis and loose anterior baleen plates. Repeated mechanical trauma to the exposed anterior baleen from closure of the mouth likely caused the observed rostral damage characterized by inflammation and necrosis of the baleen producing tissue, loose baleen plates, and underlying bone necrosis (Stimmelmayr & Anashugak 2022). Anterior baleen plates being pushed out of alignment and being deformed has been observed in cases of rope entanglement of the jaw and or rostrum and due to a fracture of the mandible resulting in misalignment of the jaw (Philo et al. 1990; Dolman and Moore 2017). Two cases of minor developmental anomalies (bilateral shortening of the digits; partial piebaldism of the fluke) were observed in two immature landed bowhead whales. Additionally a free-swimming bowhead whale with a developmental anomaly of the fluke (missing fluke notch, bilateral rounding of fluke tips, and partial lack of pigmentation) was observed during a 2021 drone survey (Madison Kosma, pers. comm. 2021). Developmental anomalies of the skull and appendages in baleen whales are rare (Kato 1979; Cooper et al. 2009; Stimmelmayr et al. 2021b), thus our recent case material contributes to this scarce knowledge base. Lastly, a few cases of minor anatomic variations of internal organs, mostly shape and size, presence of hindlimb buds and epidermal inclusions cysts were observed in a few whales. Hindlimb buds and epidermal inclusion cysts are occasionally reported in bowhead whales (Thewissen et al. 2021; Stimmelmayr et al. 2021b).

Malignant neoplastic lesions remain a rare occurrence in bowhead whales (Stimmelmayr et al. 2021b), while benign masses such as hepatic lipomas/myelolipomas (Stimmelmayr et al. 2017) and encapsulated fat necrosis (Stimmelmayr et al. 2021a) have been documented over the years. During 2020 and 2021, two whales with hepatic lipomas and one whale with abdominal encapsulated fatty masses were documented. Both conditions are incidental findings during post-mortem examination that need to be differentiated from neoplastic and inflammatory lesions, as the latter may have public health implications.

Over the last 10 years two marine threats, namely marine harmful algal biotoxins and microplastics have been gaining importance within the marine arctic ecosystem. The signifcance of marine algal biotoxin exposure for marine mammals and their role in unusual mortality events of marine species was reviewed in the 2017 IWC workshop report (SC/67A/REP/09). In the Pacific Arctic monitoring for marine algae biotoxins including domoic acid (DA) and saxitoxin (STX) in feces of landed bowhead whales and other key marine mammal species has been ongoing for nearly a decade now (Lefebvre et al. 2016; Bowers et al. 2021; Hendrix et al. 2021). Although present in feces, indicating exposure of bowhead whales through the food web, toxins levels detected over the years are consistently below US Food and Drug Administration (FDA) regulatory safety levels (Saxitoxin for shellfish (< 80 μg saxitoxin per 100 g shellfish for commercial shellfish products; Domoic Acid for fish < 20 mg/kg domoic acid). In 2019, unusual warm conditions resulted in elevated STX levels in the Arctic food web, underlining the importance of warming climate as a major driver of blooms and toxin levels in prey items (Anderson et al. 2021; Lefebvre et al. 2022). Sixty-four percent of bowhead whales (6/9) feces tested for STX were positive, in contrast to Pacific walrus (*Odobenus rosmarus*), which all tested positive (13/13). Toxin concentrations quantified in bowhead whales ranged from undetectable (BDL = below detection limit) to 8.5 μg STX eq. 100 g−1 feces. Toxin concentrations quantified in walruses ranged from 1.6 to 78 μg STX eq. 100 g−1 feces and approached seafood safety regulatory limits in two animals at 78 and 72 μg STX eq. 100 g−1. Maximum ecologically-relevant daily toxin doses to bowhead whales feeding on zooplankton were estimated to 0.7 μg STX eq. kg body weight− 1 day− 1, significantly lower than for Pacific Walrus (21.5 μg STX eq. kg body weight− 1 day− 1). Average and maximum STX doses in bowhead whales were well below levels reported previously to cause illness and/ or death in humans and humpback whales. Given the accelerated transformation of the Pacific Arctic, continued monitoring for biotoxin exposure in key marine mammals including the bowhead whales will remain important.

Microplastics in the Arctic marine environment and marine mammals are an emerging issue (Collard and Ask 2021; Mua et al. 2019). Although plastic debris has only been occasionally detected in landed bowhead whales (Sheffield and George 2021; Stimmelmayr et al. 2021b) particle capture studies by Werth et al. (2019) using baleen plates from various baleen whales including bowhead whales indicate that baleen effectively captures small, buoyant plastic microspheres (microplastics), thus further highlighting the potential vulnerability of bowhead whales and other baleen whales to marine microplastic pollution (Fossi et al. 2012; Garcia et al. 2021). Starting in 2022, we will initiate a pilot study to assess the daily ingestion rates of synthetic particles by BCB bowhead whales that feed off the coast of northern Alaska.

In conclusion, similar to previous years (George et al. 2017a; Stimmelmayr et al. 2018, 2020) various abnormal findings ranging from infectious to non-infectious disease conditions were observed in landed whales. Prevalence of kidney worm infection in landed whales in Utqiaġvik remains high (80 -100%) and studies are ongoing to further define the ecology of kidney worms and to assess impacts from renal lesions on renal function and individual bowhead health. With the exception of the case of the shortened jaw, the majority of non-infectious disease conditions were unlikely to interfere with proper function of the affected structure(s) or impact the health of the individual animal.

Hunter Observations of Bowhead Whales

Over 150 whaling captains from 11 whaling communities annually organize bowhead whale hunting crews along the northern and western coasts of Alaska. Astute observers of bowhead whale life history and the ocean, Inupiaq and St. Lawrence island Yupik whale hunters have been instrumental in guiding and advancing scientific knowledge of bowhead whales. For over 40 years, whaling communities have shared in the successful management and research of bowhead whales through their collaborative efforts to integrate vast traditional and local knowledge with whale biologists and regulatory bodies (e.g., Albert 2000; Huntington et al. 2009; Noongwook et al. 2007).

As in previous years, 2020-2021 hunter observations during spring and fall bowhead whale hunting (for detailed summary see Scheimreif et al. 2022) illustrate the intricate relationship between environmental conditions and the seasonal bowhead whale hunt. Among regional observations on notable marine issues during 2020 and 2021 were the foreign marine debris noted throughout the Bering strait (see Sheffield et al. 2021b), the unusually nearshore migration of bowhead whales near Wainwright during fall 2021, an unusual proliferative skin condition observed by Kaktovik whalers in a live bowhead whale calf that was deemed sick during 2020, and the first visual sighting of a group of killer whales in the western Beaufort Sea by Nuiqsut whaling crews during their 2021 fall hunt near Cross Island, Alaska.

These observations agree with previous reports (George et al. 2017a; Stimmelmayr et al. 2018, 2020) that the marine environment is transitioning and that bowhead whales, like other Arctic marine wildlife, are responding to those changes by altering the timing and distribution of their seasonal migrations.

CONCLUSIONS

Ongoing risk surveillance of core bowhead whale habitat and our increasing understanding of direct and indirect climate change impacts on the Pacific Arctic-subarctic marine ecosystem indicates an increasing complexity of environmental, ecological and anthropogenic stressors being present within the bowhead whale core habitat (Stafford 2021a,b; Sheffield et al. 2021a; Lefevbre et al. 2022; Stimmelmayr and Sheffield 2021c; Willoughby et al. 2020, 2022a). Notwithstanding these aforementioned ongoing changes, this most recent data analysis of the various indices reiterates that the BCB bowhead whale population remains robust, general health of whales is good and the harvest is sustainable. Continued monitoring of the BCB bowhead whale population remains critical to aid in our general understanding of the complex pathways and mechanisms by which climate change has likely influenced (e.g., migration timing; distribution) or could influence the BCB population in the foreseeable future.

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REFERENCES

Albert, T.F. 2000. The influence of Harry Brower Sr, an Inupiaq Eskimo hunter, on the bowhead whale research program conducted at the UIC-NARL facility by the North-slope. In: Norton, D.W. (ed) 50 more years Below Zero, 265-278 pg. Arctic Institute of North America.

Anderson, D.M., Fachon, E., Pickart, R.S., Lin, P., Fischer, A.D, Richlen, M.L, Uva V., Brosnahan, M.L., McRaven, L., Bahr, F., Lefebvre, K., Grebmeier, J.M., Danielson, S.L., Lyu, Y., and Fukai, Y. 2021. Evidence for massive and recurrent toxic blooms of Alexandrium catenella in the Alaskan Arctic. Proc Natl Acad Sci U S A. 2021 Oct 12;118(41):e2107387118.

Ashjian, C.J., Cambell, R.G., and Okkonen, S.R., 2021a. Biological environment, pp. 403-416. In: Thewissen, J.G.M. and J.C. George (Eds.), The Bowhead Whale, Elsevier Publishing. ISBN: 978-0-12-818969-6.

Ashjian, C.J., Okkonen, S.R., Campbell, R.G., and Alatalo, P. 2021b. Lingering Chukchi Sea ice and Chukchi Sea mean winds influence population age structure of euphausiids (krill) found in the bowhead whale feeding hotspot near Pt. Barrow, Alaska. PLoS ONE 16(7): e0254418.

Blaker, H. 2000. Confidence curves and improved exact confidence intervals for discrete distributions. Canadian Journal of Statistics 28:783-798.

Bowers, E.K., Stimmelmayr, R., and Lefebvre, K.A. 2021. Stability of Domoic Acid in 50% Methanol Extracts and Raw Fecal Material from Bowhead Whales (Balaena mysticetus). Mar Drugs. 19(8):423.

Bracht, A. J., Brudek, R. L., Ewing, R. Y., Manire, C. A., Burek, K. A., Rosa, C., Beckmen, K. B., Maruniak, J. E., and Romero, C. H. 2006. Genetic identification of novel poxviruses of cetaceans and pinnipeds. Archives of virology, 151(3), 423–438.

Citta, J. J., Quakenbush, L. T., George, J. C., Small, R. J., Heide-Jorgensen, M. P., Brower, H., Adams, B., and Brower, L. 2012. Winter Movements of Bowhead Whales (*Balaena mysticetus*) in the Bering Sea. Arctic, 65(1), 13–34.

Citta, J.J., Quakenbush, L.T., and George, J.C. 2021. Distribution and behavior of Bering-Beaufort-Chukchi bowhead whales as inferred by telemetry. pp.31-56 In: Thewissen, J.G.M. and J.C. George (Eds.), The Bowhead Whale, Elsevier Publishing. ISBN: 978-0-12-818969-6.

Čižauskas, C. A., Carlson, C. J., Burgio. K.R., Clements, C.F., Dougherty, E.R., Harris Nyeema, C. and Phillips, A.J. 2017. Parasite vulnerability to climate change: an evidence-based functional trait approach. R. Soc. open sci.4160535160535.

Clarke, J.T., Ferguson, M.C., Okkonen, S.R., Brower, A.A., and Willoughby, A.L. 2022. Bowhead whale calf detections in the western Beaufort Sea during the open-water season, 2012-2019. Arctic Science. e-First. https://doi.org/10.1139/as-2021-0020

Collard, F., and Ask, A. 2021. Plastic ingestion by Arctic fauna: A review. Science of The Total Environment 786 (10), 147462.

Cooper, L.N., and Dawson, S.D. 2009. The trouble with flippers: a report on the prevalence of digital anomalies in Cetacea, Zoological Journal of the Linnean Society, 135:3: 722–735.

De Luca, E., Stimmelmayr, R., Rotstein, D.S., and Sanchez. S. 2021. A Novel Adenovirus Detected in Bering-Chukchi-Beaufort Seas Bowhead Whale (*Balaena mysticetus*): Epidemiologic Data and Phylogenetic Characterization. J Wild Dis 57(3), 652-656.

Díaz-Delgado J., Fernández A., Xuriach A., Sierra E., Bernaldo de Quirós Y., and Mompeo B. 2016. Verminous arteritis due to Crassicauda sp. in Cuvier's Beaked Whales (*Ziphius cavirostris*) Vet. Pathol. 53:1233–1240.

Dolman, S. J. and Moore, M. J. 2017. Welfare implications of cetacean bycatch and entanglements.pp. 41-65 In: Marine Mammal Welfare (ed. A. Butterworth),. New York: Springer

Ferguson, M.C., Miller, D.L., Clarke, J.T., Brower, A.A., Willoughby, A.L and Rotrock, A.D. 2022. Spatial modeling, parameter uncertainty, and precision of density estimates from line-transect surveys: a case study with Western Arctic bowhead whales. Paper to be submitted to the 2022 IWC scientific committee.

Fossi, M. C., Panti, C., Guerranti, C., Coppola, D., Giannetti, M., Marsili, L., and Minutoli, R. 2012. Are baleen whales exposed to the threat of microplastics? A case study of the Mediterranean fin whale (*Balaenoptera physalus*). Marine pollution bulletin, 64(11), 2374–2379.

Frey, K.E., Comiso, J.C., Cooper, L.W., Grebmeier, J.M., and Stock L.V. 2021. Arctic Ocean Primary Productivity: The Response of Marine Algae to Climate Warming and Sea Ice DeclineArctic report card 2021 NOAA Technical Report OAR ARC; 21-07.

Garcia-Garin, O., Aguilar, A., Vighi, M., Víkingsson, G.A., Chosson, V., and Borrell, A. 2021. Ingestion of synthetic particles by fin whales feeding off western Iceland in summer. Chemosphere. 279:130564.

Gehman, A. M., Hall, R. J., and Byers, J. E. 2018. Host and parasite thermal ecology jointly determine the effect of climate warming on epidemic dynamics. Proceedings of the National Academy of Sciences of the United States of America, 115(4), 744–749.

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

George, J.C., Suydam, R., and Stimmelmayr, R. 2016. A possible structure for a bowhead whale health report. Paper SC/66B/BRG/14 submitted to the IWC scientific committee. Available from www.iwc.int.

George, J.C, Stimmelmayr, R., Brower, A., Clarke, J., Ferguson, M., Von Duyke, A., Sheffield, G., Stafford, K., Sformo, T., Person, B., Sousa, L., Tudor, B., and Suydam, R. 2017a. 2016 Health report for the Bering – Chukchi - Beaufort Seas bowhead whales – Preliminary findings. Paper SC/67A/AWMP/10 submitted to the IWC Scientific Committee. Available from www.iwc.int.

George, J. C., Sheffield, G., Reed, D. J., Tudor, B., Stimmelmayr, R., Person, B.T., Sformo, T., and Suydam, R. 2017b. Frequency of Injuries from Line Entanglements, Killer Whales, and Ship Strikes on Bering-Chukchi-Beaufort Seas Bowhead Whales. Arctic 70(1):37-46

George, J.C., Suydam, R., Givens, G., Horstmann, L., Stimmelmayr, R., and Sheffield, G., 2018. Length at sexual maturity and pregnancy rates of Bering-Chukchi-Beaufort seas bowhead whales. Paper SC/67b/AWMP07 to the IWC Scientific Committee. Available from www.iwc.int.

George, J.C., Thewissen, J.G.M., Von Duyke, A., Breed, G.A., Suydam, R., Sformo, T.L., Person, B.T., and Brower, H.K. 2021a. Life history, growth, and form. pp. 87-115 In: Thewissen, J.G.M. and J.C. George (Eds.), The Bowhead Whale, Elsevier Publishing. ISBN: 978-0-12-818969-6.

George, J.C., Sheffield, G., Tudor, B., Stimmelmayr, R., and Moore, M. 2021b. Fishing gear entanglement and vessel collisions. pp. 577-590 In: Thewissen, J.G.M. and J.C. George (Eds.), The Bowhead Whale, Elsevier Publishing. ISBN: 978-0-12-818969-6.

George, J.C., Givens, G.H., Horstmann, L., Suydam, R., Scheimreif, K., Stimmelmayr, R., Sheffield, G., Sformo, T., Person, B., VonDuyke, A., Sousa, L., and Tarpley, R. In prep. Age and length at sexual maturity and pregnancy rate of Bering-Chukchi-Beaufort Seas bowhead whales.

Givens, G.H., Edmondson, S.L., George, J.C., Suydam, R., Charif, R.A., Rahaman, A., Hawthorne, D.L., Tudor, B., Delong, R.A., and Clark, C.W., 2016. Horvitz-Thompson whale abundance estimation adjusting for uncertain recapture, temporal availability variation and intermittent effort. Environmetrics, 27: 134-14.

Givens, G.H, Mocklin, J.A., Vate Brattström, L., Tudor, B.J., Koski, W.R., George, J.C., Zeh, J.E. and Suydam, R. 2017. Survival rate and 2011 abundance of Bering-Chukchi-Beaufort Seas bowhead whales from photo-identification data over three decades. SC/67a/AWMP09 presented to the IWC Scientific Committee. Available from www.iwc.int.

Givens, G.H., George, J.C., Suydam, R. and Tudor, B. 2021a, Bering-Chukchi-Beaufort Seas bowhead whale (*Balaena mysticetus*) abundance estimate from the 2019 ice-based survey. J. Cetacean Res. Manage. 22: 61-73.

Givens, G.H., George, J.C., Suydam, R., Tudor, B., Von Duyke, A., Person, B., and Scheimreif, K. 2021b. Correcting the 2019 survey abundance of Bering-Chukchi-Beaufort Seas bowhead whales for disturbance from powered skiffs. Paper SC/68c/ASI/01 presented to the IWC Scientific Committee. Available from www.iwc.int.

Gulland, F.M., Baker, J.D.,Howe, M., LaBrecque E., Leach,L., Moore, S.E., Randall, R. Reeves, R.R. and Thomas, P.O. 2022. A review of climate change effects on marine mammals in United States waters: Past predictions, observed impacts, current research and conservation imperatives. Climate Change Ecology, 3: 100054.

Hendrix, A. M., Lefebvre, K. A., Quakenbush, L., Bryan, A., Stimmelmayr, R., Sheffield, G., Wisswaesser, G., Willis, M. L., Bowers, E. K., Kendrick, P., Frame, E., Burbacher, T., and Marcinek, D. J. 2021. Ice Seals as Sentinels for Algal Toxin Presence in the Pacific Arctic and Subarctic Marine Ecosystems Mar Mam Sci 37(4):1292-1308.

Huntington, H.P., Danielson, S.L., Wiese, F.K., Baker, M., Boveng, P., Citta, J.J., De Robertis A., Dickson, D.M.S., Farley, E., George, J, C., Iken, K., Kimmel, D,G., Kuletz, K., Ladd, C., Levine, R., Quakenbush, L., Stabeno, P., Stafford, K,M., Stockwell, D., and Wilson, C. 2020. Evidence suggests potential transformation of the Pacific Arctic ecosystem is underway. Nat. Clim. Chang. 10, 342–348.

Insley, S.J., Halliday, W.D., Mouy, X., and Diogou, N. 2021. Bowhead whales overwinter in the Amundsen Gulf and JEastern Beaufort Sea. R Soc Open Sci. 8(202268):1–9.

IWC 2017. Report of the workshop on Harmful Algal blooms (HABs) and associated toxins. SC/67A/REP/09 presented to the IWC Scientific Committee. Available from www.iwc.int.

IWC. 2019. Report of the Scientific Committee, Annex E, Appendix 9: Scientific Aspects of an Aboriginal Whaling Scheme. J. Cetacean Res. Manage. 20(Suppl): 179-182.

IWC. 2022. Report of the Scientific Committee. J. Cetacean Res. Manage. 23(Suppl.): to appear. Available from www.iwc.int.

Kato, H. 1979. Unusual minke whale with deformed jaws Sci. Rψ. IV hales Res. Inst., No. 31.

Keane M, Semeiks J, Webb AE, Li YI, Quesada V, Craig T, Madsen LB, van Dam S, Brawand D, Marques PI, Michalak P, Kang L, Bhak J, Yim HS, Grishin NV, Nielsen NH, Heide-Jørgensen MP, Oziolor EM, Matson CW, Church GM, Stuart GW, Patton JC, George JC, Suydam R, Larsen K, López-Otín C, O'Connell MJ, Bickham JW, Thomsen B, and de Magalhães JP. 2015. Insights into the evolution of longevity from the bowhead whale genome. Cell Rep. 10(1):112-22.

Koski, W.R., Zeh, J., Mocklin, J., Davis, A.R., Rugh, D.J., George, J.C. and Suydam, R. 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.

Lambertsen,R.,H., 1986. Disease of the Common Fin Whale (*Balaenoptera physalus*): Crassicaudiosis of the Urinary System, J of Mammal 67 (2): 353–366.

Lefebvre, K.L., Quakenbush, L., Frame, E., Huntington, K., Sheffield, G., Stimmelmayr, R., Bryan, A., Kendrick, P., Ziel, H., Goldstein, T., Snyder, J., Gelatt, T., Gulland, F., Dickerson, B. and Gill, V. 2016. Prevalence of algal toxins in Alaskan marine mammals foraging in a changing Arctic and subarctic environment. Harmful Algae 55: 13-24.

Lefebvre, K.A., Fachon, E., Bowers, E.K., Kimmel, D.G., Snyder, J.A., Stimmelmayr, R., Grebmeier, J.M., Kibler, S., Hardison, D.R., Anderson, D.M., Kulis, D., Murphy, J., Gann, J.C., Cooper, D., Eisner, L.B., Duffy-Anderson, J.T., Sheffield, G., Pickart, R.S., Mounsey, A., Willis, M.L., Stabeno, P., and Siddon, E. 2022. Paralytic shellfish toxins in Arctic food webs in 2019 during anomalously warm ocean conditions and estimated toxin doses to Pacific walruses and bowhead whales. Harmful Algae 114, 102205.

Lubetkin, S.C., Zeh, J.E., Rosa, C., and George, J.C. 2008. Age estimation for young bowhead whales (*Balaena mysticetus*) using annual baleen growth increments. Can J Zoology 86 (6), 525–538.

Lubetkin, S.C., Zeh, J.E., and George, J.C., 2012. Statistical modeling of baleen and body length at age in bowhead whales (*Balaena mysticetus*). Can J of Zoology 90, 915–931.

Moore, S.E., and Reeves, R.R. 2018. Tracking arctic marine mammal resilience in an era of rapid ecosystem alteration. PLoS Biol 16(10): e2006708.

Moore, M.J., der Hoop, J., Barco, S.G., Costidis, A.M., Gulland, F.M., Jepson, P.D., Moore, K.T., Raverty, S., and McLellan, W.A. 2013. Criteria and case definitions for serious injury and death of pinnipeds and cetaceans caused by anthropogenic trauma. Dis Aquat Organ. 2013 103(3):229-64.

Mua, J., Zhang, S., Qu, L., Jin, F., Fang, C., Ma, X., Zhang, W., and Wang, J. 2019. Microplastics abundance and characteristics in surface waters from the Northwest Pacific, the Bering Sea, and the Chukchi Sea. Mar. Pollut. Bull., 143, 58-65.

Noongwook, G., The Native Village of Savoonga, The Native Village of Gambell, Huntington, H.P., and George, J.C. 2007. Traditional Knowledge of the Bowhead Whale (*Balaena mysticetus*) around St. Lawrence Island, Alaska. Arctic, 60 (1), 47–54.

Okkonen, S.R., Clarke, J.T., and Potter, R.A., 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.

Pedersen, E.J., Miller, D.L., Simpson, G.L., and Ross, N. 2019. Hierarchical generalized additive models in ecology: an introduction with mgcv. PeerJ: 7, e6876. doi:10.7717/peerj.6876.

Philo, L.M., Hanns, C., and George J.C. 1990. Fractured Mandible and Associated Oral Lesions in a Subsistence-Harvested Bowhead Whale (*Balaena mysticetus*), J Wildl Dis 26(1), 125-128.

Scheimreif, K., Citta, J., Stimmelmayr, R., Sformo, T.L., Olemaun, F., Anashugak, P., VonDuyke, A.L., Acker, R., Person, B.T., Sousa, L., Agnasagga, L., SimsKayotuk, C., Kanayurak, N., George, J.C., and Suydam, R. Subsistence harvest of bowhead whales (Balaena mysticetus) by Alaskan Natives during 2021. Paper to be submitted to the 2022 IWC Scientific committee.

Sheffield, G., Stimmelmayr, R., Rausch, R., and George, J.C. 2016. Anisakis spp. infection in legally harvested BCB Bowhead whales (*Balaena mysticetus*): Preliminary data from stomach content analysis and field post-mortem examinations. Paper SC 66B/E/6 submitted to the IWC Scientific Committee. Available from www.iwc.int.

Sheffield, G., and George, J.C. 2021a. Diet and Distribution. pp. 429-455. In: Thewissen, J.G.M. and J.C. George (Eds.), The Bowhead Whale, Elsevier Publishing. ISBN: 978-0-12-818969-6.

Sheffield, G., Ahmasuk, A., Ivanoff, F., Noongwook, A., and Koonooka, J. 2021b. Foreign marine debris event Bering Strait. Arctic Report Card 2021 NOAA Technical Report OAR ARC: 21-12.

Smith, A.W., Skilling, D.E., Benirschke, K., Albert, T.F., and Barlough, J.E. 1987. Serology and virology of the bowhead whale (*Balaena mysticetus* L.). J Wildl Dis. 23(1):92-8.

Stafford, K., 2021a. The changing Arctic marine soundscape. Arctic report card 2021 NOAA Technical Report OAR ARC; 21-14.

Stafford, K.M., Citta, J.J., Okkonen, S.R., and Zhang, J. 2021b. Bowhead and beluga whale acoustic detections in the western Beaufort Sea 2008–2018. PLoS ONE 16(6): e0253929.

Stimmelmayr, R., Rotstein, D., Seguel, M., and Gottdenker, N. 2017. Hepatic Lipomas and Myelolipomas in subsistence harvested bowhead whales (*Balaena mysticetus*), Barrow, Alaska: A case review 1980-2016. Dis Aquat Organ. 19;127(1):71-74.

Stimmelmayr, R., George, C.J., Willoughby. A., Brower, A., Clarke, J., Ferguson, M., Sheffield, G., Stafford, K., Von Duyke, A., SformoT., Person, B., Sousa, L., and Suydam, R. 2018. Bowhead health report-preliminary findings. Paper SC/67B/AWMP/08 submitted to the IWC Scientific committee.Available from www.iwc.int.

Stimmelmayr, R., George, J.C., Clarke, J., Ferguson, M., Willoughby, A., Brower, A., Sheffield, G,, Stafford, K., Von Duyke, A., Person, B., Sformo, T., de Sousa, L., and Suydam, R. 2020. 2019 Health report for the Bering-Chukchi-Beaufort Seas bowhead whales - Preliminary findings. Paper SC68B/ASW/03 submitted to the IWC scientific committee. Available from www.iwc.int.

Stimmelmayr, R., Rotstein, D.S., Sheffield, G., and George J.C. 2021a. Subcutaneous, abdominal, and thoracic encapsulated fat necrosis in bowhead whales *Balaena mysticetus* from Alaska, USA. Dis Aquat Org 145:159-164.

Stimmelmayr, R., Rotstein, D., Sheffield, G., Brower, H. Jr., and George, J.C. 2021b. Diseases and parasites. Pp. 471-498. In Thewissen, J.G.M. and J.C. George (Eds.), The Bowhead Whale, Elsevier Publishing. ISBN: 978-0-12-818969-6.

Stimmelmayr, R. and Sheffield, G. 2021c. Arctic Risk Monitoring and Real Time Emerging Cumulative Issues: Bering-Chukchi-Beaufort Sea Perspective in RS19418 Climate Change Workshop report. Available from www.iwc.int.

Stimmelmayr, R., and Anashugak P. 2022. Shortened jaw in a subadult female bowhead whale (*Balaena mysticetus*): A case report Alaska Marine Science Symposium, Anchorage, Alaska.

Stimmelmayr, R., Hoffland L., Barrow Whaling Captains Wives Association, Hubbard, K., in prep. Insights into crassicauda spp. lifecycle from urine sediment analysis in bowhead whales (*Balaena mysticetus*).

Tarpley, R.J., Hillmann, D.J., George, J.C., and Thewissen, J.G.M. 2021. Female in male reproduction. Pp. 185-211. In: Thewissen, J.G.M. and J.C. George (Eds.), The Bowhead Whale, Elsevier Publishing. ISBN: 978-0-12-818969-6.

Von Duyke, A.L., Stimmelmayr, R., Sheffield, G., Sformo, T., Suydam,R., Givens, G.H., and George, J.C. 2016. Assessment of the prevalence of cyamid “whale lice” (Cyamus ceti) on subsistence harvested bowhead whales (Balaena mysticetus). Arctic 69(4):331-340.

Werth, A.J., Blakeney, S.M., and Cothren, A.I. 2019. Oil adsorption does not structurally or functionally alter whale baleen. Royal Society open science, 6(5), 182194. https://doi.org/10.1098/rsos.182194.

Willoughby, A.L., Ferguson, M.C., Stimmelmayr, R., Clarke, J.T., and Brower, A.A. 2020. Bowhead whale (*Balaena mysticetus*) and killer whale (*Orcinus orca*) co-occurrence in the US Pacific Arctic, 2009–2018: evidence from bowhead whale carcasses, Polar Biol 43:1669–1679.

Willoughby, A.L., A.A. Brower, M.C. Ferguson, and K. Scheimreif. 2022. Bering-Chukchi-Beaufort seas Bowhead Whale Calf Sightings from the North Slope Borough Autumn Aerial Survey Project, 2020–2021 with a Comparison to the Aerial Surveys of Arctic Marine Mammals Project, 2009–2019. Paper to be submitted to the 2022 IWC scientific committee.

Willoughby, A.L, Stimmelmayr, R., Brower, A.A., Clarke, J.T., and Ferguson, M.C. 2022b. Gray whale (Eschrichtius robustus) and killer whale (Orcinus orca) co-occurrence in the eastern Chukchi Sea, 2009–2019: evidence from gray whale carcasses observed during aerial surveys. Polar Biol 45: 737-748.

Wood, S.N., Bravington, M.V., and Hedley, S.L 2008. Soap film smoothing. Journal of the Royal Statistical Society: Series B (Statistical Methodology) 70(5): 931-955. doi:10.1111/j.1467-9868.2008.00665.x.

Wuersig, B., and Koski, W.R., 2021. Natural and potentially disturbed behavior of bowhead whales. Pp. 339-363. In: Thewissen, J.G.M. and J.C. George (Eds.), The Bowhead Whale, Elsevier Publishing. ISBN: 978-0-12-818969-6.

Thewissen, J.G.M., Hillmann, D.J., George, J.C., Tarpley, R.J., Sheffield, G., Stimmelmayr, R., and Suydam, R. 2021. Postcranial skeleton and musculature. pp.137-149 In: Thewissen, J.G.M. and J.C. George (Eds.), The Bowhead Whale, Elsevier Publishing. ISBN: 978-0-12-818969-6.

Zhang, B., Bilder, C., Biggerstaff, B., Schaarschmidt, F., and Hitt, B. 2018. binGroup: Evaluation and Experimental Design for Binomial Group Testing. R package version 2.2-1. https://CRAN.R-project.org/package=binGroup